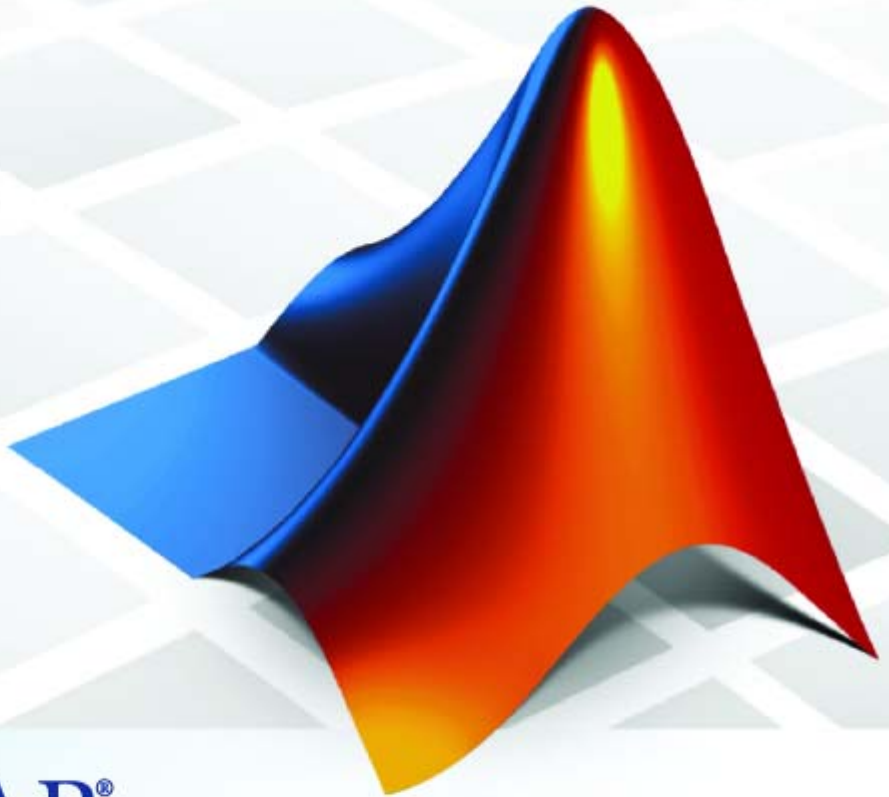


Simulink® 7

Writing S-Functions



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Writing S-Functions

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Revision History

October 1998	First printing	Revised for Simulink 3.0 (Release R11)
November 2000	Second printing	Revised for Simulink 4.0 (Release R12)
July 2002	Third printing	Revised for Simulink 5.0 Release R13)
April 2003	Online only	Revised for Simulink 5.1 (Release R13SP1)
April 2004	Online only	Revised for Simulink 5.1.1 (Release R13SP1+)
June 2004	Online only	Revised for Simulink 6.0 (Release R14)
October 2004	Online only	Revised for Simulink 6.1 (Release R14SP1)
March 2005	Online only	Revised for Simulink 6.2 (Release R14SP2)
September 2005	Online Only	Revised for Simulink 6.3 (Release R14SP3)
March 2006	Online only	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)

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Overview of S-Functions

What Is an S-Function? (p. 1-2)	Brief overview of S-functions.
Using S-Functions in Models (p. 1-3)	How to insert S-functions as blocks in a model and pass parameters to them.
How S-Functions Work (p. 1-7)	How Simulink invokes S-functions when simulating a model that includes them.
Implementing S-Functions (p. 1-11)	How to write S-functions.
S-Function Concepts (p. 1-14)	Key concepts needed to write certain types of S-functions.
S-Function Examples (p. 1-20)	Examples that illustrate the creation of various types of S-functions and S-function features.

What Is an S-Function?

S-functions (system-functions) provide a powerful mechanism for extending the capabilities of Simulink®. An *S-function* is a computer language description of a Simulink block. S-functions can be written in MATLAB®, C, C++, Ada, or Fortran. C, C++, Ada, and Fortran S-functions are compiled as MEX-files using the mex utility (see “Building MEX-Files” in the External Interfaces User’s Guide). As with other MEX-files, they are dynamically linked into MATLAB when needed.

S-functions use a special calling syntax that enables you to interact with Simulink equation solvers. This interaction is very similar to the interaction that takes place between the solvers and built-in Simulink blocks. The form of an S-function is very general and can accommodate continuous, discrete, and hybrid systems.

S-functions allow you to add your own blocks to Simulink models. You can create your blocks in MATLAB, C, C++, Fortran, or Ada. By following a set of simple rules, you can implement your algorithms in an S-function. After you write your S-function and place its name in an S-Function block (available in the User-Defined Functions block library), you can customize the user interface by using masking.

You can use S-functions with Real-Time Workshop®. You can also customize the code generated by Real-Time Workshop for S-functions by writing a Target Language Compiler (TLC) file. See “Writing S-Functions for Real-Time Workshop” in the Real-Time Workshop User’s Guide for more information.

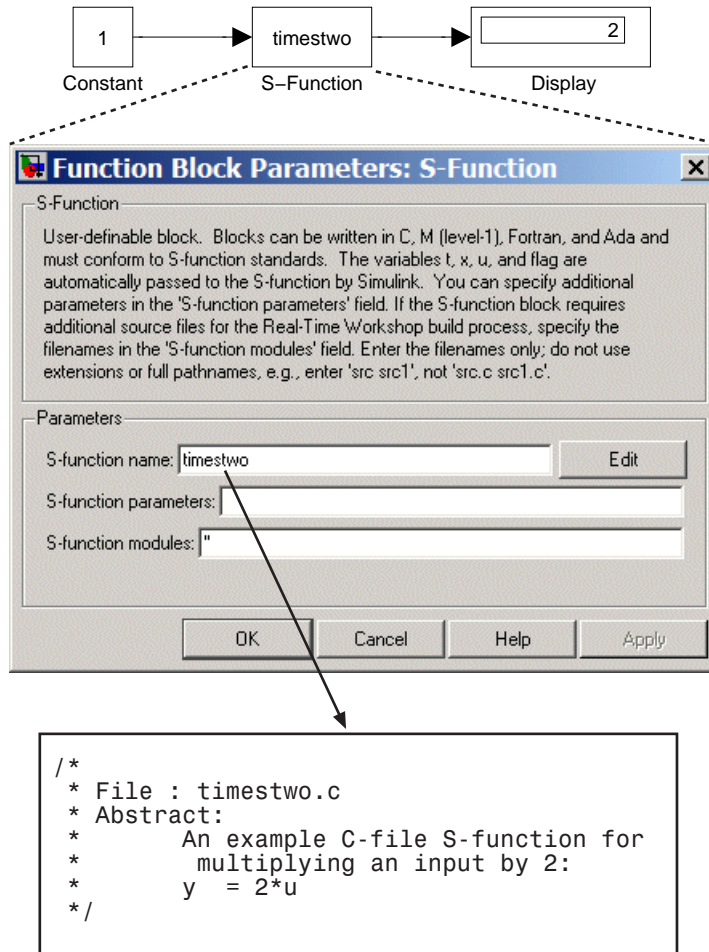
Using S-Functions in Models

In this section...
“Overview” on page 1-3
“Passing Parameters to S-Functions” on page 1-5
“When to Use an S-Function” on page 1-6

Overview

To incorporate an S-function into a Simulink model, drag an S-Function block from the Simulink User-Defined Functions block library into the model.

Then specify the name of the S-function in the **S-function name** field of the S-Function block’s dialog box, as illustrated in the following figure.



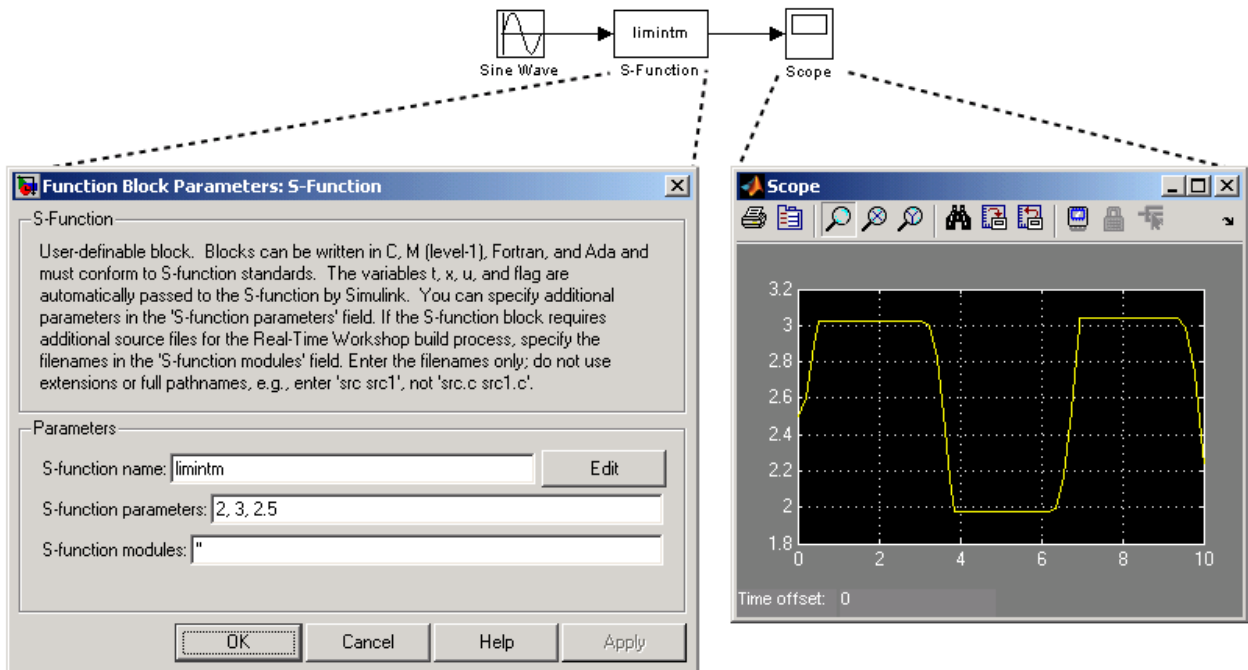
In this example, the model contains an instance of an S-Function block that references a C MEX-file having the root name timestwo.

Note If the MATLAB path includes a C MEX-file and an M-file having the same root name referenced by an S-function block, the S-function block uses the C MEX-file.

Passing Parameters to S-Functions

The S-function block's **S-function parameters** field allows you to specify parameter values to be passed to the corresponding S-function. To use this field, you must know the parameters the S-function requires and the order in which the function requires them. (If you do not know, consult the S-function's author, documentation, or source code.) Enter the parameters, separated by a comma, in the order required by the S-function. The parameter values can be constants, names of variables defined in the MATLAB or model workspace, or MATLAB expressions.

The following example illustrates usage of the **S-function parameters** field to enter user-defined parameters.



The model in this example incorporates `limintm`, a sample S-function that comes with Simulink. The function's source code resides in `toolbox/simulink/blocks`. The `limintm` function accepts three parameters: a lower bound, an upper bound, and an initial condition. It outputs the time

integral of the input signal if the time integral is between the lower and upper bounds, the lower bound if the time integral is less than the lower bound, and the upper bound if the time integral is greater than the upper bound. The dialog box in the example specifies a lower and upper bound and an initial condition of 2, 3, and 2.5, respectively. The scope shows the resulting output when the input is a sine wave of amplitude 1.

See “Processing S-Function Parameters” on page 2-13 and “Handling Errors” on page 7-59 for information on how to access user-specified parameters in an S-function.

You can use the Simulink masking facility to create custom dialog boxes and icons for your S-function blocks. Masked dialog boxes can make it easier to specify additional parameters for S-functions. For discussions of additional parameters and masking, see “Creating Block Masks” in the Using Simulink documentation.

When to Use an S-Function

The most common use of S-functions is to create custom Simulink blocks. You can use S-functions for a variety of applications, including

- Adding new general purpose blocks to Simulink
- Adding blocks that represent hardware device drivers
- Incorporating existing C code into a simulation
- Describing a system as a set of mathematical equations
- Using graphical animations (see the inverted pendulum demo, `penddemo`)

An advantage of using S-functions is that you can build a general-purpose block that you can use many times in a model, varying parameters with each instance of the block.

How S-Functions Work

In this section...

“Introduction” on page 1-7

“Mathematics of Simulink Blocks” on page 1-7

“Simulation Stages” on page 1-8

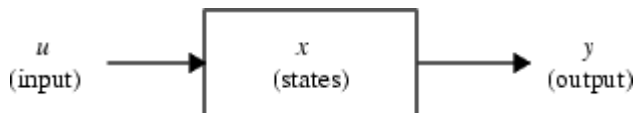
“S-Function Callback Methods” on page 1-9

Introduction

To create S-functions, you need to know how S-functions work. Understanding how S-functions work, in turn, requires understanding how Simulink simulates a model, and this, in turn requires an understanding of the mathematics of blocks. This section begins by explaining the mathematical relationship between a block’s inputs, states, and outputs.

Mathematics of Simulink Blocks

A Simulink block consists of a set of inputs, a set of states, and a set of outputs, where the outputs are a function of the simulation time, the inputs, and the block’s states.



The following equations express the mathematical relationships between the inputs, outputs, states, and simulation time.

$$y = f_0(t, x, u) \quad (\text{Outputs})$$

$$\dot{x}_c = f_d(t, x, u) \quad (\text{Derivatives})$$

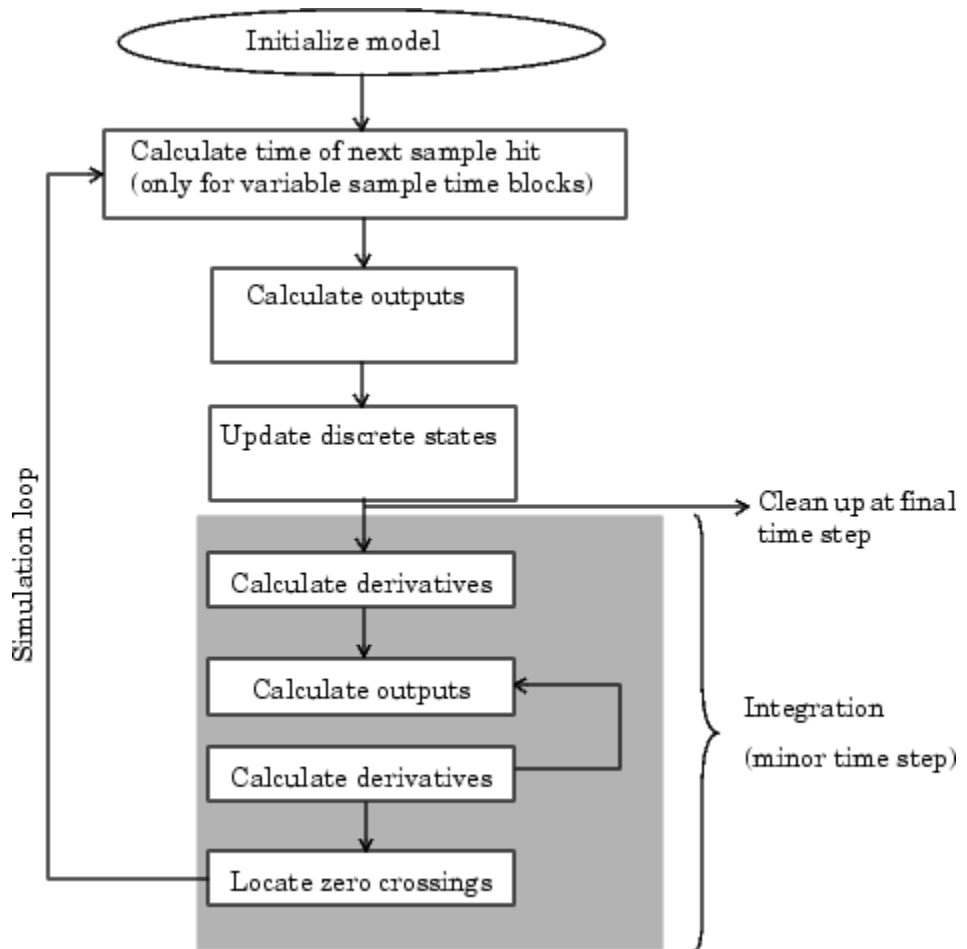
$$x_{d_{k+1}} = f_u(t, x_c, x_{d_k}, u) \quad (\text{Update})$$

$$\text{where } x = [x_c; x_d]$$

Simulation Stages

Execution of a Simulink model proceeds in stages. First comes the initialization phase. In this phase, Simulink incorporates library blocks into the model, propagates widths, data types, and sample times, evaluates block parameters, determines block execution order, and allocates memory. Then Simulink enters a *simulation loop*, where each pass through the loop is referred to as a *simulation step*. During each simulation step, Simulink executes each of the model's blocks in the order determined during initialization. For each block, Simulink invokes functions that compute the block's states, derivatives, and outputs for the current sample time. This continues until the simulation is complete.

The following figure illustrates the stages of a simulation.



How Simulink Performs Simulation

S-Function Callback Methods

An S-function comprises a set of *S-function callback methods* that perform tasks required at each simulation stage. During simulation of a model, at each simulation stage, Simulink calls the appropriate methods for each S-Function block in the model. Tasks performed by S-function methods include

- Initialization — Prior to the first simulation loop, Simulink initializes the S-function. During this stage, Simulink
 - Initializes the `SimStruct`, a simulation structure that contains information about the S-function
 - Sets the number and dimensions of input and output ports
 - Sets the block sample times
 - Allocates storage areas and the `sizes` array
- Calculation of next sample hit — If you've created a variable sample time block, this stage calculates the time of the next sample hit; that is, it calculates the next step size.
- Calculation of outputs in the major time step — After this call is complete, all the output ports of the blocks are valid for the current time step.
- Update of discrete states in the major time step — In this call, all blocks should perform once-per-time-step activities such as updating discrete states for next time around the simulation loop.
- Integration — This applies to models with continuous states and/or nonsampled zero crossings. If your S-function has continuous states, Simulink calls the output and derivative portions of your S-function at minor time steps. This is so Simulink can compute the states for your S-function. If your S-function (C MEX only) has nonsampled zero crossings, Simulink calls the output and zero-crossings portions of your S-function at minor time steps so that it can locate the zero crossings.

Note See “How Simulink Works” in the Using Simulink documentation for an explanation of major and minor time steps.

Implementing S-Functions

In this section...

“M-File S-Functions” on page 1-11

“MEX-File S-Functions” on page 1-12

M-File S-Functions

An M-file S-function consists of a MATLAB function of the following form:

```
[sys,x0,str,ts]=f(t,x,u,flag,p1,p2,...)
```

where *f* is the S-function’s name, *t* is the current time, *x* is the state vector of the corresponding S-function block, *u* is the block’s inputs, *flag* indicates a task to be performed, and *p1*, *p2*, ... are the block’s parameters. During simulation of a model, Simulink repeatedly invokes *f*, using *flag* to indicate the task to be performed for a particular invocation. Each time the S-function performs the task, it returns the result in a structure having the format shown in the syntax example.

A template implementation of an M-file S-function, *sfuntmpl.m*, resides in *matlabroot/toolbox/simulink/blocks*. The template consists of a top-level function and a set of skeleton subfunctions, each of which corresponds to a particular value of *flag*. The top-level function invokes the subfunction indicated by *flag*. The subfunctions, called S-function callback methods, perform the tasks required of the S-function during simulation. The following table lists the contents of an M-file S-function that follows this standard format.

Simulation Stage	S-Function Routine	Flag
Initialization	<code>mdlInitializeSizes</code>	<code>flag = 0</code>
Calculation of next sample hit (variable sample time block only)	<code>mdlGetTimeOfNextVarHit</code>	<code>flag = 4</code>
Calculation of outputs	<code>mdlOutputs</code>	<code>flag = 3</code>

Simulation Stage	S-Function Routine	Flag
Update of discrete states	mdlUpdate	flag = 2
Calculation of derivatives	mdlDerivatives	flag = 1
End of simulation tasks	mdlTerminate	flag = 9

We recommend that you follow the structure and naming conventions of the template when creating M-file S-functions. This makes it easier for others to understand and maintain M-file S-functions that you create. See Chapter 2, “Writing S-Functions in M” for information on creating M-file S-functions.

MEX-File S-Functions

Like an M-file S-function, a MEX-file function consists of a set of callback routines that Simulink invokes to perform various block-related tasks during a simulation. Significant differences exist, however. For one, MEX-file functions are implemented in a different programming language: C, C++, Ada, or Fortran. Also, Simulink invokes MEX S-function routines directly instead of via a flag value as with M-file S-functions. Because Simulink invokes the functions directly, MEX-file functions must follow standard naming conventions specified by Simulink.

Other key differences exist. For one, the set of callback functions that MEX functions can implement is much larger than can be implemented by M-file functions. A MEX function also has direct access to the internal data structure, called the SimStruct, that Simulink uses to maintain information about the S-function. MEX-file functions can also use the MATLAB MEX-file API to access the MATLAB workspace directly.

A C MEX-file S-function template, called `sfuntmpl_basic.c`, resides in the `matlabroot/simulink/src` directory. The template contains skeleton implementations of all the required and optional callback routines that a C MEX-file S-function can implement. For a more amply commented version of the template, see `sfuntmpl_doc.c` in the same directory.

MEX-File Versus M-File S-Functions

M-file and MEX-file S-functions each have advantages. The advantage of M-file S-functions is speed of development. Developing M-file S-functions avoids the time-consuming compile-link-execute cycle required by development in a compiled language. M-file S-functions also have easier access to MATLAB and toolbox functions.

The primary advantage of MEX-file functions is versatility. The larger number of callbacks and access to the SimStruct enable MEX-file functions to implement functionality not accessible to M-file S-functions. Such functionality includes the ability to handle data types other than double, complex inputs, matrix inputs, and so on.

S-Function Concepts

In this section...

“Direct Feedthrough” on page 1-14

“Dynamically Sized Arrays” on page 1-15

“Setting Sample Times and Offsets” on page 1-16

Direct Feedthrough

Direct feedthrough means that the output (or the variable sample time for variable sample time blocks) is controlled directly by the value of an input port. A good rule of thumb is that an S-function input port has direct feedthrough if

- The output function (`mdlOutputs` or `flag==3`) is a function of the input u . That is, there is direct feedthrough if the input u is accessed in `mdlOutputs`. Outputs can also include graphical outputs, as in the case of an XY Graph scope.
- The “time of next hit” function (`mdlGetTimeOfNextVarHit` or `flag==4`) of a variable sample time S-function accesses the input u .

An example of a system that requires its inputs (i.e., has direct feedthrough) is the operation $y = k \times u$, where u is the input, k is the gain, and y is the output.

An example of a system that does not require its inputs (i.e., does not have direct feedthrough) is this simple integration algorithm

Outputs: $y = x$

Derivative: $\dot{x} = u$

where x is the state, \dot{x} is the state derivative with respect to time, u is the input, and y is the output. Note that \dot{x} is the variable that Simulink integrates. It is very important to set the direct feedthrough flag correctly because it affects the execution order of the blocks in your model and is used to detect algebraic loops.

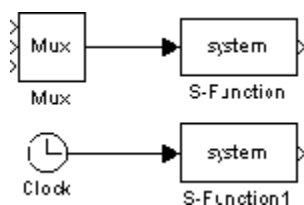
Dynamically Sized Arrays

S-functions can be written to support arbitrary input dimensions. In this case, the actual input dimensions are determined dynamically when a simulation is started by evaluating the dimensions of the input vector driving the S-function. The input dimensions can also be used to determine the number of continuous states, the number of discrete states, and the number of outputs.

M-file S-functions can have only one input port and that input port can accept only one-dimensional (vector) signals. However, the signals can be of varying widths. Within an M-file S-function, to indicate that the input width is dynamically sized, specify a value of -1 for the appropriate fields in the `sizes` structure, which is returned during the `mdlInitializeSizes` call. You can determine the actual input width when your S-function is called by using `length(u)`. If you specify a width of 0, the input port is removed from the S-function block.

A C S-function can have multiple I/O ports and the ports can have different dimensions. The number of dimensions and the size of each dimension can be determined dynamically.

For example, the following illustration shows two instances of the same S-Function block in a model.



The upper S-Function block is driven by a block with a three-element output vector. The lower S-Function block is driven by a block with a scalar output. By specifying that the S-Function block has dynamically sized inputs, the same S-function can accommodate both situations. Simulink automatically calls the block with the appropriately sized input vector. Similarly, if other block characteristics, such as the number of outputs or the number of discrete or continuous states, are specified as dynamically sized, Simulink defines these vectors to be the same length as the input vector.

C S-functions give you more flexibility in specifying the widths of input and output ports. See “Creating Input and Output Ports” on page 7-16.

Setting Sample Times and Offsets

Both M-file and C MEX S-functions allow a high degree of flexibility in specifying when an S-function executes. Simulink provides the following options for sample times:

- Continuous sample time — For S-functions that have continuous states and/or nonsampled zero crossings (see “How Simulink Works” in Using Simulink documentation for explanation of zero crossings). For this type of S-function, the output changes in minor time steps.
- Continuous but fixed in minor time step sample time — For S-functions that need to execute at every major simulation step, but do not change value during minor time steps.
- Discrete sample time — If your S-Function block’s behavior is a function of discrete time intervals, you can define a sample time to control when Simulink calls the block. You can also define an offset that delays each sample time hit. The value of the offset cannot exceed the corresponding sample time.

A *sample time hit* occurs at time values determined by the formula

$$\text{TimeHit} = (n * \text{period}) + \text{offset}$$

where n , an integer, is the current simulation step. The first value of n is always zero.

If you define a discrete sample time, Simulink calls the S-function `mdlOutput` and `mdlUpdate` routines at each sample time hit (as defined in the above equation).

- Variable sample time — A discrete sample time where the intervals between sample hits can vary. At the start of each simulation step, S-functions with variable sample times are queried for the time of the next hit.
- Inherited sample time — Sometimes an S-Function block has no inherent sample time characteristics (that is, it is either continuous or discrete, depending on the sample time of some other block in the system). You can

specify that the block's sample time is *inherited*. A simple example of this is a Gain block that inherits its sample time from the block driving it.

A block can inherit its sample time from

- The driving block
- The destination block
- The fastest sample time in the system

To set a block's sample time as inherited, use -1 in M-file S-functions and `INHERITED_SAMPLE_TIME` in C S-functions as the sample time. For more information on the propagation of sample times, see “Displaying Sample Time Colors” in Using Simulink.

S-functions can be either single or multirate; a multirate S-function has multiple sample times.

Sample times are specified in pairs in this format: [sample_time, offset_time]. The valid sample time pairs are

```
[CONTINUOUS_SAMPLE_TIME, 0.0]
[CONTINUOUS_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
[discrete_sample_time_period, offset]
[VARIABLE_SAMPLE_TIME, 0.0]
```

where

```
CONTINUOUS_SAMPLE_TIME = 0.0
FIXED_IN_MINOR_STEP_OFFSET = 1.0
VARIABLE_SAMPLE_TIME = -2.0
```

and the italics indicate that a real value is required.

Alternatively, you can specify that the sample time is inherited from the driving block. In this case the S-function can have only one sample time pair

```
[INHERITED_SAMPLE_TIME, 0.0]
```

or

```
[INHERITED_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
```

where

```
INHERITED_SAMPLE_TIME = -1.0
```

The following guidelines might help you specify sample times:

- A continuous S-function that changes during minor integration steps should register the [CONTINUOUS_SAMPLE_TIME, 0.0] sample time.
- A continuous S-function that does not change during minor integration steps should register the [CONTINUOUS_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET] sample time.
- A discrete S-function that changes at a specified rate should register the discrete sample time pair, [*discrete_sample_time_period*, *offset*], where

```
discrete_sample_period > 0.0
```

and

```
 $0.0 \leq \textit{offset} < \textit{discrete\_sample\_period}$ 
```

- A discrete S-function that changes at a variable rate should register the variable step discrete sample time.

```
[VARIABLE_SAMPLE_TIME, 0.0]
```

The `mdlGetTimeOfNextVarHit` routine is called to get the time of the next sample hit for the variable step discrete task.

If your S-function has no intrinsic sample time, you must indicate that your sample time is inherited. There are two cases:

- An S-function that changes as its input changes, even during minor integration steps, should register the [INHERITED_SAMPLE_TIME, 0.0] sample time.
- An S-function that changes as its input changes, but doesn't change during minor integration steps (that is, remains fixed during

minor time steps), should register the [INHERITED_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET] sample time.

The Scope block is a good example of this type of block. This block should run at the rate of its driving block, either continuous or discrete, but should never run in minor steps. If it did, the scope display would show the intermediate computations of the solver rather than the final result at each time point.

S-Function Examples

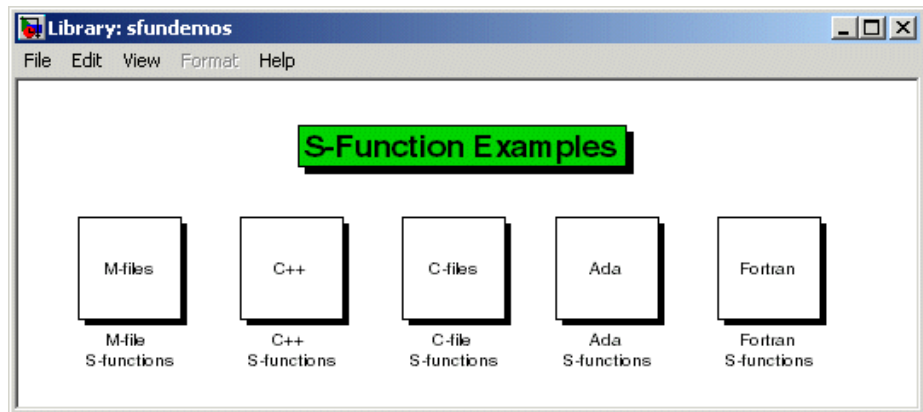
In this section...
“Overview of Examples” on page 1-20
“Level-2 M-File S-Function Examples” on page 1-22
“Level-1 M-File S-Function Examples” on page 1-22
“C S-Function Examples” on page 1-25
“Fortran S-Function Examples” on page 1-29
“C++ S-Function Examples” on page 1-30
“Ada S-Function Examples” on page 1-30

Overview of Examples

To run an example:

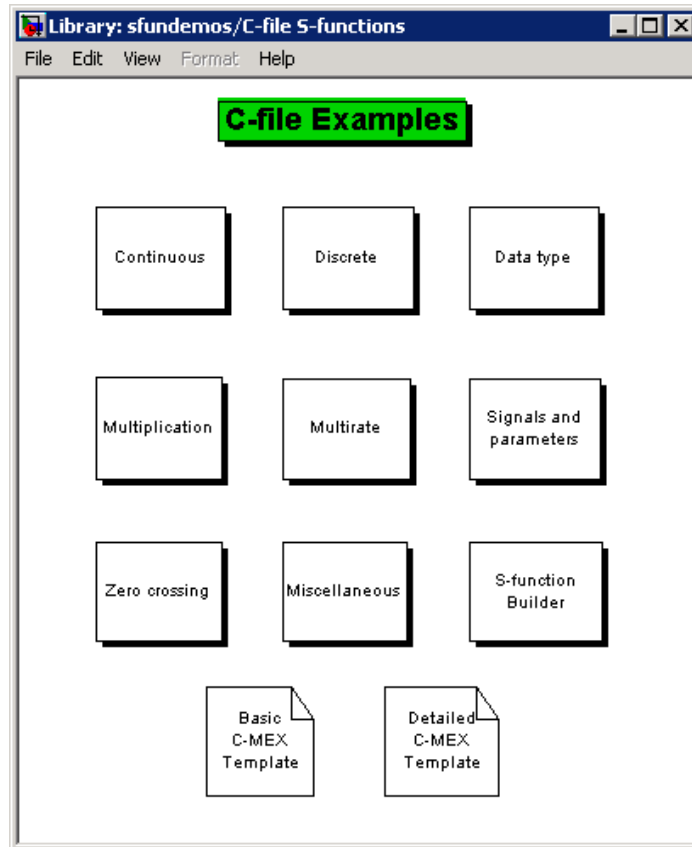
- 1 Enter `sfundemos` at the MATLAB command line.

MATLAB displays the S-function demo library.



Each block represents a category of S-function examples.

- 2 Click a category to display the examples that it includes.



3 Click a block to open and run the example that it represents.

It might be helpful to examine some sample S-functions as you read the next chapters. Code for the examples is stored in these subdirectories under the MATLAB root directory:

M-files	toolbox/simulink/blocks
C, C++, and Fortran	simulink/src
Ada	simulink/ada/examples

Level-2 M-File S-Function Examples

The `simulink/blocks` directory contains many Level-2 M-file S-functions. Consider starting off by looking at these files.

Filename	Description
<code>msfcn_dsc.m</code>	Inherited sample time example.
<code>msfcn_limintm.m</code>	Implement a continuous limited integrator where the output is bounded by lower and upper bounds and includes initial conditions.
<code>msfcn_times_two.m</code>	Basic Level-2 M-file S-function that doubles its input.
<code>msfcn_unit_delay.m</code>	Implement a unit delay.
<code>msfcn_varpulse.m</code>	Implement a variable pulse width generator by calling <code>set_param</code> from within a Level-2 S-function.
<code>msfcn_vs.m</code>	Implement a variable sample time block in which the first input is delayed by an amount of time determined by the second input.

Level-1 M-File S-Function Examples

The `simulink/blocks` directory also contains many Level-1 M-file S-functions, provided as reference for legacy models.

Filename	Description
<code>csfunc.m</code>	Define a continuous system in state-space format.
<code>dsfunc.m</code>	Define a discrete system in state-space format.

Filename	Description
vsfunc.m	Illustrates how to create a variable sample time block. This block implements a variable step delay in which the first input is delayed by an amount of time determined by the second input.
mixedm.m	Implement a hybrid system consisting of a continuous integrator in series with a unit delay.
vdpm.m	Implement the Van der Pol equation (similar to the demo model, vdp).
simom.m	<p>Example state-space M-file S-function with internal A, B, C, and D matrices. This S-function implements</p> $\begin{aligned} dx/dt &= Ax + Bu \\ y &= Cx + Du \end{aligned}$ <p>where x is the state vector, u is the input vector, and y is the output vector. The A, B, C, and D matrices are embedded in the M-file.</p>
simom2.m	Example state-space M-file S-function with external A, B, C, and D matrices. The state-space structure is the same as in <code>simom.m</code> , but the A, B, C, and D matrices are provided externally as parameters to this file.
limintm.m	Implement a continuous limited integrator where the output is bounded by lower and upper bounds and includes initial conditions.

Filename	Description
<code>sfun_varargm.m</code>	Example M-file S-function showing how to use the MATLAB vararg facility.
<code>vlimintm.m</code>	Example of a continuous limited integrator S-function. This illustrates how to use the size entry of -1 to build an S-function that can accommodate a dynamic input/state width.
<code>vdlmintm.m</code>	Example of a discrete limited integrator S-function. This example is identical to <code>vlimint.m</code> , except that the limited integrator is discrete.

C S-Function Examples

The `simulink/src` directory also contains examples of C MEX S-functions, many of which have an M-file S-function counterpart. These C MEX S-functions are listed in this table.

Filename	Description
<code>barplot.c</code>	Access Simulink signals without using the standard block inputs.
<code>csfunc.c</code>	Example C MEX S-function for defining a continuous system.
<code>dlimintc.c</code>	Implement a discrete-time limited integrator.
<code>dsfunc.c</code>	Example C MEX S-function for defining a discrete system.
<code>fcncallgen.c</code>	Execute function-call subsystems n times at the designated rate (sample time).
<code>limintc.c</code>	Implement a limited integrator.
<code>mixedm.c</code>	Implement a hybrid dynamic system consisting of a continuous integrator ($1/s$) in series with a unit delay ($1/z$).
<code>mixedmex.c</code>	Implement a hybrid dynamic system with a single output and two inputs.
<code>quantize.c</code>	Example MEX-file for a vectorized quantizer block. Quantizes the input into steps as specified by the quantization interval parameter, q .
<code>sdotproduct</code>	Compute dot product (multiply-accumulate) of two real or complex vectors.
<code>sftable2.c</code>	Two-dimensional table lookup in S-function form.

Filename	Description
<code>sfun_atol.c</code>	Set different absolute tolerances for each continuous state.
<code>sfun_cplx.c</code>	Complex signal add with one input port and one parameter.
<code>sfun_directlook.c</code>	Direct 1-D lookup.
<code>sfun_dtype_io.c</code>	Example of the use of Simulink data types for inputs and outputs.
<code>sfun_dtype_param.c</code>	Example of the use of Simulink data types for parameters.
<code>sfun_dynsize.c</code>	Simple example of how to size outputs of an S-function dynamically.
<code>sfun_errhdl.c</code>	Simple example of how to check parameters using the <code>mdlCheckParams</code> S-function routine.
<code>sfun_fcncall.c</code>	Example of an S-function that is configured to execute function-call subsystems on the first and second output elements.
<code>sfun_frmad.c</code>	Frame-based A/D converter.
<code>sfun_frmda.c</code>	Frame-based D/A converter.
<code>sfun_frmdft.c</code>	Multichannel frame-based Discrete-Fourier transformation (and its inverse).
<code>sfun_frmunbuff.c</code>	Frame-based unbuffer block.
<code>sfun_multiport.c</code>	S-function that has multiple input and output ports.
<code>sfun_manswitch.c</code>	Manual switch.
<code>sfun_matadd.c</code>	Matrix add with one input port, one output port, and one parameter.
<code>sfun_multirate.c</code>	Demonstrate how to specify port-based sample times.

Filename	Description
sfun_psbbreaker.c	Implement the logic for the Breaker block in the SimPowerSystems Blockset.
sfun_psbcontc.c	Continuous implementation of state-space system.
sfun_psbdiscc.c	Discrete implementation of state-space system.
sfun_runtime1.c	Run-time parameter example.
sfun_runtime2.c	Run-time parameter example.
sfun_zc.c	Demonstrate use of nonsampled zero crossings to implement $\text{abs}(u)$. This S-function is designed to be used with a variable-step solver.
sfun_zc_sat.c	Saturation example that uses zero crossings.
sfunmem.c	A one-integration-step delay and hold memory function.
simomex.c	<p>Implements a single-input, two-output state-space dynamic system described by these state-space equations</p> $\begin{aligned} dx/dt &= Ax + Bu \\ y &= Cx + Du \end{aligned}$ <p>where x is the state vector, u is vector of inputs, and y is the vector of outputs.</p>

Filename	Description
stspace.c	Implement a set of state-space equations. You can turn this into a new block by using the S-Function block and mask facility. This example MEX-file performs the same function as the built-in State-Space block. This is an example of a MEX-file where the number of inputs, outputs, and states is dependent on the parameters passed in from the workspace. Use this as a template for other MEX-file systems.
stvctf.c	Implement a continuous-time transfer function whose transfer function polynomials are passed in via the input vector. This is useful for continuous time adaptive control applications.
stvdtf.c	Implement a discrete-time transfer function whose transfer function polynomials are passed in via the input vector. This is useful for discrete-time adaptive control applications.
stvmgain.c	Time-varying matrix gain.
table3.c	3-D lookup table.
timestwo.c	Basic C MEX S-function that doubles its input.
vdlmintc.c	Implement a discrete-time vectorized limited integrator.
vdpmex.c	Implement the Van der Pol equation.

Filename	Description
vlimintc.c	Implement a vectorized limited integrator.
vfunc.c	Illustrate how to create a variable sample time block in Simulink. This block implements a variable-step delay in which the first input is delayed by an amount of time determined by the second input.

Fortran S-Function Examples

The following table lists sample Fortran S-functions available in the `simulink/src` directory.

Filename	Description
sfun_timestwo_for.F	Sample Level 1 Fortran representation of a C timestwo S-function.
sfun_atmos.c sfun_atmos_sub.F	Calculation of the 1976 standard atmosphere to 86 km using a Fortran subroutine.
simomexf.F	Sample Level 1 Fortran representation of the C simomex S-function.
vdpmexf.F	Sample Level 1 Fortran representation of the C vdpdex S-function.

C++ S-Function Examples

The following table lists sample C++ S-functions.

Filename	Description
<code>sfun_counter_cpp.cpp</code>	Store a C++ object in the pointers vector PWork.

Ada S-Function Examples

The `simulink/ada/examples` directory contains the following subdirectories with examples of S-functions implemented in Ada.

Subdirectory Name	Description
<code>matrix_gain</code>	Implement a Matrix Gain block.
<code>multi_port</code>	Multiport block.
<code>simple_lookup</code>	Lookup table. Illustrates use of a wrapper S-function that wraps stand-alone Ada code (i.e., Ada packages and procedures) both for use with Simulink as an S-function and directly with Ada code generated using the Real-Time Workshop Ada Coder.
<code>times_two</code>	Output twice its input.

Writing S-Functions in M

Introduction (p. 2-2)

Introduction to writing S-functions in the MATLAB M language.

Writing Level-2 M-File S-Functions (p. 2-3)

Explains how to create M-file S-functions based on the current Level-2 M-file S-function application programming interface (API).

Maintaining Level-1 M-File S-Functions (p. 2-9)

Provides information on maintaining Level-1 M-file S-functions developed for earlier versions of Simulink.

Introduction

Simulink provides an application programming interface (API) that lets you create custom blocks whose properties and behavior are defined by M-file programs called M-file S-functions. The Level-2 M-file S-function API allows you to create blocks that have all of the features and capabilities of Simulink built-in blocks, including multiple input and output ports, the ability to accept vector or matrix signals of any data type supported by Simulink, real or complex signals, signal frames, and the ability to operate at multiple sample rates. For information on how to use the API to create custom blocks, see “Writing Level-2 M-File S-Functions” on page 2-3.

Note This version of Simulink also supports a predecessor API, called Level 1, for writing M-file S-functions. This is done to ensure that Simulink can simulate models that use M-file S-function blocks developed for use with earlier Simulink releases (see “Maintaining Level-1 M-File S-Functions” on page 2-9). You should not use the Level-1 API to develop new M-file S-functions. Instead, you should use the Level-2 API.

Simulink allows you to generate code for M-file S-functions if they are inlined. See “Inlining S-Functions” in the Target Language Compiler documentation for more information.

Writing Level-2 M-File S-Functions

In this section...

“About Level-2 M-File S-Functions” on page 2-3

“Level-2 M-File S-Function API” on page 2-4

“M-File S-Function Demos” on page 2-4

“S-Function Template” on page 2-4

“Instantiating a Level-2 M-File S-Function” on page 2-4

“Generating Code from a Level-2 M-File S-Function” on page 2-5

“Callback Methods” on page 2-5

“Setup Method” on page 2-6

“Run-time Object” on page 2-8

About Level-2 M-File S-Functions

The Level-2 M-file S-function application programming interface (API) allows you to use the MATLAB M language to create full-fledged custom blocks having multiple inputs and outputs and capable of handling any type of signal produced by a Simulink model, including matrix and frame signals of any data type. The Level-2 M-File S-Function API corresponds closely to the API for creating C MEX-file S-functions. Much of the documentation for creating C MEX-file S-functions (see Chapter 3, “Writing S-Functions in C” and Chapter 7, “Implementing Block Features”) applies also to Level-2 M-file S-functions. To avoid duplication, this section focuses on providing information that is specific to writing Level-2 M-file S-functions.

A Level-2 M-file S-function is an M-file that defines the properties and behavior of an instance of a Level-2 M-File S-Function block that references the M-file in a Simulink model. The M-file itself comprises a set of callback methods (see “Callback Methods” on page 2-5) that Simulink invokes when updating or simulating the model. The callback methods perform the actual work of initializing and computing the outputs of the block defined by the S-function.

To facilitate these tasks, Simulink passes a run-time object to the callback methods as an argument. The run-time object effectively serves as an M proxy for the S-function block, allowing the callback method to set and access the block's properties during simulation or model updating (see “Run-time Object” on page 2-8 for more information).

Level-2 M-File S-Function API

The Level-2 M-File S-function API defines the signatures and general purpose of the callback methods that constitute a Level-2 M-file S-function. The S-function itself provides the implementations of these callback methods. The implementations in turn determine the block's attributes (e.g., ports, parameters, and states) and behavior (e.g., the block's outputs as a function of time and the block's inputs, states, and parameters). By creating an S-function with an appropriate set of callback implementations, you can define a block type that meets the specific requirements of your application.

M-File S-Function Demos

Simulink provides a set of self-documenting demo models that illustrate creation and usage of Level-2 M-file S-functions. Enter `sfundemos` at the MATLAB command line to view the demos.

S-Function Template

To give you a head start on creating Level-2 M-file S-functions, Simulink provides an annotated M-file template containing skeleton implementation of the callbacks defined by the Level-2 M-File S-function API. The template resides at

```
matlabroot/toolbox/simulink/blocks/msfuntmpl.m
```

To create an M-file S-function, make a copy of the template and edit the copy as necessary to reflect the desired behavior of the S-function you are creating. The comments in the template explain how to do this.

Instantiating a Level-2 M-File S-Function

To create an instance of the S-function in a model, first create an instance of the Level-2 M-File S-Function block in the model. Then open the block's

parameter dialog box and enter the name of the M-file that implements your S-function in the dialog box's **M-file name** field. If your function uses any additional parameters, enter their values as a comma-separated list in the dialog box's **Parameters** field.

Generating Code from a Level-2 M-File S-Function

Generating code from a model containing a Level-2 M-file S-function requires that you provide a corresponding TLC file. You do not need a TLC file to run a model in accelerated mode as the Accelerator mode in Simulink runs Level-2 M-file S-functions in interpreted mode. See “Inlining M-File S-Functions” in the Real-Time Workshop User's Guide for more information on writing TLC-files for M-file S-functions.

Callback Methods

The Level-2 M-file S-function API specifies a set of callback methods that an M-file S-function must implement (see “Callback Methods That an S-Function Must Implement” on page 3-50) and others that it may choose to omit, depending on the requirements of the block that the S-function defines. The methods defined by the Level-2 M-file S-function API generally correspond to that of similarly named methods defined by the C MEX-file S-function API. For information on what each method does, see “How Simulink Works” in *Using Simulink* and Chapter 8, “S-Function Callback Methods — Alphabetical List”.

The following table lists the Level-2 M-file S-function callback methods and their C MEX-file counterparts.

Level-2 M-File Method	C MEX-File Method
setup method (see “Setup Method” on page 2-6)	mdlInitializeSizes
CheckParameters	mdlCheckParameters
Derivatives	mdlDerivatives
Disable	mdlDisable
Enable	mdlEnable
InitializeCondition	mdlInitializeConditions

Level-2 M-File Method	C MEX-File Method
Outputs	mdlOutputs
PostPropagationSetup	mdlSetWorkWidths
ProcessParameters	mdlProcessParameters
Projection	mdlProjection
SetInputPortComplexSignal	mdlSetInputPortComplexSignal
SetInputPortDataType	mdlSetInputPortDataType
SetInputPortDimensions	mdlSetInputPortDimensionInfo
SetInputPortSampleTime	mdlSetInputPortSampleTime
SetInputPortSamplingMode	mdlSetInputPortFrameData
SetOutputPortComplexSignal	mdlSetOutputPortComplexSignal
SetOutputPortDataType	mdlSetOutputPortDataType
SetOutputPortDimensions	mdlSetOutputPortDimensionInfo
SetOutputPortSampleTime	mdlSetOutputPortSampleTime
SimStatusChange	mdlSimStatusChange
Start	mdlStart
Terminate	mdlTerminate
Update	mdlUpdate
WriteRTW	mdlRTW
ZeroCrossings	mdlZeroCrossings

Setup Method

The body of the setup method of a Level-2 M-file S-function initializes instances of the corresponding Level-2 M-File S-Function block in a model. In this respect, the main function is similar to the `mdlInitializeSizes` callback method implemented by C MEX S-functions. Setup tasks that the main function performs include:

- Setting up the number of input and output ports of the block.

- Setting attributes such as dimensions, data types, complexity, and sample times for these ports.
- Setting up the number of parameters and checking for the validity of these parameters.
- Registering the various block methods using the handles for other local functions in the M-file, using the `RegBlockMethod` method of the S-function block's run-time object passed to it. See the documentation for `Simulink.MSFcnRunTimeBlock` for information on using this method.

The `setup` method in `matlabroot/toolbox/simulink/blocks/msfcn_unit_delay.m` initializes an S-function with one input port, one output port, and one dialog parameter. It initializes the compiled properties of the input and output ports using the run-time object methods `SetPreCompInPortInfoToDynamic` and `SetPreCompOutPortInfoToDynamic` as well as by directly setting certain properties. Finally, the method registers four S-function methods.

```
function setup(block)

%% Register a single dialog parameter
block.NumDialogPrms = 1;

%% Register number of input and output ports
block.NumInputPorts = 1;
block.NumOutputPorts = 1;

%% Setup functional port properties to dynamically
%% inherited.
block.SetPreCompInPortInfoToDynamic;
block.SetPreCompOutPortInfoToDynamic;

%% Hard-code certain port properties
block.InputPort(1).Dimensions = 1;
block.InputPort(1).DirectFeedthrough = false;

block.OutputPort(1).Dimensions = 1;

%% Set block sample time to inherited
```

```
block.SampleTimes = [0.1 0];

%% Register methods
block.RegBlockMethod('PostPropagationSetup',@DoPostPropSetup);
block.RegBlockMethod('InitializeConditions',@InitConditions);
block.RegBlockMethod('Outputs',           @Output);
block.RegBlockMethod('Update',           @Update);
```

Run-time Object

When Simulink invokes a Level-2 M-file S-function callback method, it passes an instance of `Simulink.MSFcnRunTimeBlock` class to the method as an argument. This instance, known as the S-function block's run-time object, serves the same purpose for Level-2 M-file S-function callback methods as the `SimStruct` structure serves for C MEX-file S-function callback methods. It enables the method to provide and obtain information about various elements of the block: ports, parameters, states, and work vectors. The method does this by getting or setting properties or invoking methods of the block run-time object. See the documentation for `Simulink.MSFcnRunTimeBlock` class for information on getting and setting the run-time object's properties and invoking its methods.

Note Other M-file programs besides M-file S-functions can use run-time objects to obtain information about an M-file S-function or other blocks in a model that is simulating. See “Accessing Block Data During Simulation” in *Using Simulink* for more information.

Maintaining Level-1 M-File S-Functions

In this section...

“About the Maintenance of Level-1 M-File S-Functions” on page 2-9

“S-Function Arguments” on page 2-10

“S-Function Outputs” on page 2-11

“Defining S-Function Block Characteristics” on page 2-12

“Processing S-Function Parameters” on page 2-13

“Converting Level-1 M-File S-functions to Level-2” on page 2-13

About the Maintenance of Level-1 M-File S-Functions

Note The information provided in this section is intended only for use in maintaining existing M-file S-functions based on Level-1 API. You should use the more capable Level-2 API to develop new M-file S-functions (see “Writing Level-2 M-File S-Functions” on page 2-3). Level-1 M-file S-functions do not support multidimensional signals.

A Level-1 M-file S-function consists of a MATLAB function of the following form

$$[\text{sys}, \text{x0}, \text{str}, \text{ts}] = \text{f}(\text{t}, \text{x}, \text{u}, \text{flag}, \text{p1}, \text{p2}, \dots)$$

where *f* is the name of the S-function. During simulation of a model, Simulink repeatedly invokes *f*, using the *flag* argument to indicate the task (or tasks) to be performed for a particular invocation. Each time the S-function performs the task and returns the results in an output vector.

A template implementation of an M-file S-function, *sfuntmpl.m*, resides in *matlabroot/toolbox/simulink/blocks*. The template consists of a top-level function and a set of skeleton subfunctions, called S-function callback methods, each of which corresponds to a particular value of *flag*. The top-level function invokes the subfunction indicated by *flag*. The subfunctions perform the actual tasks required of the S-function during simulation.

S-Function Arguments

Simulink passes the following arguments to an S-function:

t	Current time
x	State vector
u	Input vector
flag	Integer value that indicates the task to be performed by the S-function

The following table describes the values that `flag` can assume and lists the corresponding S-function method for each value.

Flag Argument

Flag	S-Function Routine	Description
0	setup, mdlInitializeSizes	Defines basic S-Function block characteristics, including sample times, initial conditions of continuous and discrete states, and the sizes array.
1	mdlDerivatives	Calculates the derivatives of the continuous state variables.
2	mdlUpdate	Updates discrete states, sample times, and major time step requirements.
3	mdlOutputs	Calculates the outputs of the S-function.

Flag Argument (Continued)

Flag	S-Function Routine	Description
4	<code>mdlGetTimeOfNextVarHit</code>	Calculates the time of the next hit in absolute time. This routine is used only when you specify a variable discrete-time sample time in <code>mdlInitializeSizes</code> .
9	<code>mdlTerminate</code>	Performs any necessary end-of-simulation tasks.

S-Function Outputs

An M-file returns an output vector containing the following elements:

- `sys`, a generic return argument. The values returned depend on the flag value. For example, for `flag = 3`, `sys` contains the S-function outputs.
- `x0`, the initial state values (an empty vector if there are no states in the system). `x0` is ignored, except when `flag = 0`.
- `str`, reserved for future use. M-file S-functions must set this to the empty matrix, `[]`.
- `ts`, a two-column matrix containing the sample times and offsets of the block (see “Specifying Sample Time” in the *Using Simulink* for information on how to specify a block’s sample time and offset).

For example, if you want your S-function to run at every time step (continuous sample time), set `ts` to `[0 0]`. If you want your S-function to run at the same rate as the block to which it is connected (inherited sample time), set `ts` to `[-1 0]`. If you want it to run every 0.25 seconds (discrete sample time) starting at 0.1 seconds after the simulation start time, set `ts` to `[0.25 0.1]`.

You can create S-functions that do multiple tasks, each at a different sample rate (i.e., a multirate S-function). In this case, `ts` should specify all the sample rates used by your S-function in ascending order by sample time. For example, suppose your S-function performs one task every 0.25 second starting from the simulation start time and another task every 1

second starting 0.1 second after the simulation start time. In this case, your S-function should set `ts` equal to `[.25 0; 1.0 .1]`. This will cause Simulink to execute the S-function at the following times: `[0 0.1 0.25 0.5 0.75 1 1.1 ...]`. Your S-function must decide at every sample time which task to perform at that sample time.

You can also create an S-function that performs some tasks continuously (i.e., at every time step) and others at discrete intervals.

Defining S-Function Block Characteristics

For Simulink to recognize an M-file S-function, you must provide it with specific information about the S-function. This information includes the number of inputs, outputs, states, and other block characteristics.

To give Simulink this information, call the `simsizes` function at the beginning of `mdlInitializeSizes`.

```
sizes = simsizes;
```

This function returns an uninitialized `sizes` structure. You must load the `sizes` structure with information about the S-function. The table below lists the fields of the `sizes` structure and describes the information contained in each field.

Fields in the `sizes` Structure

Field Name	Description
<code>sizes.NumContStates</code>	Number of continuous states
<code>sizes.NumDiscStates</code>	Number of discrete states
<code>sizes.NumOutputs</code>	Number of outputs
<code>sizes.NumInputs</code>	Number of inputs
<code>sizes.DirFeedthrough</code>	Flag for direct feedthrough
<code>sizes.NumSampleTimes</code>	Number of sample times

After you initialize the `sizes` structure, call `simsizes` again:

```
sys = simsizes(sizes);
```


This passes the information in the `sizes` structure to `sys`, a vector that holds the information for use by Simulink.

Processing S-Function Parameters

When invoking an M-file S-function, Simulink always passes the standard block parameters, `t`, `x`, `u`, and `flag`, to the S-function as function arguments. Simulink can pass additional block-specific parameters specified by the user to the S-function. The user specifies the parameters in the **S-function parameters** field of the S-function's block parameter dialog (see "Passing Parameters to S-Functions" on page 1-5). If the block dialog specifies additional parameters, Simulink passes the parameters to the S-function as additional function arguments. The additional arguments follow the standard arguments in the S-function argument list in the order in which the corresponding parameters appear in the block dialog. You can use this block-specific S-function parameter capability to allow the same S-function to implement various processing options. See the `limintm.m` example in the `toolbox/simulink/blocks` directory for an example of an S-function that uses block-specific parameters in this way.

Converting Level-1 M-File S-functions to Level-2

You can convert Level-1 M-file S-functions to Level-2 M-file S-functions by mapping the code associated with each Level-1 S-function flag to the appropriate Level-2 S-function method. See the Flag Arguments table for a mapping of Level-1 flags to Level-2 methods. In addition

- Store state information for Level-2 S-functions in Dwork vectors, initialized in the `PostPropagationSetup` method.
- Access Level-2 S-function dialog parameters using the `DialogPrm` run-time object property, instead of passing them into the S-function calling syntax.
- For S-functions with variable sample times, update the `NextTimeHit` run-time object property in the `Outputs` method to set the next sample time hit for the Level-2 S-function.

Compare the code in the Level-1 and Level-2 S-functions `sfundsc2.m` and `msfcn_unit_delay.m` for an example.

Writing S-Functions in C

Introduction (p. 3-3)	Overview of writing a C S-function.
Building S-Functions Automatically (p. 3-6)	How to use the S-Function Builder to generate S-functions automatically from specifications that you supply.
S-Function Builder Dialog Box (p. 3-11)	Describes the S-Function Builder dialog box
Example of a Basic C MEX S-Function (p. 3-41)	Illustrates the code needed to create a C S-function.
Templates for C S-Functions (p. 3-48)	Describes code templates that you can use as starting points for writing your own C S-functions.
Integrating Existing C Functions into Simulink Models with the Legacy Code Tool (p. 3-53)	How to use the Legacy Code Tool to generate S-functions automatically from existing C code.
How Simulink Interacts with C S-Functions (p. 3-74)	Describes how Simulink interacts with a C S-function. This is information that you need to know in order to create and debug your own C S-functions.
Writing Callback Methods (p. 3-82)	How to write methods that Simulink calls as it executes your S-function.
Using S-Functions in Normal Mode Referenced Models (p. 3-83)	Describes requirements that must be met by a C S-function that is used in a referenced model that executes in Normal mode

Debugging C MEX S-Functions
(p. 3-85)

How to debug C MEX S-Functions while Simulink executes your S-function.

Converting Level 1 C MEX S-Functions to Level 2 (p. 3-89)

How to convert S-functions written for earlier releases of Simulink to work with the current version.

Introduction

In this section...
“About Writing C S-Functions” on page 3-3
“Creating C MEX S-Functions” on page 3-4

About Writing C S-Functions

A C MEX-file that defines an S-Function block must provide information about the model to Simulink during the simulation. As the simulation proceeds, Simulink, the ODE solver, and the C MEX-file interact to perform specific tasks. These tasks include defining initial conditions and block characteristics, and computing derivatives, discrete states, and outputs.

As with M-file S-functions, Simulink interacts with a C MEX-file S-function by invoking callback methods that the S-function implements. Each method performs a predefined task, such as computing block outputs, required to simulate the block whose functionality the S-function defines. Simulink defines in a general way the task of each callback. The S-function is free to perform the task according to the functionality it implements. For example, Simulink specifies that the S-function's `mdlOutput` method must compute that block's outputs at the current simulation time. It does not specify what those outputs must be. This callback-based API allows you to create S-functions, and hence custom blocks, of any desired functionality.

The set of callback methods, hence functionality, that C MEX-files can implement is much larger than that available for M-file S-functions. See Chapter 8, “S-Function Callback Methods — Alphabetical List” for descriptions of the callback methods that a C MEX-file S-function can implement. Unlike M-file S-functions, C MEX-files can access and modify the data structure that Simulink uses internally to store information about the S-function. The ability to implement a broader set of callback methods and to access internal data structures allows C MEX-files to implement a wider set of block features, such as the ability to handle matrix signals and multiple data types.

C MEX-file S-functions are required to implement only a small subset of the callback methods that Simulink defines. If your block does not implement a

particular feature, such as matrix signals, you are free to omit the callback methods required to implement a feature. This allows you to create simple blocks very quickly.

The general format of a C MEX S-function is shown below:

```
#define S_FUNCTION_NAME  your_sfunction_name_here
#define S_FUNCTION_LEVEL 2
#include "simstruc.h"

static void mdlInitializeSizes(SimStruct *S)
{
}

<additional S-function routines/code>

static void mdlTerminate(SimStruct *S)
{
}

#ifdef MATLAB_MEX_FILE    /* Is this file being compiled as a
                           MEX-file? */
#include "simulink.c"    /* MEX-file interface mechanism */
#else
#include "cg_sfun.h"    /* Code generation registration
                           function */
#endif

#endif
```

`mdlInitializeSizes` is the first routine Simulink calls when interacting with the S-function. Simulink subsequently invokes other S-function methods (all starting with `mdl`). At the end of a simulation, Simulink calls `mdlTerminate`.

Creating C MEX S-Functions

You can create C MEX S-functions using any of the following approaches:

- Handcrafted S-function — You can write a C MEX S-function from scratch. “Example of a Basic C MEX S-Function” on page 3-41 provides a step-by-step example of how to write a simple S-function from scratch. See “Templates for C S-Functions” on page 3-48 for a complete skeleton

implementation of a C MEX S-function that you can use as a starting point for creating your own S-functions.

- **S-Function Builder** — This block builds a C MEX S-function from specifications and code fragments that you supply using a graphical user interface. This eliminates the need for you to write S-functions from scratch. See “Building S-Functions Automatically” on page 3-6 for more information about the S-Function Builder.
- **Legacy Code Tool** — This utility builds a C MEX S-function from existing C code and specifications that you supply using MATLAB M-code. See “Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” on page 3-53 for more information about integrating legacy C code with Simulink.

Each of these approaches involves a tradeoff between the ease of writing an S-function and the Simulink features supported by an S-function. Although handcrafted S-functions support the widest range of Simulink features, they can be difficult to write. The S-Function Builder block simplifies the task of writing C MEX S-functions but supports fewer Simulink features. The Legacy Code Tool provides the easiest approach to creating C MEX S-functions from existing C code but supports the fewest Simulink features.

Building S-Functions Automatically

In this section...
“About Building S-Functions Automatically” on page 3-6
“Deploying the Generated S-Function” on page 3-9
“How the S-Function Builder Builds an S-Function” on page 3-10

About Building S-Functions Automatically

The S-Function Builder is a Simulink block that builds an S-function from specifications and C code that you supply. The S-Function Builder also serves as a wrapper for the generated S-function in models that use the S-function. This section explains how to use the S-Function Builder to build simple C MEX S-functions.

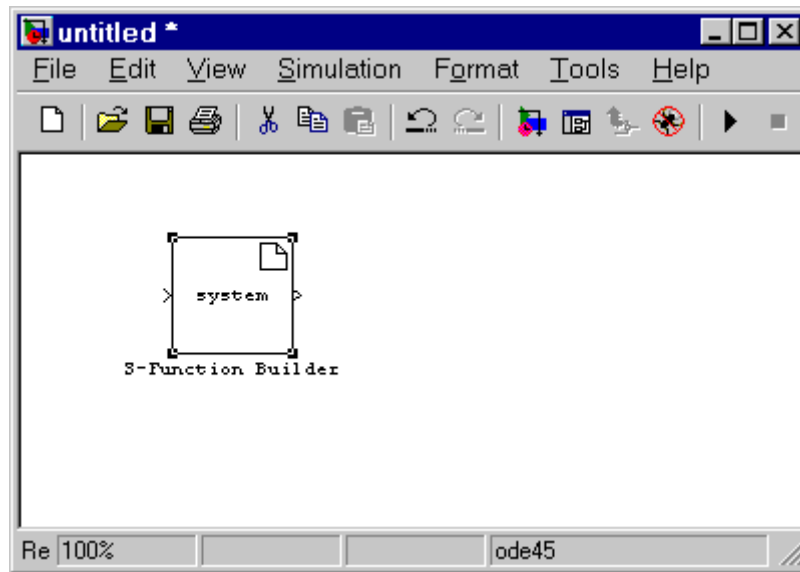
Note For examples of using the S-Function Builder to build S-functions, see the “C-file S-functions” section of the S-function demos provided with Simulink. To display the demos, enter `sfundemos` at the MATLAB command line (see “S-Function Examples” on page 1-20 for more information).

To build an S-function with the S-Function Builder:

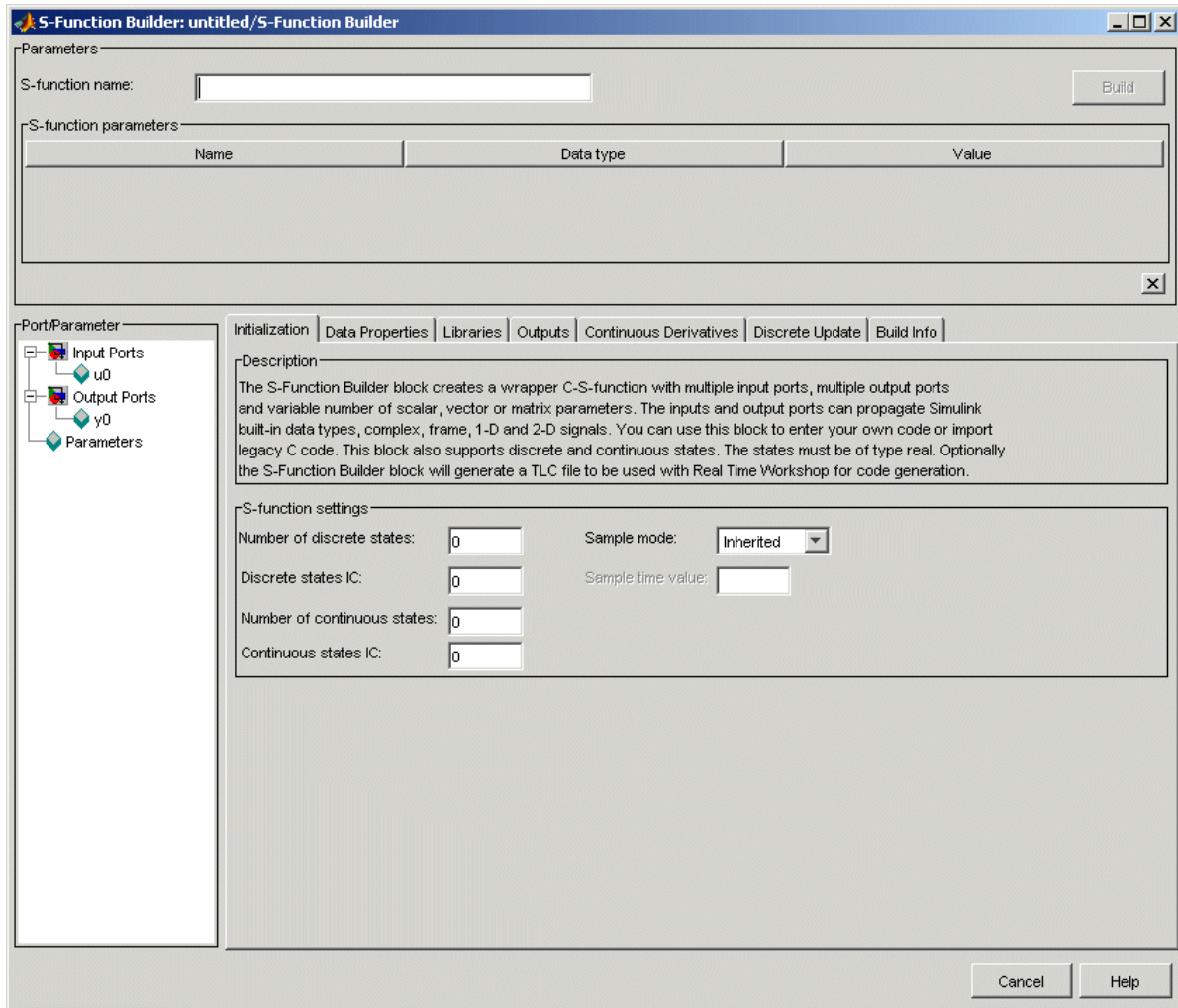
- 1 Set the MATLAB current directory to the directory in which you want to create the S-function.

Note This directory must be on the MATLAB path.

- 2 Create a new Simulink model.
- 3 Copy an instance of the S-Function Builder block from the Simulink User-Defined Functions library into the new model.



- 4 Double-click the block to open the S-Function Builder dialog box (see “S-Function Builder Dialog Box” on page 3-11).



- 5 Use the specification and code entry panes on the S-Function Builder dialog box to enter information and custom source code required to tailor the generated S-function to your application (see “S-Function Builder Dialog Box” on page 3-11).
- 6 If you have not already done so, configure the MATLAB mex command to work on your system.

To configure the mex command, type `mex -setup` at the MATLAB command line.

- 7 Click **Build** on the dialog box to start the build process.

Simulink builds a MEX-file that implements the specified S-function and saves the file in the current directory (see “How the S-Function Builder Builds an S-Function” on page 3-10).

- 8 Save the model containing the S-Function Builder block.

Deploying the Generated S-Function

To use the generated S-function in another model, first check to ensure that the directory containing the generated S-function is on the MATLAB path. Then copy the S-Function Builder block from the model used to create the S-function into the target model and set its parameters, if necessary, to the values required by the target model.

Alternatively, you can deploy the generated S-function without using the S-Function Builder block or exposing the underlying C source file. To do this:

- 1 Open the Simulink model will include the S-function.
- 2 Copy an S-Function block from the User-Defined Functions Simulink library into the model.
- 3 Double-click on the S-Function block.
- 4 In the dialog box that opens, enter the name of the executable file generated by the S-Function Builder into the **S-Function name** edit field.
- 5 Enter any parameters needed by the S-function into the **S-function parameters** edit field. Enter the parameters in the order they appear in the S-Function Builder dialog box.
- 6 Click **OK** on the S-Function block dialog box.

You can use the generated executable file, for example, the `.mexw32` file, in any S-Function block in any model as long as the executable file is on the MATLAB path.

How the S-Function Builder Builds an S-Function

The S-Function Builder builds an S-function as follows. First, it generates the following source files in the current directory:

- `sfun.c`

where `sfun` is the name of the S-function that you specified in the **S-function name** field of the S-Function Builder's dialog box. This file contains the C source code representation of the standard portions of the generated S-function.

- `sfun_wrapper.c`

This file contains the custom code that you entered in the S-Function Builder dialog box.

- `sfun.tlc`

This file permits Simulink to run the generated S-function in accelerated mode and Real-Time Workshop to include this S-function in the code it generates.

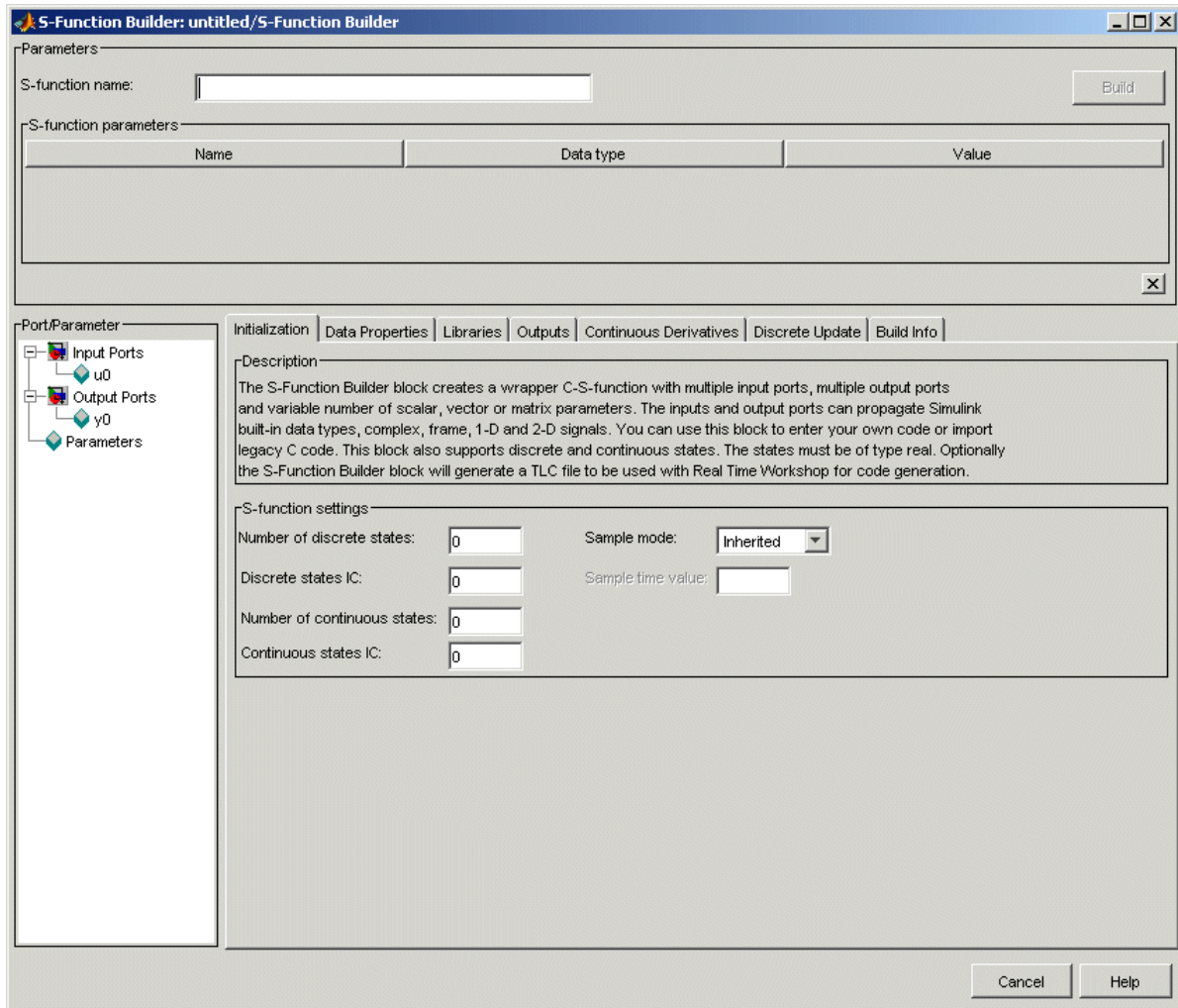
After generating the S-function source code, the S-Function Builder uses the MATLAB `mex` command to build the MEX-file representation of the S-function from the generated source code and any external custom source code and libraries that you specified.

S-Function Builder Dialog Box

In this section...
“About S-Function Builder” on page 3-11
“Parameters/S-Function Name Pane” on page 3-13
“Port/Parameter Pane” on page 3-14
“Initialization Pane” on page 3-14
“Data Properties Pane” on page 3-16
“Input Ports Pane” on page 3-18
“Output Ports Pane” on page 3-19
“Parameters Pane” on page 3-21
“Data Type Attributes Pane” on page 3-22
“Libraries Pane” on page 3-23
“Outputs Pane” on page 3-25
“Continuous Derivatives Pane” on page 3-29
“Discrete Update Pane” on page 3-31
“Build Info Pane” on page 3-33
“Example: Modeling a Two-Input/Two-Output System” on page 3-35

About S-Function Builder

The S-Function Builder dialog box enables you to specify the attributes of an S-function to be built by an S-Function Builder block. To display the dialog box, click twice on the block’s icon or select the block and then select **Open Block** from the model editor’s **Edit** menu or the block’s context menu. The dialog box appears.



The dialog box contains controls that let you enter information needed for the S-Function Builder block to build an S-function to your specifications. The controls are grouped into panes. See the following sections for information on the panes and the controls that they contain.

Note The following sections use the term *target S-function* to refer to the S-function specified by the S-Function Builder dialog box.

See “Example: Modeling a Two-Input/Two-Output System” on page 3-35 for an example showing how to use the S-Function Builder to model a two-input/two-output discrete state-space system.

Parameters/S-Function Name Pane

This pane displays the target S-function’s name and parameters.

The screenshot shows a dialog box titled "Parameters". At the top, there is a label "S-function name:" followed by a text input field and a "Build" button. Below this is a section titled "S-function parameters" containing a table with three columns: "Name", "Data type", and "Value".

Name	Data type	Value
a	double	1
b	double	1

There is a close button (X) in the bottom right corner of the dialog box.

The pane contains the following controls.

S-function name

Specifies the name of the target S-function.

S-function parameters

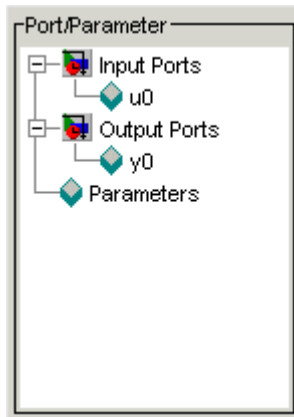
This table displays the parameters of the target S-function. Each row of the table corresponds to a parameter, and each column displays a property of the parameter as follows:

- **Name** — Name of the parameter. Define and modify this property from the “Parameters Pane” on page 3-21.
- **Data type** — Lists the data type of the parameter. Define and modify this property from the “Parameters Pane” on page 3-21.

- **Value** — Specifies the value of the parameter. Enter a valid MATLAB expression in this field.

Port/Parameter Pane

This pane displays the ports and parameters that the dialog box specifies for the target S-function.



The pane contains a tree control whose top nodes correspond to the target S-function's input ports, output ports, and parameters, respectively. Expanding the Input Ports, Output Ports, or Parameter node displays the input ports, output ports, or parameters, respectively, specified for the target S-function. Selecting any of the port or parameter nodes selects the corresponding entry on the corresponding port or parameter specification pane.

Initialization Pane

The **Initialization** pane allows you to specify basic features of the S-function, such as the width of its input and output ports and its sample time.

The screenshot shows the 'Initialization' pane of the S-Function Builder dialog box. It features a tabbed interface with 'Initialization' selected. The 'Description' section contains text explaining the block's purpose. The 'S-function settings' section includes input fields for discrete and continuous states, a sample mode dropdown, and a sample time value field.

Initialization | Data Properties | Libraries | Outputs | Continuous Derivatives | Discrete Update | Build Info

Description

The S-Function Builder block creates a wrapper C-S-function with multiple input ports, multiple output ports and variable number of scalar, vector or matrix parameters. The inputs and output ports can propagate Simulink built-in data types, complex, frame, 1-D and 2-D signals. You can use this block to enter your own code or import legacy C code. This block also supports discrete and continuous states. The states must be of type real. Optionally the S-Function Builder block will generate a TLC file to be used with Real Time Workshop for code generation.

S-function settings

Number of discrete states: Sample mode:

Discrete states IC: Sample time value:

Number of continuous states:

Continuous states IC:

The S-Function Builder uses the information that you enter on this pane to generate the S-function's `mdlInitializeSizes` callback method. Simulink invokes this method during the model initialization phase of the simulation to obtain basic information about the S-function. (See “How Simulink Interacts with C S-Functions” on page 3-74 for more information on the model initialization phase.)

The **Initialization** pane contains the following fields.

Number of discrete states

Number of discrete states that the S-function has.

Discrete states IC

Initial conditions of the S-function's discrete states. You can enter the values as a comma-separated list or as a vector (e.g., `[0 1 2]`). The number of initial conditions must equal the number of discrete states.

Number of continuous states

Number of continuous states that the S-function has.

Continuous states IC

Initial conditions of the S-function's continuous states. You can enter the values as a comma-separated list or as a vector (e.g., [0 1 2]). The number of initial conditions must equal the number of continuous states.

Sample mode

Sample mode of the S-function. The sample mode determines the length of the interval between the times when the S-function updates its output. You can select one of the following options:

- Inherited

The S-function inherits its sample time from the block connected to its input port.

- Continuous

The block updates its outputs at each simulation step.

- Discrete

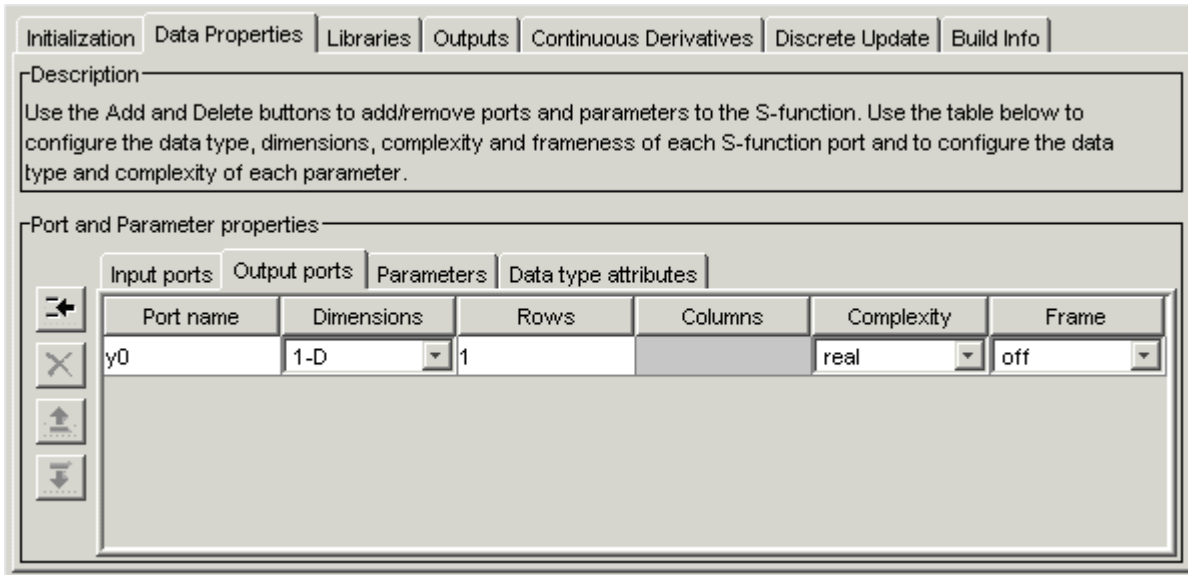
The S-function updates its outputs at the rate specified in the **Sample time value** field of the S-Function Builder dialog box.

Sample time value

Interval between updates of the S-function's outputs. This field is enabled only if you have selected **Discrete** as the S-function's **Sample mode**.

Data Properties Pane

The **Data Properties** pane allows you to add ports and parameters to your S-function.



The column of buttons to the left of the panes allows you to add, delete, or reorder ports or parameters, depending on the currently selected pane.

- To add a port or parameter, click the **Add** button (the top button in the column of buttons).
- To delete the currently selected port/parameter, click the **Delete** button (located beneath the **Add** button).
- To move the currently selected port/parameter up one position in the corresponding S-Function port/parameter list, click the **Up** button (beneath the **Delete** button).
- To move the currently selected port/parameter down one position in the corresponding S-function port/parameter list, click the **Down** button (beneath the **Up** button).

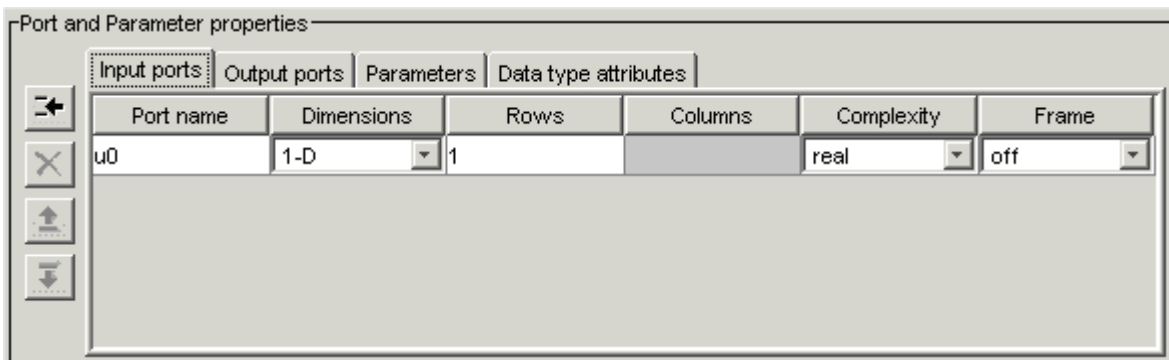
This pane also contains tabbed panes that enable you to specify the attributes of the ports and parameters that you create. See the following topics for more information.

- “Input Ports Pane” on page 3-18

- “Output Ports Pane” on page 3-19
- “Parameters Pane” on page 3-21
- “Data Type Attributes Pane” on page 3-22

Input Ports Pane

The **Input Ports** pane allows you to inspect and modify the properties of the S-function’s input ports.



The pane comprises an editable table that lists the properties of the input ports in the order in which the ports appear on the S-function block. Each row of the table corresponds to a port. Each entry in the row displays a property of the port as follows.

Port name

Name of the port. Edit this field to change the port name.

Dimensions

Lists the number of dimensions of input signals accepted by the port. To display a list of supported dimensions, click the adjacent button. To change the port’s dimensionality, select a new value from the list. Specify 1-D to size the signal dynamically, regardless of the signal’s actual dimensionality.

Rows

Specifies the size of the input signal's first (or only) dimension. Specify -1 to size the signal dynamically.

Columns

Specifies the size of the input signal's second dimension (only if the input port accepts 2-D signals).

Note For input signals with two dimensions, if the row dimension is dynamically sized, the column dimension must also be dynamically sized or set to 1. If the column dimension is set to some other value, the S-function will compile, but any simulation containing this S-function will not run due to an invalid dimension specification.

Complexity

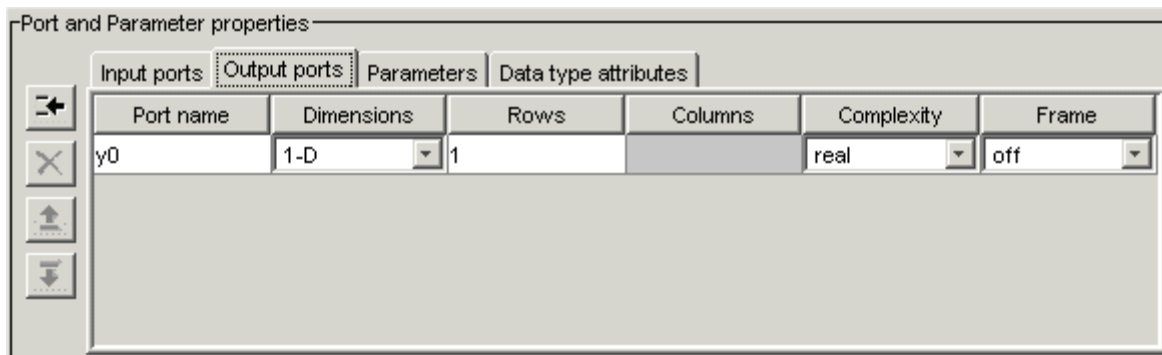
Specifies whether the input port accepts real or complex-valued signals.

Frame

Specifies whether this port accepts frame-based signals generated by Signal Processing Blockset or Communications Blockset. For more information, see the documentation for these blocksets.

Output Ports Pane

The **Output Ports** pane allows you to inspect and modify the properties of the S-function's output ports.



The pane comprises an editable table that lists the properties of the output ports in the order in which the ports appear on the S-function block. Each row of the table corresponds to a port. Each entry in the row displays a property of the port as follows.

Port name

Name of the port. Edit this field to change the port name.

Dimensions

Lists the number of dimensions of signals output by the port. To display a list of supported dimensions, click the adjacent button. To change the port's dimensionality, select a new value from the list. Specify 1-D to size the signal dynamically, regardless of the signal's actual dimensionality.

Rows

Specifies the size of the output signal's first (or only) dimension. Specify -1 to size the signal dynamically.

Columns

Specifies the size of the output signal's second dimension (only if the port outputs 2-D signals).

Note For output signals with two dimensions, if one of the dimensions is dynamically sized the other dimension must also be dynamically sized or set to 1. If the second dimension is set to some other value, the S-function will compile, but any simulation containing this S-function will not run due to an invalid dimension specification. In some cases, the default Simulink methods that determine the dimensions of dynamically sized output ports may be insufficient and both dimensions of the 2-D output signal may need to be hard coded.

Complexity

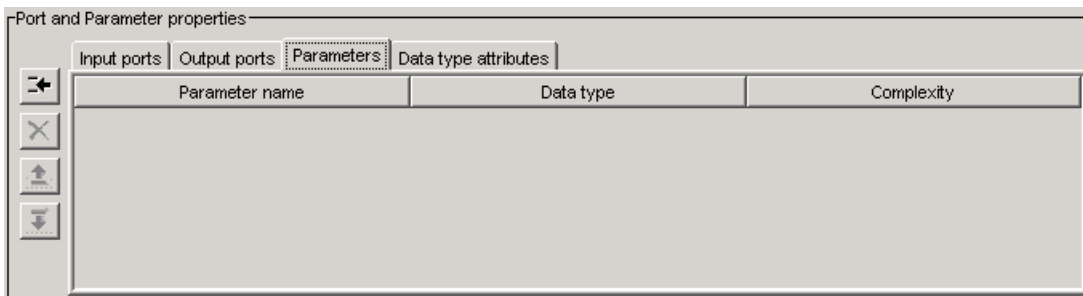
Specifies whether the port outputs real or complex-valued signals.

Frame

Specifies whether this port outputs frame-based signals generated by Signal Processing Blockset or Communications Blockset. For more information, see the documentation for these blocksets.

Parameters Pane

The **Parameters** pane allows you to inspect and modify the properties of the S-function's parameters.



The pane comprises an editable table that lists the properties of the S-function's parameters. Each row of the table corresponds to a parameter. The order in which the parameters appear corresponds to the order in which

the user must specify them. Each entry in the row displays a property of the parameter as follows.

Parameter name

Name of the parameter. Edit this field to change the name.

Data type

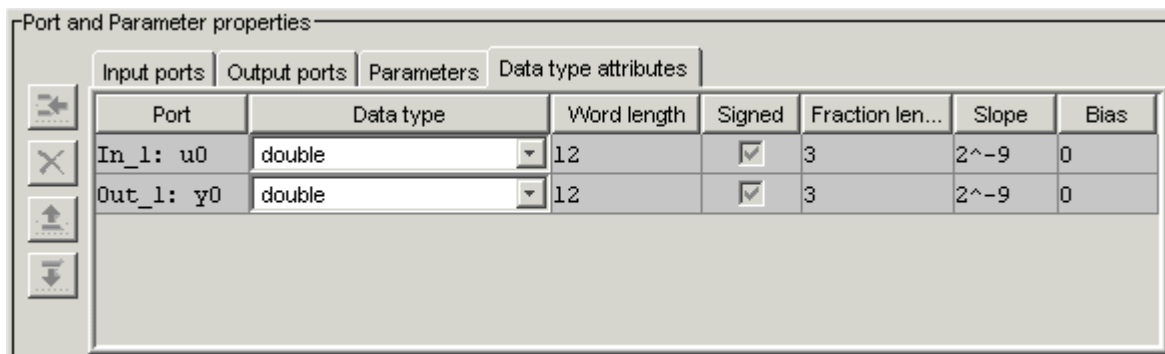
Lists the data type of the parameter. Click the adjacent button to display a list of supported data types. To change the parameter's data type, select a new type from the list.

Complexity

Specifies whether the parameter has real or complex values.

Data Type Attributes Pane

This pane allows you to specify the data type attributes of the target S-function's input and output ports.



The pane contains a table listing the data type attributes of each of the S-functions ports. Only some of the fields in the table are editable. Non-editable fields are grayed out. Each row corresponds to a port of the target S-function. Each column specifies an attribute of the corresponding port.

Port

Name of the port. This field is not editable.

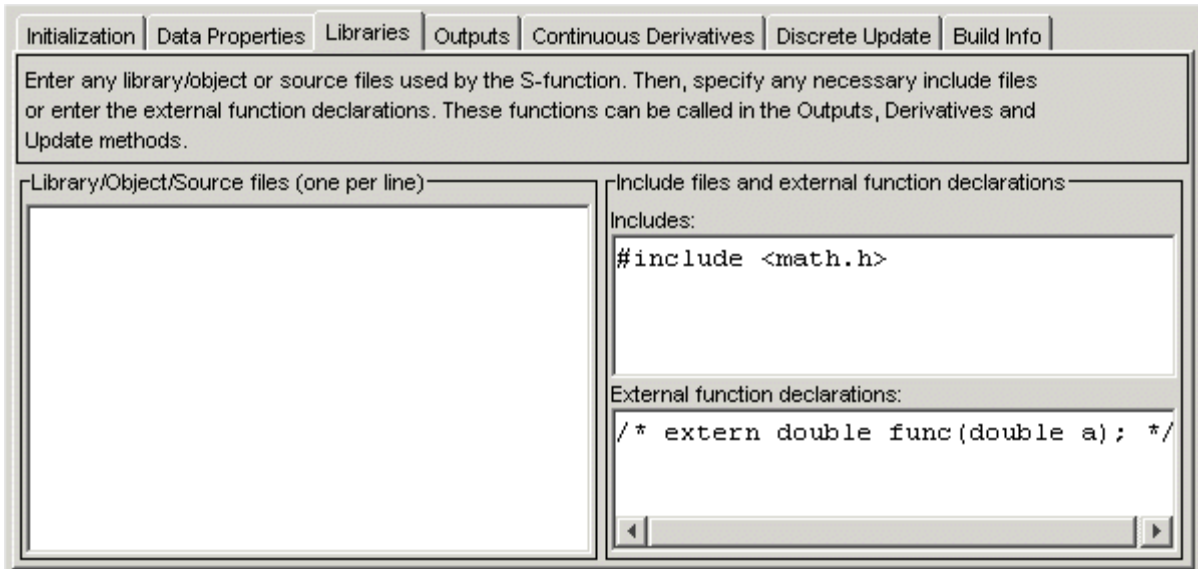
Data Type

Data type of the port. To display a list of specifiable data types, select the adjacent pulldown list control. To change the data type, select a different data type from the list.

The remaining fields on this pane are enabled only if the **Data Type** field specifies a fixed-point data type. See “Fixed-Point Data” for more information.

Libraries Pane

The **Libraries** pane allows you to specify the location of external code files referenced by custom code that you enter in other panes of the S-Function Builder dialog box.



The **Libraries** pane includes the following fields.

Library/Object/Source files

External library, object code, and source files referenced by custom code that you enter elsewhere on the S-Function Builder dialog box. List each file on a separate line. If the file resides in the current directory, you need specify only the file's name. If the file resides in another directory, you must specify the full path of the file.

Alternatively, you can also use this field to specify search paths for libraries, object files, header files, and source files. To do this, enter the tag `LIB_PATH`, `INC_PATH`, or `SRC_PATH`, respectively, followed by the path name. You can make as many entries of this kind as you need but each must reside on a separate line.

For example, consider an S-Function Builder project that resides at `d:\matlab6p5\work` and needs to link against the following files:

- `c:\customfolder\customfunctions.lib`
- `d:\matlab7\customobjs\userfunctions.obj`
- `d:\externalsource\freesource.c`

The following entries enable the S-Function Builder to find these files:

```
SRC_PATH d:\externalsource
LIB_PATH $MATLABROOT\customobjs
LIB_PATH c:\customfolder\customfunctions.lib
userfunctions.obj
freesource.c
```

As this example illustrates, you can use `LIB_PATH` to specify both object and library file paths. You can include the library name in the `LIB_PATH` declaration, however you must place the object file name on a separate line. The tag `$MATLABROOT` indicates a path relative to the `MATLAB` installation. You include multiple `LIB_PATH` entries on separate lines. The paths are searched in the order specified.

You can also enter preprocessor (`-D`) directives in this field, e.g.,

```
-DDEBUG
```

Each directive must reside on a separate line.

Includes

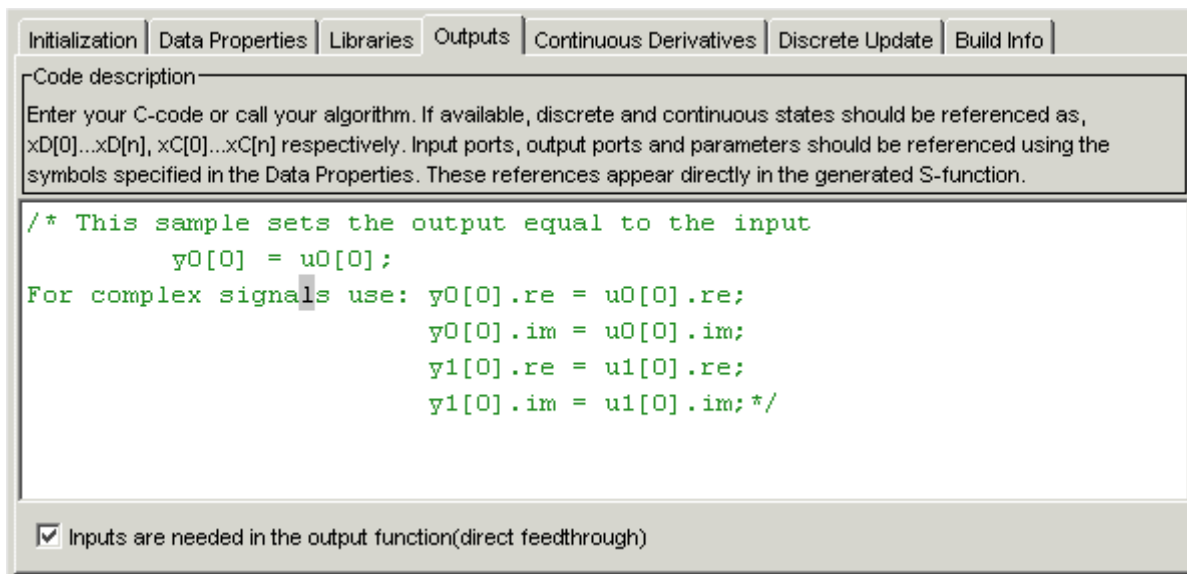
Header files containing declarations of functions, variables, and macros referenced by custom code that you enter elsewhere on the S-Function Builder dialog box. Specify each file on a separate line as `#include` statements. Use brackets to enclose the names of standard C header files (e.g., `#include <math.h>`). Use quotation marks to enclose names of custom header files (e.g., `#include "myutils.h"`). If your S-function uses custom include files that do not reside in the current directory, you must use the `INC_PATH` tag in the **Library/Object/Source files** field to set the S-Function Builder's include path to the directories containing the include files (see "Library/Object/Source files" on page 3-24).

External function declarations

Declarations of external functions not declared in the header files listed in the **Includes** field. Put each declaration on a separate line. The S-Function Builder includes the specified declarations in the S-function source file that it generates. This allows S-function code that computes the S-function's states or output to invoke the external functions.

Outputs Pane

Use the **Outputs** pane to enter code that computes the outputs of the S-function at each simulation time step.



The **Outputs** pane contains the following fields.

Code for the mdlOutputs function

Code that computes the output of the S-function at each simulation time step (or sample time hit, in the case of a discrete S-function). When generating the source code for the S-function, the S-Function Builder inserts the code in this field in a wrapper function of the form

```

void sfun_Outputs_wrapper(const real_T *u,
    real_T      *y,
    const real_T *xD, /* optional */
    const real_T *xC, /* optional */
    const real_T *param0, /* optional */
    int_T p_width0 /* optional */
    real_T *param1 /* optional */
    int_t p_width1 /* optional */
    int_T y_width, /* optional */
    int_T u_width) /* optional */
{

```

```

/* Your code inserted here */
}

```

where `sfun` is the name of the S-function. The S-Function Builder inserts a call to this wrapper function in the `mdlOutputs` callback method that it generates for your S-function. Simulink invokes the `mdlOutputs` method at each simulation time step (or sample time step in the case of a discrete S-function) to compute the S-function's output. The S-function's `mdlOutputs` method in turn invokes the wrapper function containing your output code. Your output code then actually computes and returns the S-function's output.

The `mdlOutputs` method passes some or all of the following arguments to the outputs wrapper function.

Argument	Description
u0, u1, ... uN	Pointers to arrays containing the inputs to the S-function, where N is the number of input ports specified on the Input ports pane found on the Data Properties pane. The names of the arguments that appear in the outputs wrapper function are the same as the names found on the Input ports pane. The width of each array is the same as the input width specified for each input on the Input ports pane. If you specified -1 as an input width, the width of the array is specified by the wrapper function's <code>u_width</code> argument (see below).

Argument	Description
y0, y1, ... yN	<p>Pointer to arrays containing the outputs of the S-function, where N is the number of output ports specified on the Output ports pane found on the Data Properties pane. The names of the arguments that appear in the outputs wrapper function are the same as the names found on the Output ports pane. The width of each array is the same as the output width specified for each output on the Output ports pane. If you specified -1 as the output width, the width of the array is specified by the wrapper function's <code>y_width</code> argument (see below). Use this array to pass the outputs that your code computes back to Simulink.</p>
xD	<p>Pointer to an array containing the discrete states of the S-function. This argument appears only if you specified discrete states on the Initialization pane. At the first simulation time step, the discrete states have the initial values that you specified on the Initialization pane. At subsequent sample-time steps, the states are obtained from the values that the S-function computes at the preceding time step (see “Discrete Update Pane” on page 3-31 for more information).</p>
xC	<p>Pointer to an array containing the continuous states of the S-function. This argument appears only if you specified continuous states on the Initialization pane. At the first simulation time step, the continuous states have the initial values that you specified on the Initialization pane. At subsequent time steps, the states are obtained by numerically integrating the derivatives of the states at the preceding time step (see “Continuous Derivatives Pane” on page 3-29 for more information).</p>

Argument	Description
param0, p_width0, param1, p_width1, ... paramN, p_widthN	param0, param1, ...paramN are pointers to arrays containing the S-function's parameters, where N is the number of parameters specified on the Parameters pane found on the Data Properties pane. p_width0, p_width1, ...p_widthN are the widths of the parameter arrays. If a parameter is a matrix, the width equals the product of the dimensions of the arrays. For example, the width of a 3-by-2 matrix parameter is 6. These arguments appear only if you specify parameters on the Data Properties pane.
y_width	Width of the array containing the S-function's outputs. This argument appears in the generated code only if you specified -1 as the width of the S-function's output. If the output is a matrix, y_width is the product of the dimensions of the matrix.
u_width	Width of the array containing the S-function's inputs. This argument appears in the generated code only if you specified -1 as the width of the S-function's input. If the input is a matrix, u_width is the product of the dimensions of the matrix.

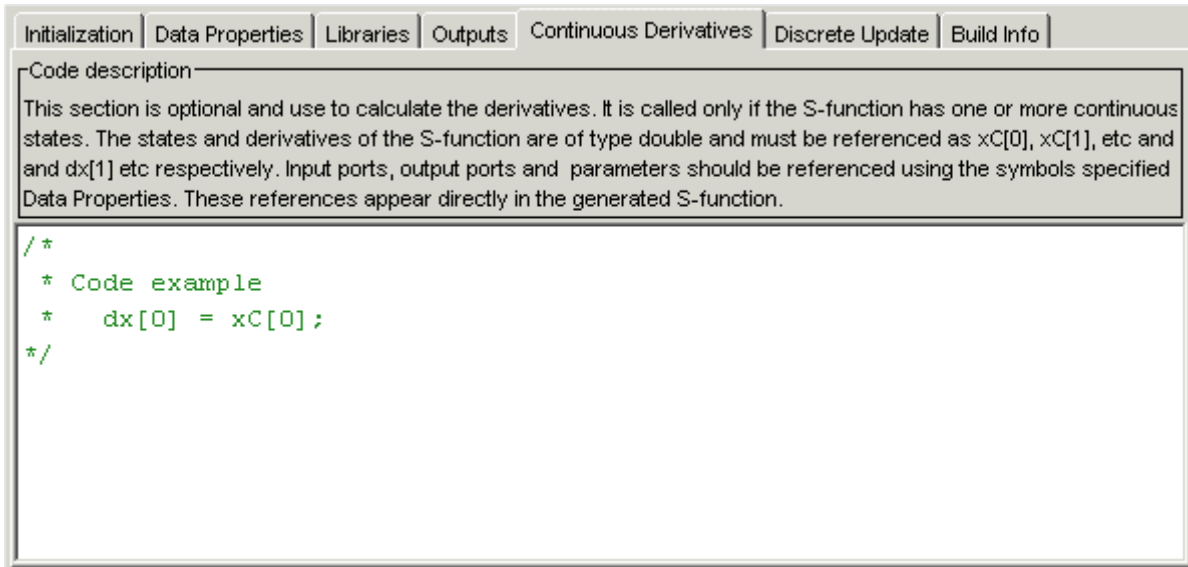
These arguments permit you to compute the output of the block as a function of its inputs and, optionally, its states and parameters. The code that you enter in this field can invoke external functions declared in the header files or external declarations on the **Libraries** pane. This allows you to use existing code to compute the outputs of the S-function.

Inputs are needed in the output function

Selected if the current values of the S-function's inputs are used to compute its outputs. Simulink uses this information to detect algebraic loops created by directly or indirectly connecting the S-function's output to its input.

Continuous Derivatives Pane

If the S-function has continuous states, use the **Continuous Derivatives** pane to enter code required to compute the state derivatives.



Enter code to compute the derivatives of the S-function's continuous states in the **Code for the mdlDerivatives function** field on this pane. When generating code, the S-Function Builder takes the code in this pane and inserts it in a wrapper function of the form

```

void sfun_Derivatives_wrapper(const real_T *u,
    const real_T *y,
    real_T *dx,
    real_T *xC,
    const real_T *param0, /* optional */
    int_T p_width0, /* optional */
    real_T *param1, /* optional */
    int_T p_width1, /* optional */
    int_T y_width, /* optional */
    int_T u_width) /* optional */
{
    /* Your code inserted here. */
}

```


where `sfun` is the name of the S-function. The S-Function Builder inserts a call to this wrapper function in the `mdlDerivatives` callback method that it generates for the S-function. Simulink calls the `mdlDerivatives` method at the end of each time step to obtain the derivatives of the S-function's continuous states (see “How Simulink Interacts with C S-Functions” on page 3-74). The Simulink solver numerically integrates the derivatives to determine the continuous states at the next time step. At the next time step, Simulink passes the updated states back to the S-function's `mdlOutputs` method (see “Outputs Pane” on page 3-25).

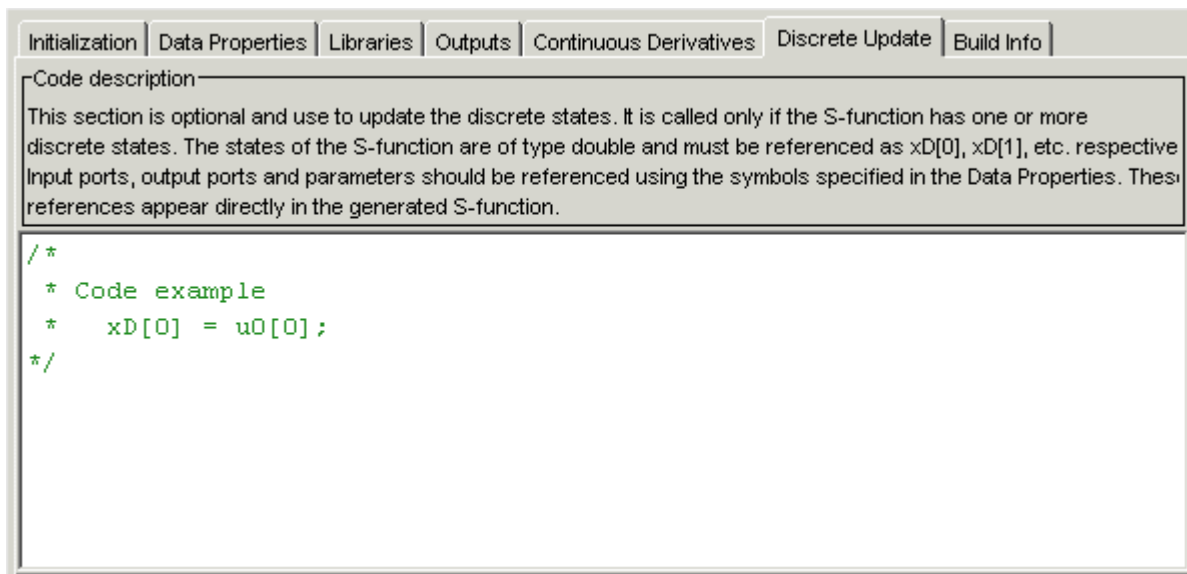
The generated S-function's `mdlDerivatives` callback method passes the following arguments to the derivatives wrapper function:

- `u`
- `y`
- `dx`
- `xC`
- `param0, p_width0, param1, p_width1, ... paramN, p_widthN`
- `y_width`
- `u_width`

The `dx` argument is a pointer to an array whose width is the same as the number of continuous derivatives specified on the **Initialization** pane. Your code should use this array to return the values of the derivatives that it computes. See “Outputs Pane” on page 3-25 for the meanings and usage of the other arguments. The arguments allow your code to compute derivatives as a function of the S-function's inputs, outputs, and, optionally, parameters. Your code can invoke external functions declared on the **Libraries** pane.

Discrete Update Pane

If the S-function has discrete states, use the **Discrete Update** pane to enter code that computes at the current time step the values of the discrete states at the next time step.



Enter code to compute the values of the S-function's discrete states in the **Code for the mdlUpdate function** field on this pane. When generating code, the S-Function Builder takes the code in this pane and inserts it in a wrapper function of the form

```

void sfun_Update_wrapper(const real_T *u,
    const real_T *y,
    real_T *xD,
    const real_T *param0, /* optional */
    int_T p_width0, /* optional */
    real_T *param1, /* optional */
    int_T p_width1, /* optional */
    int_T y_width, /* optional */
    int_T u_width) /* optional */
{
    /* Your code inserted here. */
}

```

where `sfun` is the name of the S-function. The S-Function Builder inserts a call to this wrapper function in the `mdlUpdate` callback method that it generates for the S-function. Simulink calls the `mdlUpdate` method at the end of each time step to obtain the values of the S-function's discrete states at the next time step (see "How Simulink Interacts with C S-Functions" on page 3-74). At the next time step, Simulink passes the updated states back to the S-function's `mdlOutputs` method (see "Outputs Pane" on page 3-25).

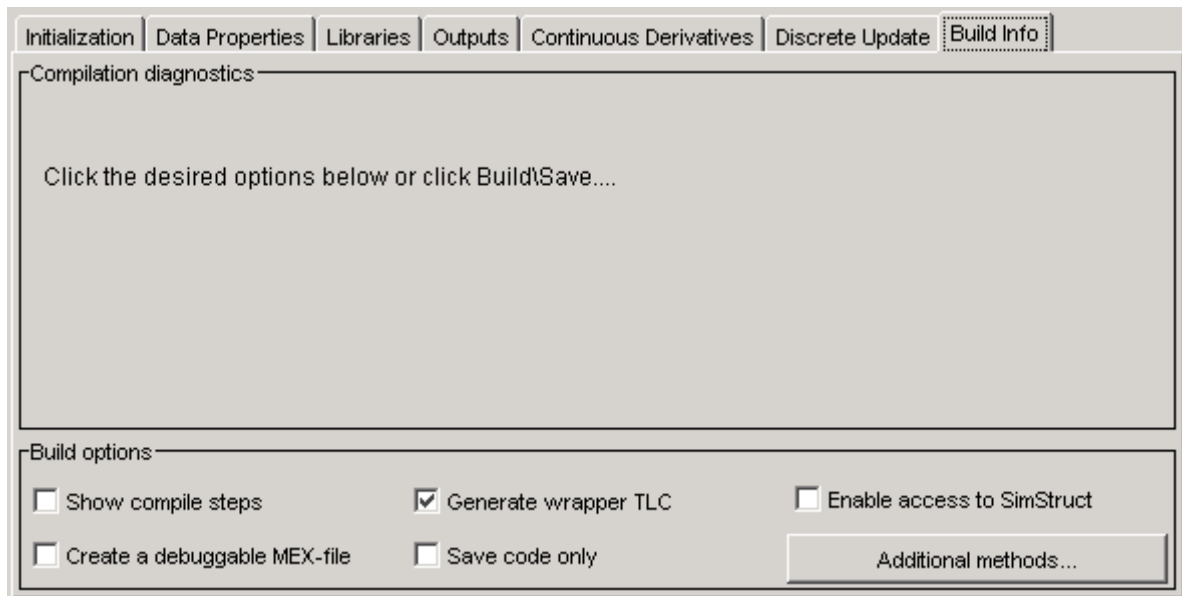
The generated S-function's `mdlUpdates` callback method passes the following arguments to the updates wrapper function:

- `u`
- `y`
- `xD`
- `param0, p_width0, param1, p_width1, ... paramN, p_widthN`
- `y_width`
- `u_width`

See "Outputs Pane" on page 3-25 for the meanings and usage of these arguments. Your code should use the `xD` (discrete states) variable to return the values of the discrete states that it computes. The arguments allow your code to compute the discrete states as functions of the S-function's inputs, outputs, and, optionally, parameters. Your code can invoke external functions declared on the **Libraries** pane.

Build Info Pane

Use the **Build Info** pane to specify options for building the S-function MEX-file.



This pane contains the following fields.

Show compile steps

Log each build step in the **Compilation diagnostics** field.

Create a debuggable MEX-file

Include debug information in the generated MEX-file.

Generate wrapper TLC

Generate a TLC file. You do not need to generate a TLC file if you do not expect the S-function ever to run in accelerated mode or be used in a model from which Real-Time Workshop generates code.

Save code only

Do not build a MEX-file from the generated source code.

Enable access to SimStruct

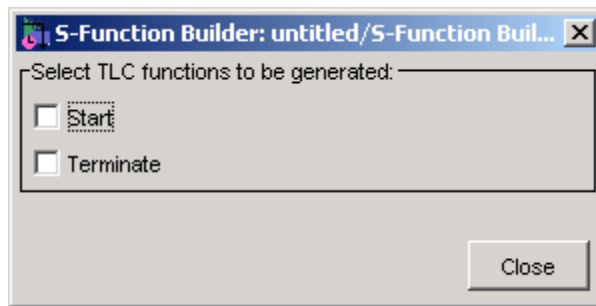
Makes the SimStruct (S) accessible to the wrapper functions that S-Function Builder generates. This enables you to use the SimStruct macros and functions with your code in the **Outputs**, **Continuous Derivatives**, and **Discrete Updates** panes. For example, with this option enabled, you can use macros such as `ssGetT` in code that computes the S-function's outputs:

```
double t = ssGetT(S);
if(t < 2 ) {
    y0[0] = u0[0];
} else {
    y0[0]= 0.0;
}
```

For a complete listing of SimStruct macros and functions, see in the online documentation.

Additional methods

Click this button to include TLC methods in your S-function. The following dialog box appears.



Check the methods you want to add and click the **Close** button to include the methods in your S-function. See “Block Target File Methods” for more information.

Example: Modeling a Two-Input/Two-Output System

The example `sfbuilder_example.mdl` shows how to use the S-Function Builder to model a two-input/two-output discrete state-space system with two states.

In the example, the state-space matrices are parameters to the S-function and the S-function input and output are vectors. You can find a manually written version of the S-function in `dsfunc.c`.

Note You need to build the S-function before running the example model. To build the S-function, double-click on the S-Function Builder block in the model and click **Build** on the S-Function Builder dialog box that opens.

Initializing S-Function Settings

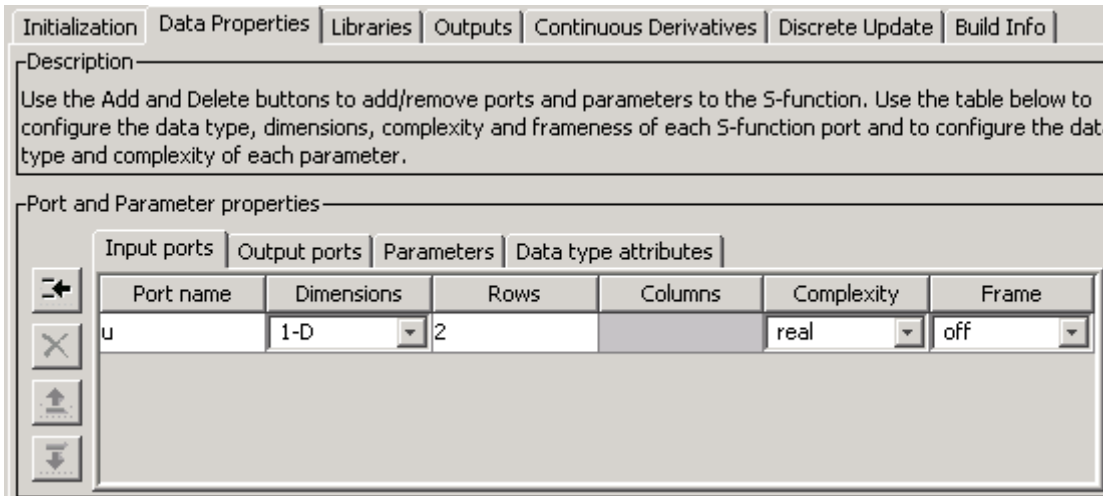
The **Initialization** pane specifies the number of discrete states and their initial conditions, as well as sets the sample time of the S-function. This example contains two discrete states, each initialized to 1, and a discrete sample mode with a sample time of 1.

The screenshot shows the 'Initialization' pane of the S-Function Builder dialog box. The dialog has several tabs: 'Initialization', 'Data Properties', 'Libraries', 'Outputs', 'Continuous Derivatives', 'Discrete Update', and 'Build Info'. The 'Initialization' tab is selected. Below the tabs is a 'Description' section with the following text: 'The S-Function Builder block creates a wrapper C-MEX S-function from your supplied C code with multiple input ports, output ports, and a variable number of scalar, vector, or matrix parameters. The input and output ports can propagate Simulink built-in data types, fixed-point datatypes, complex, frame, 1-D, and 2-D signals. This block also supports discrete and continuous states of type real. You can optionally have the block generate a TLC file to be used with Real-Time Workshop for code generation.' Below the description is the 'S-function settings' section, which contains the following fields: 'Number of discrete states' (text box with '2'), 'Sample mode' (dropdown menu with 'Discrete'), 'Discrete states IC' (text box with '1,1'), 'Sample time value' (text box with '1'), 'Number of continuous states' (text box with '0'), and 'Continuous states IC' (text box with '0').

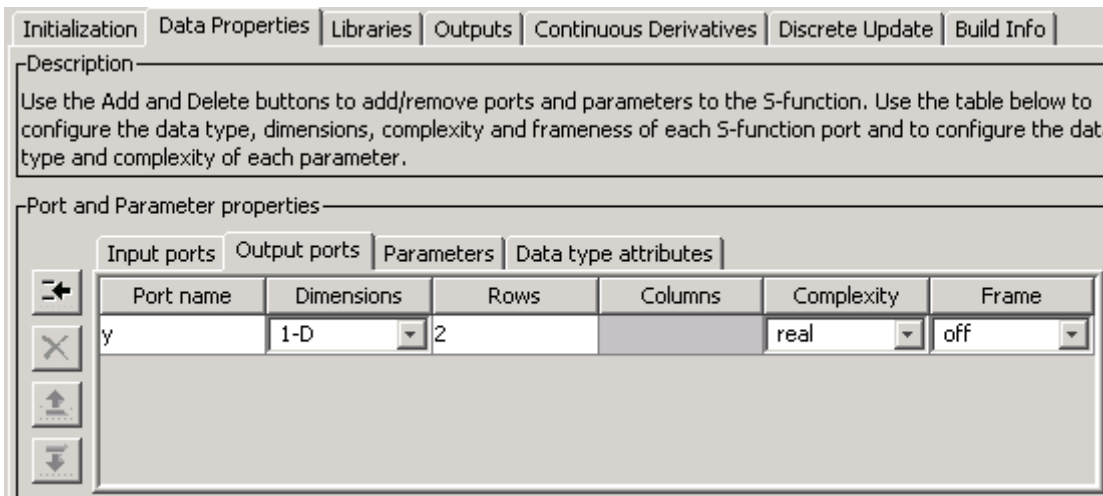
Initializing Inputs, Outputs, and Parameters

The **Data Properties** pane specifies the dimensions of the S-function input and output, as well as initializes the state-space matrices.

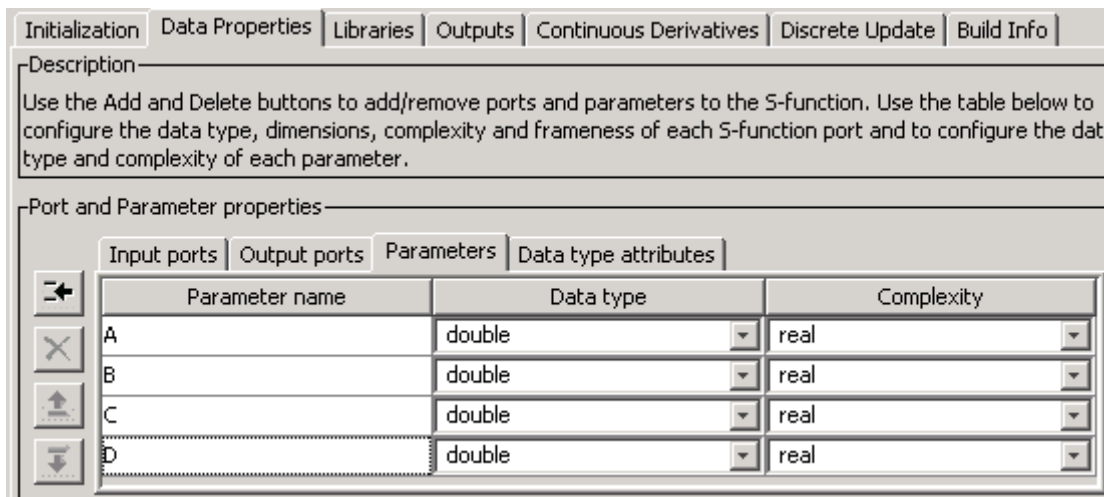
The **Input ports** pane defines the one S-function input port as a 1-D vector with two rows.



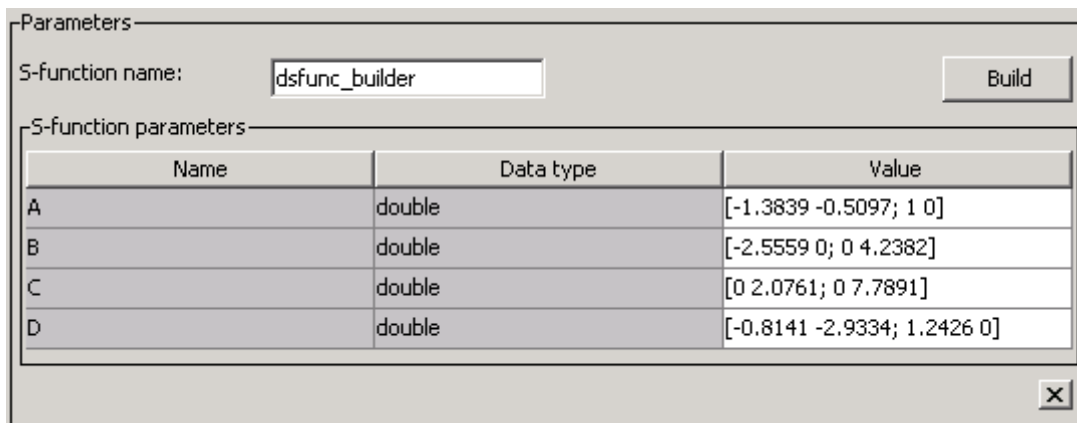
The **Output ports** pane similarly defines the one S-function output port as a 1-D vector with two rows.



The **Parameters** pane defines four parameters, one for each of the four state-space matrices.



The **S-function parameters** pane at the top of the S-Function Builder contains the actual values for the state-space matrices, entered as MATLAB expressions. In this example, each state-space parameter is a two-by-two matrix. Alternatively, you could store the state-space matrices in variables in the MATLAB workspace and enter the variable names into the **Value** field for each parameter.



Defining the Output Method

The **Outputs** pane calculates the S-function's output as a function of the input and state vectors and the state-space matrices. In the outputs code, reference S-function parameters using the parameter names defined on the **Data Properties — Parameters** pane. Index into 2-D matrices using a scalar index, keeping in mind that S-functions use zero-based indexing. For example, to access the element $C(2, 1)$ in the S-function parameter C , use $C[1]$ in the S-function code.

Initialization | Data Properties | Libraries | **Outputs** | Continuous Derivatives | Discrete Update | Build Info

-Code description-

Enter your C-code or call your algorithm. If available, discrete and continuous states should be referenced as, $xD[0] \dots xD[n]$, $xC[0] \dots xC[n]$ respectively. Input ports, output ports and parameters should be referenced using symbols specified in the Data Properties. These references appear directly in the generated S-function.

```

y[0]=C[0] *xD[0]+C[2] *xD[1]+D[0] *u[0]+D[2] *u[1] ;
  y[1]=C[1] *xD[0]+C[3] *xD[1]+D[1] *u[0]+D[3] *u[1] ;

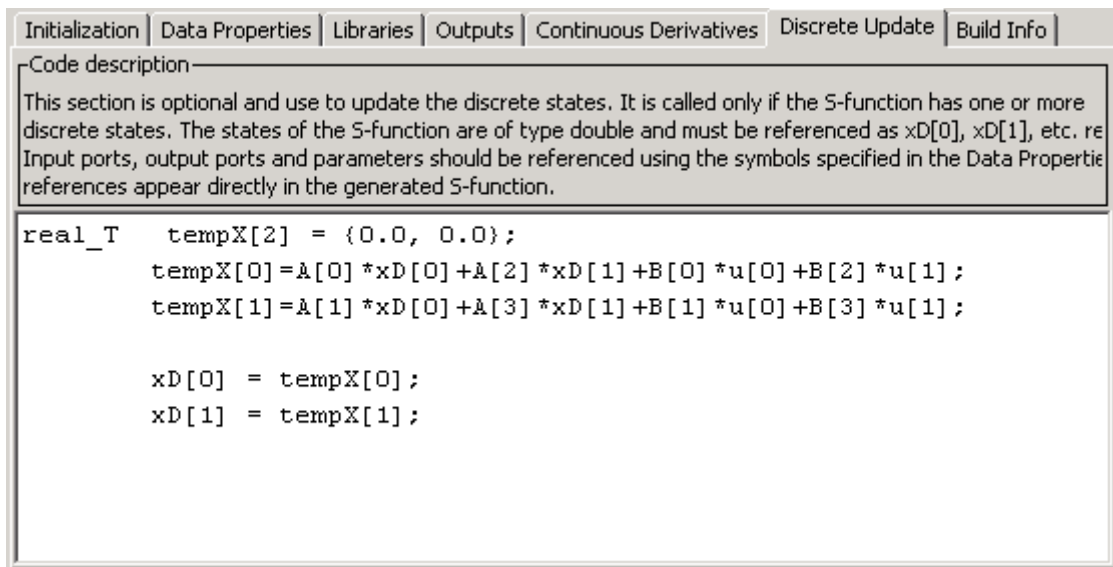
```

Inputs are needed in the output function(direct feedthrough)

The **Outputs** pane also selects the **Inputs are needed in the output function (direct feedthrough)** option since this state-space model has a nonzero D matrix.

Defining the Discrete Update Method

The **Discrete Update** pane updates the discrete states. As with the outputs code, use the S-function parameter names and index into 2-D matrices using a scalar index, keeping in mind that S-functions use zero-based indexing. For example, to access the element $A(2, 1)$ in the S-function parameter A , use $A[1]$ in the S-function code. The variable xD stores the final values of the discrete states.



The screenshot shows the S-Function Builder interface with the 'Discrete Update' tab selected. The 'Code description' section contains the following text:

This section is optional and use to update the discrete states. It is called only if the S-function has one or more discrete states. The states of the S-function are of type double and must be referenced as `xD[0]`, `xD[1]`, etc. re Input ports, output ports and parameters should be referenced using the symbols specified in the Data Properties references appear directly in the generated S-function.

```
real_T    tempX[2] = {0.0, 0.0};
tempX[0] = A[0] *xD[0] + A[2] *xD[1] + B[0] *u[0] + B[2] *u[1];
tempX[1] = A[1] *xD[0] + A[3] *xD[1] + B[1] *u[0] + B[3] *u[1];

xD[0] = tempX[0];
xD[1] = tempX[1];
```

Building the State-Space Example

Click the **Build** button on the S-Function Builder to create an executable for this S-function. You can now run the model and compare the output to the original discrete state-space S-function contained in `sfcndemo_dsfunc.mdl`.

Example of a Basic C MEX S-Function

In this section...

“Introducing an Example of a Basic C MEX S-Function” on page 3-41

“Defines and Includes” on page 3-44

“Callback Implementations” on page 3-44

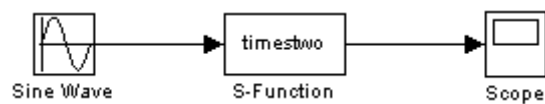
“Simulink/Real-Time Workshop Interface” on page 3-46

“Building the Timestwo Example” on page 3-46

Introducing an Example of a Basic C MEX S-Function

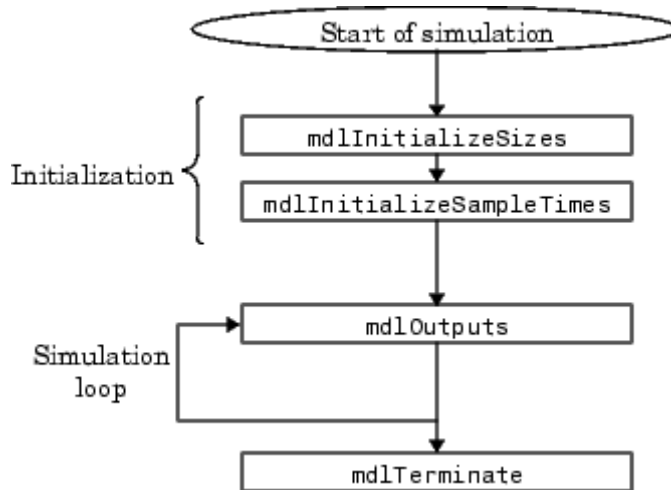
This section presents an example of a C MEX S-function that you can use as a model for creating simple C S-functions. The example is the `timestwo` S-function example that comes with Simulink (see `matlabroot/simulink/src/timestwo.c`). This S-function outputs twice its input.

The following model uses the `timestwo` S-function to double the amplitude of a sine wave and plot it in a scope.



The block dialog for the S-function specifies `timestwo` as the S-function name; the parameters field is empty.

The `timestwo` S-function contains the S-function callback methods shown in this figure.



The contents of `timestwo.c` are shown below. A description of the code is provided after the example.

```

#define S_FUNCTION_NAME timestwo /* Defines and Includes */
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, 0);
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
        return; /* Parameter mismatch will be reported by Simulink */
    }

    if (!ssSetNumInputPorts(S, 1)) return;
    ssSetInputPortWidth(S, 0, DYNAMICALLY_SIZED);
    ssSetInputPortDirectFeedThrough(S, 0, 1);

    if (!ssSetNumOutputPorts(S, 1)) return;
    ssSetOutputPortWidth(S, 0, DYNAMICALLY_SIZED);

    ssSetNumSampleTimes(S, 1);
  
```

```

/* Take care when specifying exception free code - see sfuntmpl.doc */
ssSetOptions(S, SS_OPTION_EXCEPTION_FREE_CODE);
}

static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, INHERITED_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);
}

static void mdlOutputs(SimStruct *S, int_T tid)
{
    int_T i;
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);
    real_T *y = ssGetOutputPortRealSignal(S,0);
    int_T width = ssGetOutputPortWidth(S,0);

    for (i=0; i<width; i++) {
        *y++ = 2.0 *(*uPtrs[i]);
    }
}

static void mdlTerminate(SimStruct *S){}

/* Simulink/Real-Time Workshop Interface */

#ifdef MATLAB_MEX_FILE /* Is this file being compiled as a MEX-file? */
#include "simulink.c" /* MEX-file interface mechanism */
#else
#include "cg_sfun.h" /* Code generation registration function */
#endif

```

This example has three parts:

- Defines and includes
- Callback implementations
- Simulink (or Real-Time Workshop) interface

Defines and Includes

The example starts with the following defines.

```
#define S_FUNCTION_NAME timestwo
#define S_FUNCTION_LEVEL 2
```

The first specifies the name of the S-function (`timestwo`). The second specifies that the S-function is in the *level 2* format (for more information about level 1 and level 2 S-functions, see “Converting Level 1 C MEX S-Functions to Level 2” on page 3-89).

After defining these two items, the example includes `simstruc.h`, which is a header file that gives access to the `SimStruct` data structure and the MATLAB Application Program Interface (API) functions.

```
#define S_FUNCTION_NAME timestwo
#define S_FUNCTION_LEVEL 2
#include "simstruc.h"
```

The `simstruc.h` file defines a data structure, called the `SimStruct`, that Simulink uses to maintain information about the S-function. The `simstruc.h` file also defines macros that enable your MEX-file to set values in and get values (such as the input and output signal to the block) from the `SimStruct` (see Chapter 9, “SimStruct Functions — By Category”).

Callback Implementations

The next part of the `timestwo` S-function contains implementations of callback methods required by Simulink.

mdlInitializeSizes

Simulink calls `mdlInitializeSizes` to inquire about the number of input and output ports, sizes of the ports, and any other objects (such as the number of states) needed by the S-function.

The `timestwo` implementation of `mdlInitializeSizes` specifies the following size information:

- Zero parameters

This means that the **S-function parameters** field of the S-functions's dialog box must be empty. If it contains any parameters, Simulink reports a parameter mismatch.

- One input port and one output port

The widths of the input and output ports are dynamically sized. This tells Simulink that the S-function can accept an input signal of any width. Note that the default handling for dynamically sized S-functions for this case (one input and one output) is that the input and output widths are equal.

- One sample time

The `timestwo` example specifies the actual value of the sample time in the `mdlInitializeSampleTimes` routine.

- The code is exception free.

Specifying exception-free code speeds up execution of your S-function. You must take care when specifying this option. In general, if your S-function isn't interacting with MATLAB, it is safe to specify this option. For more details, see "How Simulink Interacts with C S-Functions" on page 3-74.

mdlInitializeSampleTimes

Simulink calls `mdlInitializeSampleTimes` to set the sample times of the S-function. A `timestwo` block executes whenever the driving block executes. Therefore, it has a single inherited sample time, `INHERITED_SAMPLE_TIME`.

mdlOutputs

Simulink calls `mdlOutputs` at each time step to calculate a block's outputs. The `timestwo` implementation of `mdlOutputs` takes the input, multiplies it by 2, and writes the answer to the output.

The `timestwo` `mdlOutputs` method uses a `SimStruct` macro,

```
InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);
```

to access the input signal. The macro returns a vector of pointers, which you *must* access using

```
*uPtrs[i]
```

For more details, see “Data View” on page 3-78.

The `timestwo mdlOutputs` method uses the macro

```
real_T *y = ssGetOutputPortRealSignal(S,0);
```

to access the output signal. This macro returns a pointer to an array containing the block’s outputs.

The S-function uses

```
int_T width = ssGetOutputPortWidth(S,0);
```

to get the width of the signal passing through the block. Finally, the S-function loops over the inputs to compute the outputs. ()

mdlTerminate

Perform tasks at the end of the simulation. This is a mandatory S-function routine. However, the `timestwo` S-function doesn’t need to perform any termination actions, so this routine is empty.

Simulink/Real-Time Workshop Interface

At the end of the S-function, specify code that attaches this example to either Simulink or Real-Time Workshop. This trailer is required at the end of every S-function. If it is omitted, any attempt to compile the S-function will abort with a failure during build of `exports file error message`.

```
#ifdef MATLAB_MEX_FILE
#include "simulink.c"
#else
#include "cg_sfun.h"
#endif
```

Building the Timestwo Example

To incorporate this S-function into Simulink, enter

```
mex timestwo.c
```


at the command line. The `mex` command compiles and links the `timestwo.c` file to create a dynamically loadable executable for Simulink to use.

The resulting executable is referred to as a MEX S-function, where MEX stands for “MATLAB EXecutable.” The MEX-file extension varies from platform to platform. For example, on a 32-bit Microsoft Windows system, the MEX-file extension is `.mexw32`.

Templates for C S-Functions

In this section...
“About the Templates for C S-Functions” on page 3-48
“S-Function Source File Requirements” on page 3-48
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About the Templates for C S-Functions

Simulink provides skeleton implementations of C MEX S-functions, called templates, intended to serve as starting points for creating your own S-functions. The templates contain skeleton implementations of callback methods with comments that explain their use. The template file, `sfuntmpl_basic.c`, which can be found in the directory `simulink/src` below the MATLAB root directory, contains commonly used S-function routines. A template containing all available routines (as well as more comments) can be found in `sfuntmpl_doc.c` in the same directory.

Note We recommend that you use the C MEX-file template when developing MEX S-functions.

S-Function Source File Requirements

This section describes requirements that every S-function source file must meet to compile correctly. The S-function templates meet these requirements.

Statements Required at the Top of S-Functions

For S-functions to operate properly, *each* source module of your S-function that accesses the `SimStruct` must contain the following sequence of defines and include

```
#define S_FUNCTION_NAME your_sfunction_name_here
#define S_FUNCTION_LEVEL 2
```

```
#include "simstruc.h"
```

where *your_sfunction_name_here* is the name of your S-function (i.e., what you enter in the Simulink S-Function block dialog). These statements give you access to the SimStruct data structure that contains pointers to the data used by the simulation. The included code also defines the macros used to store and retrieve data in the SimStruct, described in detail in “Converting Level 1 C MEX S-Functions to Level 2” on page 3-89. In addition, the code specifies that you are using the level 2 format of S-functions.

Note All S-functions from Simulink 1.3 through 2.1 are considered to be Level 1 S-functions. They are compatible with Simulink 3.0, but we recommend that you write new S-functions in the Level 2 format.

The following headers are included by *matlabroot/simulink/include/simstruc.h* when compiling as a MEX-file.

Header Files Included by *simstruc.h* When Compiling as a MEX-File

Header File	Description
<i>matlabroot/extern/include/tmwtypes.h</i>	General data types, e.g., <code>real_T</code>
<i>matlabroot/extern/include/mex.h</i>	MATLAB MEX-file API routines to interface MEX-files with MATLAB
<i>matlabroot/extern/include/matrix.h</i>	MATLAB External Interface API routines to query and manipulate MATLAB matrices

When compiling your S-function for use with Real-Time Workshop, *simstruc.h* includes the following.

Header Files Included by `simstruc.h` When Used by Real-Time Workshop

Header File	Description
<code>matlabroot/extern/include/tmwtypes.h</code>	General types, e.g., <code>real_T</code>
<code>matlabroot/rtw/c/src/rt_matrx.h</code>	Macros for MATLAB API routines

Callback Methods That an S-Function Must Implement

The S-function API requires you to implement the following functions (see “Writing Callback Methods” on page 3-82):

- `mdlInitializeSizes` specifies the sizes of various parameters in the `SimStruct`, such as the number of output ports for the block.
- `mdlInitializeSampleTimes` specifies the sample time(s) of the block.
- `mdlOutputs` calculates the output of the block.
- `mdlTerminate` performs any actions required at the termination of the simulation. If no actions are required, this function can be implemented as a stub.

Statements Required at the Bottom of S-Functions

Include this trailer code at the end of your C MEX S-function main module only.

```

#ifdef MATLAB_MEX_FILE /* Is this being compiled as MEX-file? */
#include "simulink.c" /* MEX-file interface mechanism */
#else
#include "cg_sfun.h" /* Code generation registration func */
#endif

```

These statements select the appropriate code for your particular application:

- `simulink.c` is included if the file is being compiled into a MEX-file.
- `cg_sfun.h` is included if the file is being used in conjunction with the Real-Time Workshop to produce a stand-alone or real-time executable.

Note This trailer code must not be in the body of any S-function routine.

The SimStruct

The file `matlabroot/simulink/include/simstruc.h` is a C language header file that defines the Simulink data structure and the `SimStruct` access macros. It encapsulates all the data relating to the model or S-function, including block parameters and outputs.

There is one `SimStruct` data structure allocated for the Simulink model. Each S-function in the model has its own `SimStruct` associated with it. The organization of these `SimStruct`s is much like a directory tree. The `SimStruct` associated with the model is the *root* `SimStruct`. The `SimStruct`s associated with the S-functions are the *child* `SimStruct`s.

Simulink provides a set of macros that S-functions can use to access the fields of the `SimStruct`. See Chapter 9, “`SimStruct` Functions — By Category” for more information.

Data Types in S-Functions

The file `matlabroot/extern/include/tmwtypes.h` is a C language header file that defines a set of data types used in the S-function template and in the `SimStruct`. These data types, such as `real_T`, `uint32_T`, etc., provide a way to switch between different data types for 16, 32, and 64 bit systems, allowing greater platform independence and flexibility.

S-functions are not required to use these data types. For example, you can edit the Simulink example `matlabroot/simulink/src/csfunc.c` on a PC and change `real_T` to `double` and `int_T` to `int`. If you compile and simulate the S-function, the results will be identical to the results using the previous data types.

Compiling C S-Functions

S-functions can be compiled in one of three modes identified by the presence of one of the following defines:

- `MATLAB_MEX_FILE` — Indicates that the S-function is being built as a MEX-file for use with Simulink.
- `RT` — Indicates that the S-function is being built with the Real-Time Workshop generated code for a real-time application using a fixed-step solver.
- `NRT` — Indicates that the S-function is being built with the Real-Time Workshop generated code for a non-real-time application using a variable-step solver.

These define statements do not appear in the S-function. The mode definition are made by either the `mex` command or by Real-Time Workshop when the S-function is built.

Integrating Existing C Functions into Simulink Models with the Legacy Code Tool

In this section...

“Overview” on page 3-53

“Example of Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” on page 3-56

“Registering Legacy Code Tool Data Structures” on page 3-60

“Declaring Legacy Code Tool Function Specifications” on page 3-62

“Generating and Compiling the S-Functions” on page 3-69

“Generating a Masked S-Function Block for Calling a Generated S-Function” on page 3-70

“Forcing Accelerator Mode to Use S-Function TLC Inlining Code” on page 3-71

“Handling Multiple Registration Files” on page 3-71

“Deploying Generated S-Functions” on page 3-72

“Legacy Code Tool Demos” on page 3-72

“Legacy Code Tool Limitations” on page 3-73

Overview

You can integrate existing C (or C++) functions—for example, device drivers, lookup tables, and general functions and interfaces—into Simulink simulations by using the Legacy Code Tool. Using specifications that you supply as M-code, the tool transforms existing functions into C MEX S-functions that you can include in Simulink models. If you use Real-Time Workshop to generate code from a model, the Legacy Code Tool can insert an appropriate call to your C function into the generated code (for details, see “Using the Legacy Code Tool to Automate the Generation of Files for Fully Inlined S-Functions” in the Real-Time Workshop documentation).

In comparison to using the S-Function Builder or writing an S-function, the Legacy Code Tool can be easier to use and it generates optimized code (does not generate wrapper code) often required by embedded systems. However, you

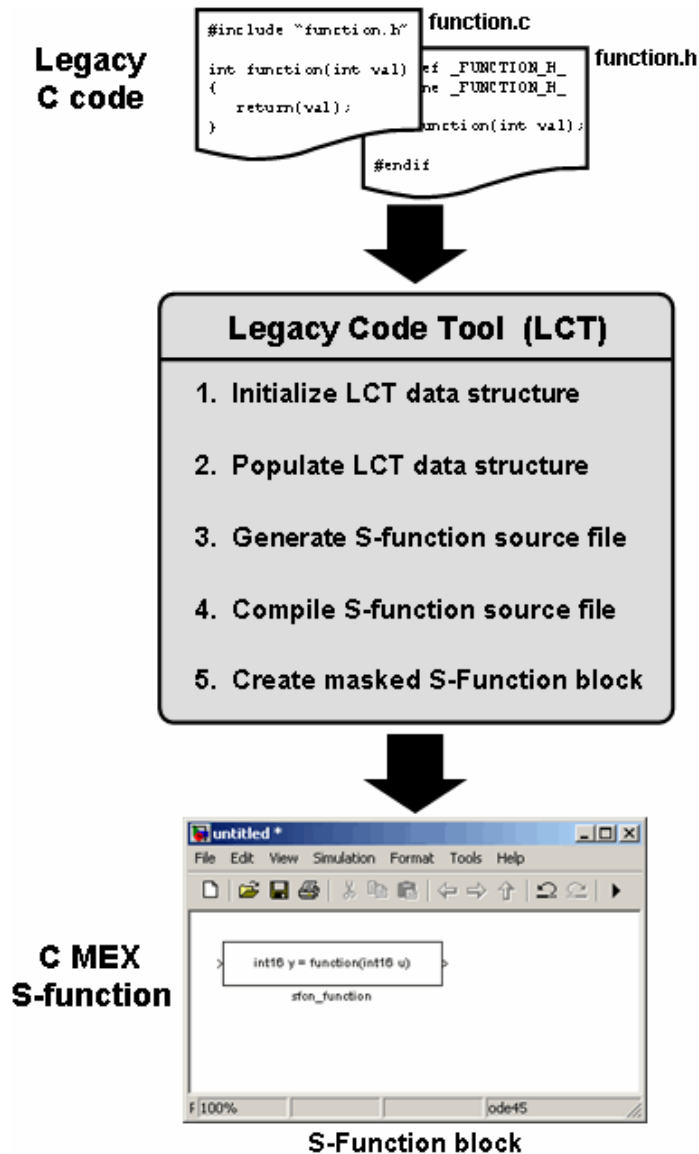
should consider one of the alternate approaches for a hybrid system, such as a system that includes a plant and controller, or a system component written in a language other than C or C++. Alternative approaches are more flexible in that they support more Simulink features and programming languages.

To interact with the Legacy Code Tool, you

- Use a Legacy Code Tool data structure to specify
 - A name for the S-function
 - Specifications for the existing C functions
 - Files and paths required for compilation
 - Options for the generated S-function
- Use the `legacy_code` function to
 - Initialize the Legacy Code Tool data structure for a given C function
 - Generate an S-function for use during simulation
 - Compile and link the generated S-function into a dynamically loadable executable
 - Generate a masked S-function block for calling the generated S-function
 - Generate a TLC block file and, if necessary, an `rtwmakecfg.m` file for code generation (Real-Time Workshop license required)

Note Before you can use `legacy_code`, you must ensure that a C compiler is set up for your MATLAB installation. If you need to set up a compiler, enter the command `mex -setup` in the MATLAB Command Window.

The following diagram illustrates a general procedure for using the Legacy Code Tool. “Example of Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” on page 3-56 provides an example that uses the Legacy Code Tool to transform an existing C function into a Simulink C MEX S-function.



If you have a Real-Time Workshop license, see “Using the Legacy Code Tool to Automate the Generation of Files for Fully Inlined S-Functions” in the

Real-Time Workshop documentation for information on using the Legacy Code Tool for code generation.

Example of Integrating Existing C Functions into Simulink Models with the Legacy Code Tool

Suppose you have an existing C function that outputs the value of its floating-point input multiplied by two. The function is defined in a source file named `doubleIt.c`, and its declaration exists in a header file named `doubleIt.h` as shown here.

```
#include "doubleIt.h"

double doubleIt(double, inVal)
{
    return(2 * inVal);
}
```

doubleIt.c

```
#ifndef _DOUBLEIT_H_
#define _DOUBLEIT_H_

double doubleIt(double inVal);

#endif
```

doubleIt.h

To use the Legacy Code Tool to incorporate this C function into a Simulink model as a C MEX S-function:

- 1 Use the `legacy_code` function to initialize a MATLAB structure with fields that represent Legacy Code Tool properties. For example, create a Legacy Code Tool data structure named `def` by entering the following command at the MATLAB prompt:

```
def = legacy_code('initialize')
```

The Legacy Code Tool data structure named `def` displays its fields in the MATLAB Command Window as shown here:

```
def =

    SFunctionName: ''
 InitializeConditionsFcnSpec: ''
    OutputFcnSpec: ''
    StartFcnSpec: ''
    TerminateFcnSpec: ''
```

```

HeaderFiles: {}
SourceFiles: {}
HostLibFiles: {}
TargetLibFiles: {}
IncPaths: {}
SrcPaths: {}
LibPaths: {}
SampleTime: 'inherited'
Options: [1x1 struct]

```

- 2 Specify appropriate values for fields in the Legacy Code Tool data structure to identify properties of the existing C function. For example, specify the C function source and header filenames by entering the following commands at the MATLAB prompt:

```

def.SourceFiles = {'doubleIt.c'};
def.HeaderFiles = {'doubleIt.h'};

```

You must also specify information about the S-function that the Legacy Code Tool produces from the C code. For example, specify a name for the S-function and its output function declaration by entering:

```

def.SFunctionName = 'ex_sfun_doubleit';
def.OutputFcnSpec = 'double y1 = doubleIt(double u1)';

```

See the `legacy_code` reference page in the Simulink reference for information about the various data structure fields. For more information about assigning values to fields in a structure, see “Structures” in the MATLAB documentation.

- 3 Use the `legacy_code` function to generate an S-function source file from the existing C function. At the MATLAB prompt, type:

```

legacy_code('sfcn_cmex_generate', def);

```

The Legacy Code Tool uses the information specified in `def` to create the S-function source file named `ex_sfun_doubleit.c` in the current MATLAB directory.

- 4 Make sure a C compiler is set up for your MATLAB installation. If you need to set up a compiler, enter the command `mex -setup` in the MATLAB Command Window.

- 5** Use the `legacy_code` function to compile and link the S-function source file into a dynamically loadable executable that Simulink can use. At the MATLAB prompt, type:

```
legacy_code('compile', def);
```

The following messages appear in the MATLAB Command Window:

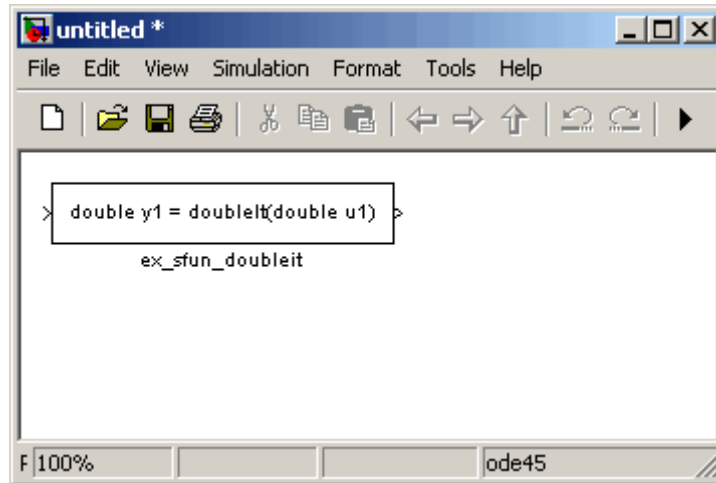
```
### Start Compiling ex_sfundoubleit
    mex('ex_sfundoubleit.c', 'd:\work\lct_demos\doubleIt.c', '-Id:\wo
### Finish Compiling ex_sfundoubleit
### Exit
```

On a 32-bit Microsoft Windows system, the resulting S-function executable is named `ex_sfundoubleit.mexw32`.

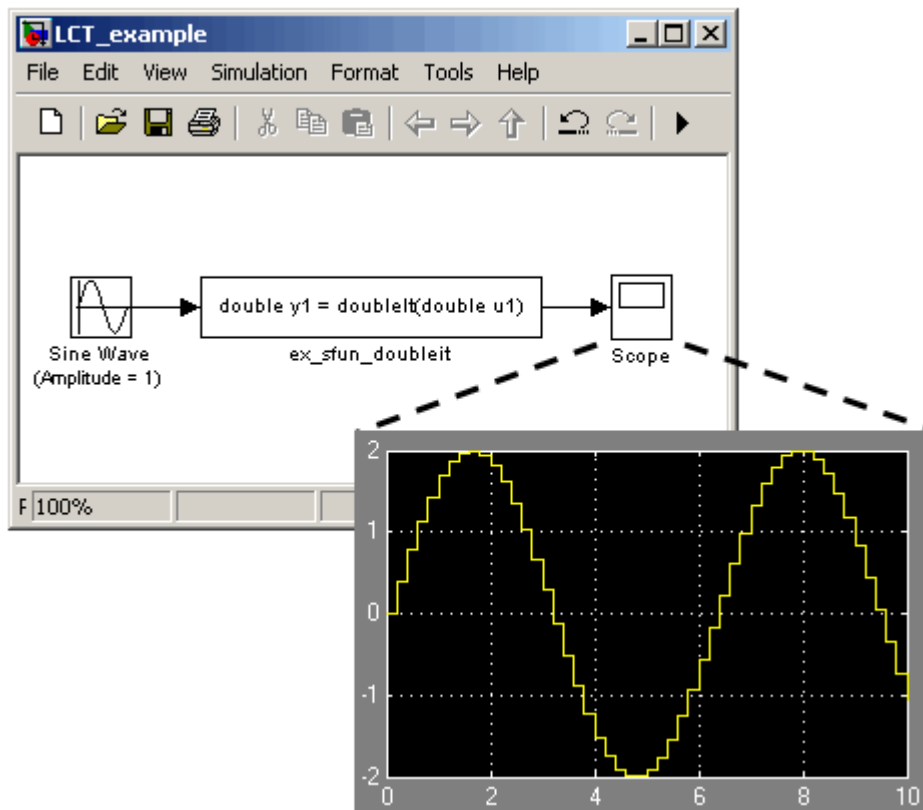
- 6** Use the `legacy_code` function to insert a masked S-Function block into a Simulink model. The Legacy Code Tool configures the block to use the C MEX S-function created in the previous step. Also, the tool masks the block such that it displays the value of its `OutputFcnSpec` property (see the description of the `legacy_code` function). For example, create a new Simulink model containing a masked S-Function block by issuing the following command at the MATLAB prompt:

```
legacy_code('slblock_generate', def);
```

The block appears in an empty model editor window as shown here:



The following Simulink model demonstrates that the C MEX S-function produced by the Legacy Code Tool behaves like the C function `doubleIt`. In particular, the S-Function block named `ex_sfuns_doubleIt` returns the value of its floating-point input multiplied by two.



Registering Legacy Code Tool Data Structures

The first step to using the Legacy Code Tool is to register one or more MATLAB structures with fields that represent properties of the existing C code and the S-function being generated. The registration process is flexible. You can choose to set up resources and initiate registration in a variety of ways, including

- Placing all required header and source files in the current working directory or in a hierarchical directory structure
- Generating and placing one or more S-functions in the current working directory

- Having one or more registration files in the same directory

To register a Legacy Code Tool data structure:

- 1 Use the `legacy_code` function, specifying `'initialize'` as the first argument.

```
lct_spec = legacy_code('initialize')
```

The Legacy Code Tool data structure named `lct_spec` displays its fields in the MATLAB Command Window as shown below:

```
lct_spec =
    SFunctionName: ''
  InitializeConditionsFcnSpec: ''
      OutputFcnSpec: ''
      StartFcnSpec: ''
  TerminateFcnSpec: ''
      HeaderFiles: {}
      SourceFiles: {}
      HostLibFiles: {}
      TargetLibFiles: {}
      IncPaths: {}
      SrcPaths: {}
      LibPaths: {}
      SampleTime: 'inherited'
      Options: [1x1 struct]
```

- 2 Define values for the data structure fields (properties) that apply to your existing C function and the S-function you intend to generate. Minimally, you must specify
 - Source and header files for the existing C function (`SourceFiles` and `HeaderFiles`)
 - A name for the S-function (`SFunctionName`)
 - At least one function specification for the S-function (`InitializeConditionsFcnSpec`, `OutputFcnSpec`, `StartFcnSpec`, `TerminateFcnSpec`)

For a complete list of the structure's fields with descriptions, see the `legacy_code` function reference page.

If you define fields that specify compilation resources and you specify relative paths, the Legacy Code Tool searches for the resources relative to the following directories, in the following order:

- 1** Current working directory
- 2** C-MEX S-function directory, if different than the current working directory
- 3** Directories you specify
 - `IncPaths` for header files
 - `SrcPaths` for source files
 - `LibPaths` for target and host libraries
- 4** Directories on the MATLAB search path, excluding toolbox directories

Declaring Legacy Code Tool Function Specifications

The `InitializeConditionsFcnSpec`, `OutputFcnSpec`, `StartFcnSpec`, and `TerminateFcnSpec` fields defined in the Legacy Code Tool data structure (see the description of the `legacy_code` function) require string values that adhere to a specific syntax format. The required syntax format enables the Legacy Code Tool to map the return value and arguments of an existing C function to the return value, inputs, outputs, parameters, and states of the S-function that the tool generates.

General syntax

```
return-spec = function-name(argument-spec)
```

For example, the following string specifies a function named `doubleIt` with return specification `double y1` and input argument specification `double u1`.

```
def.OutputFcnSpec = 'double y1 = doubleIt(double u1)';
```

For more detail on declaring function specifications, see

- “Return Specification” on page 3-63

- “Function Name” on page 3-63
- “Argument Specification” on page 3-64
- “Supported Data Types” on page 3-67
- “Function Specification Rules” on page 3-68

Return Specification

The return specification defines the data type and variable name for the return value of the existing C function.

return-type return-variable

<i>return-type</i>	A data type listed in “Supported Data Types” on page 3-67.
<i>return-variable</i>	Token of the form y_1, y_2, \dots, y_n , where n is the total number of output arguments.

If the function does not return a value, you can omit the return specification or specify it as `void`.

The following table shows valid function specification syntax for an integer return value. Use the table to identify the syntax you should use for your C function prototype.

Return Type	C Function Prototype	Legacy Code Tool Function Specification
No return value	<code>void myfunction(...)</code>	<code>void myfunction(...)</code>
Scalar value	<code>int = myfunction(...)</code>	<code>int16 y1 = myfunction(...)</code>

Function Name

The function name that you specify must be the same as your existing C function name.

For example, consider the following C function prototype:

```
float doubleIt(float inVal);
```

In this case, the function name in the Legacy Code Tool function specification must be `doubleIt`.

You should not specify the name of a C macro. If you must, set the field `Options.isMacro` to 1 to ensure that the generated code remains safe in the event that expression folding is enabled.

Argument Specification

The argument specification defines one or more data type and token pairs that represent the input, output, parameter, and state arguments of the existing C function. The function's input and output arguments map to Simulink input and output ports, parameters map to Simulink workspace parameters, and states map to Simulink Dwork vectors.

```
argument-type argument-token
```

<i>argument-type</i>	A data type listed in “Supported Data Types” on page 3-67.
<i>argument-token</i>	Token of one of the following forms: <ul style="list-style-type: none"> • Input — u_1, u_2, \dots, u_n, where n is the total number of input arguments • Output — y_1, y_2, \dots, y_n, where n is the total number of output arguments • Parameter — p_1, p_2, \dots, p_n, where n is the total number of parameter arguments • States (persistent memory) — $work_1, work_2, \dots, work_n$, where n is the total number of state arguments

If the function has no arguments, you can omit the argument specification or specify it as `void`.

Consider the following C function prototype:

```
float powerIt(float inVal, int exponent);
```

To generate an S-function that is to call the preceding function at each time step, you would set the Legacy Code Tool data structure field `OutputFcnSpec` to the following string:

```
'double y1 = powerIt(double u1, int16 p1)'
```

Using this function specification, Simulink maps the following:

Return Value or Argument...	of C Type...	To Token...	of Simulink Type...
Return value	float	y1	double
inVal	float	u1	double
exponent	int	p1	int16

The following table shows valid function specification syntax for arguments of type integer. Use the table to identify and then adapt the syntax you should use for your C function prototype.

Argument Type	C Function Prototype	Legacy Code Tool Function Specification
Input Arguments		
No arguments	<code>function(void)</code>	<code>function(void)</code>
Scalar pass by value	<code>function(int in1)</code>	<code>function(int16 u1)</code>
Scalar pass by pointer	<code>function(int *in1)</code>	<code>function(int16 u1[1])</code>
Fixed vector	<code>function(int in1[10])</code> or <code>function(int *in1)</code>	<code>function(int16 u1[10])</code>
Variable vector	<code>function(int in1[])</code> or <code>function(int *in1)</code>	<code>function(int16 u1[])</code>
Fixed matrix	<code>function(int in1[15])</code> or <code>function(int in1[])</code> or <code>function(int *in1)</code>	<code>function(int16 u1[3][5])</code>
Variable matrix	<code>function(int in1[])</code> or <code>function(int *in1)</code>	<code>function(int16 u1[][])</code>
Output Arguments		

Argument Type	C Function Prototype	Legacy Code Tool Function Specification
Scalar pointer	<code>function(int *y1)</code>	<code>function(int16 y1[1])</code>
Fixed vector	<code>function(int y1[10])</code> or <code>function(int *y1)</code>	<code>function(int16 y1[10])</code>
Fixed matrix	<code>function(int y1[15])</code> or <code>function(int y1[])</code> or <code>function(int *y1)</code>	<code>function(int16 y1[3][5])</code>
Parameter Arguments		
Scalar pass by value	<code>function(int p1)</code>	<code>function(int16 p1)</code>
Scalar pass by pointer	<code>function(int *p1)</code>	<code>function(int16 p1[1])</code>
Fixed vector	<code>function(int p1[10])</code> or <code>function(int *p1)</code>	<code>function(int16 p1[10])</code>
Variable vector	<code>function(int p1[])</code> or <code>function(int *p1)</code>	<code>function(int16 p1[])</code>
Fixed matrix	<code>function(int p1[15])</code> or <code>function(int p1[])</code> or <code>function(int *p1)</code>	<code>function(int16 p1[3][5])</code>
Variable matrix	<code>function(int p1[])</code> or <code>function(int *p1)</code>	<code>function(int16 p1[][])</code>
State Arguments		
Scalar pointer	<code>function(int *work1)</code> <code>function(void *work1)</code> <code>function(void **work1)</code>	<code>function(int16 work1[1])</code> <code>void function(void *work1)</code> <code>void function(void **work1)</code>
Fixed vector	<code>function(int work1[10])</code> or <code>function(int *work1)</code>	<code>function(int16 work1[10])</code>
Fixed matrix	<code>function(int work1[15])</code> or <code>function(int work1[])</code> or <code>function(int *work1)</code>	<code>function(int16 work1[3][5])</code>

Supported Data Types

Data Type	Supported for Input and Output?	Supported for Parameters?	Supported for States?
“Data Types Supported by Simulink”	Yes	Yes	Yes
Simulink.Bus ¹ (scalar only)	Yes	N/A	Yes
Simulink.NumericType ²	Yes	Yes	Yes
Simulink.AliasType ¹	Yes	Yes	Yes
Fixed-point ³	Yes	Yes	Yes
Fi objects	N/A	Yes	N/A
Complex numbers ⁴	Yes	Yes	Yes
1D array	Yes	Yes	Yes
2D array ⁵	Yes	Yes	Yes
nD array ⁶	Yes	Yes	Yes
void *	No	No	Yes
void **	No	No	Yes

- 1** You must supply the header file that declares the structure of the bus or the header file that defines the data type with the same name as an alias. The structure of the bus declared in the header file must match the structure of the bus object (for example, the number and order of elements, data types and widths of elements, and so on). For an example, see `sldemo_lct_bus`.
- 2** You must supply the header file that defines the data type only if the numeric data type is also an alias.
- 3** You must declare the data as a `Simulink.NumericType` object (unspecified scaling is not supported). For examples, see `sldemo_lct_fixpt_signals` and `sldemo_lct_fixpt_params`.
- 4** Limited to use with Simulink built-in data types. To specify a complex data type, enclose the built-in data type within angle brackets (<>) and prepend

the word `complex` (for example, `complex<double>`). For an example, see `sldemo_lct_cplxgain`.

- 5** MATLAB, Simulink, and Real-Time Workshop store two-dimensional matrix data in column-major format as a vector. If your external function code is written for row-major data, transpose the matrix data in MATLAB.
- 6** For a multidimensional signal, you can use the `size` function to determine the number of elements in the signal. For examples, see `sldemo_lct_lut` and `sldemo_lct_ndarray`.

For more information, see “Data Types Supported by Simulink”.

Function Specification Rules

Legacy Code Tool function specifications must adhere to the following rules:

- If an argument is not scalar, you must pass the argument by reference.
- The function must not change the value of input arguments.
- The function’s return value cannot be a pointer.
- Function specifications you define for the `StartFcnSpec`, `InitializeConditionsFcnSpec`, or `TerminateFcnSpec` cannot access input or output arguments.
- The numbering of input, output, parameter, and state argument tokens must start at 1 and increase monotonically.
- For a given Legacy Code Tool data structure, the data type and size of input, output, parameter, and state arguments must be the same across function specifications for `StartFcnSpec`, `InitializeConditionsFcnSpec`, `OutputFcnSpec`, and `TerminateFcnSpec`.
- You can use the `size` function to
 - Get the size of any input, output, parameter, or state argument and pass the size as input to the legacy function
 - Specify the input, output, or state argument dimensions as a function of other input or parameter argument dimensions

Consider the following example, which demonstrates both uses of the function:

```
def.OutputFcnSpec=
'void foo(double p1[][], double u1[size(p1,2)], double y1[size(u1,1)], ...
double work1[size(u1,1)], int32 size(u1,1))'
```

- p1 is a 2-dimensional parameter that is sized dynamically
- u1 is a 1-dimensional vector with the same number of elements as the second dimension of p1
- y1 is a 1-dimensional vector with the same number of element as u1
- work1 is a 1-dimensional vector with the same number of element as u1
- int32 size(u1,1) returns the number of elements in the vector u1 as the fifth input argument

Generating and Compiling the S-Functions

After you register a Legacy Code Tool data structure for an existing C function, use the `legacy_code` function as explained below to generate, compile, and link the S-function.

- 1 Generate a C MEX S-function based on the information defined in the structure. Call `legacy_code` with `'sfcn_cmex_generate'` as the first argument and the name of the data structure as the second argument.

```
legacy_code('sfcn_cmex_generate', lct_spec);
```

- 2 Make sure a C compiler is set up for your MATLAB installation. If you need to set up a compiler, enter the command `mex -setup` in the MATLAB Command Window.
- 3 Compile and link the S-function. This step assumes that a C compiler is set up for your MATLAB installation. Call `legacy_code` with `'compile'` as the first argument and the name of the data structure as the second argument.

```
legacy_code('compile', lct_spec);
```

Informational messages similar to the following appear in the MATLAB Command Window and a dynamically loadable executable results. On a 32-bit Microsoft Windows system, Simulink names the file `ex_sfun_doubleit.mexw32`.

```
### Start Compiling ex_sfundoubleit
mex ex_sfundoubleit.c -Id:\work\lct\lct_demos
### Finish Compiling ex_sfundoubleit
### Exit
```

As a convenience, you can generate, compile, and link the S-function in a single step by calling `legacy_code` with the string `'generate_for_sim'`. The function also generates a TLC file for accelerated simulations, if the `Options.useTlcWithAccel` field of the Legacy Code Tool data structure is set (1).

Once you have generated a dynamically loadable executable, you or others can use it in a model by adding an S-Function block that specifies the compiled S-function.

Generating a Masked S-Function Block for Calling a Generated S-Function

You have the option of using the Legacy Code Tool to generate a masked S-function block (graphical representation) that is configured to call a generated C MEX S-function. To generate such a block, call `legacy_code` with `'slblock_generate'` as the first argument and the name of the Legacy Code Tool data structure as the second argument.

```
legacy_code('slblock_generate', lct_spec);
```

The tool masks the block such that it displays the value of the `OutputFcnSpec` field. You can then add the block to a model manually.

If you prefer that the Legacy Code Tool add the block to a model automatically, specify the name of the model as a third argument. For example:

```
legacy_code('slblock_generate', lct_spec, 'myModel');
```

If the specified model (for example, `myModel.mdl`) exists, `legacy_code` opens the model and adds the masked S-function block described by the Legacy Code Tool data structure. If the model does not exist, the function creates a new model with the specified name and adds the masked S-function block.

Forcing Accelerator Mode to Use S-Function TLC Inlining Code

If you are using Simulink Accelerator mode, you can generate and force the use of TLC inlining code for the S-function generated by the Legacy Code Tool. To do this:

- 1 Generate a TLC block file for the S-function by calling the `legacy_code` function with `'sfcn_tlc_generate'` as the first argument and the name of the Legacy Code Tool data structure as the second argument.

```
legacy_code('sfcn_tlc_generate', lct_spec);
```

Consider the example in “Example of Integrating Existing C Functions into Simulink Models with the Legacy Code Tool” on page 3-56. To generate a TLC file for the model shown at the end of that example, enter the following command:

```
legacy_code('sfcn_tlc_generate', def);
```

- 2 Force Accelerator mode to use the TLC file by using `thessSetOptions SimStruct` function to set the S-function option `SS_OPTION_USE_TLC_WITH_ACCELERATOR`.

Handling Multiple Registration Files

You can have multiple registration files in the same directory and generate an S-function for each file with a single call to `legacy_code`. Likewise, you can use a single call to `legacy_code` to compile and link the S-functions and another to generate corresponding TLC block files, if appropriate.

Consider the following example, where `lct_register_1`, `lct_register_2`, and `lct_register_3` each create and initialize fields of a Legacy Code Tool structure.

```
defs1 = lct_register_1;
defs2 = lct_register_2;
defs3 = lct_register_3;
defs = [defs1(:);defs2(:);defs3(:)];
```

You can then use the following sequence of calls to `legacy_code` to generate files based on the three registration files:

```
legacy_code('sfcn_cmex_generate', defs);  
legacy_code('compile', defs);  
legacy_code('sfcn_tlc_generate', defs);
```

Alternatively, you can process each registration file separately. For example:

```
defs1 = lct_register1;  
legacy_code('sfcn_cmex_generate', defs1);  
legacy_code('compile', defs1);  
legacy_code('sfcn_tlc_generate', defs1);  
. . .  
defs2 = lct_register2;  
legacy_code('sfcn_cmex_generate', defs2);  
legacy_code('compile', defs2);  
legacy_code('sfcn_tlc_generate', defs2);  
. . .  
defs3 = lct_register3;  
legacy_code('sfcn_cmex_generate', defs3);  
legacy_code('compile', defs3);  
legacy_code('sfcn_tlc_generate', defs3);
```

Deploying Generated S-Functions

You can deploy the S-functions that you generate with the Legacy Code Tool for use by others. To deploy an S-function for simulation use only, you need to share only the compiled dynamically loadable executable.

Legacy Code Tool Demos

Simulink provides a set of demos that show applications of the Legacy Code Tool. To review the list of the demos, enter the following command in MATLAB Command Window and review the demos listed under the heading “Calling Legacy C and C++ Functions.”

```
demo('simulink', 'modeling features')
```

Legacy Code Tool Limitations

- Legacy Code Tool generates C MEX S-functions for existing functions written in C or C++. The tool does not support transformation of MATLAB, Fortran, or Ada functions.
- Complex number support is limited to use with Simulink built-in data types.

How Simulink Interacts with C S-Functions

In this section...
“Introduction” on page 3-74
“Process View” on page 3-74
“Data View” on page 3-78

Introduction

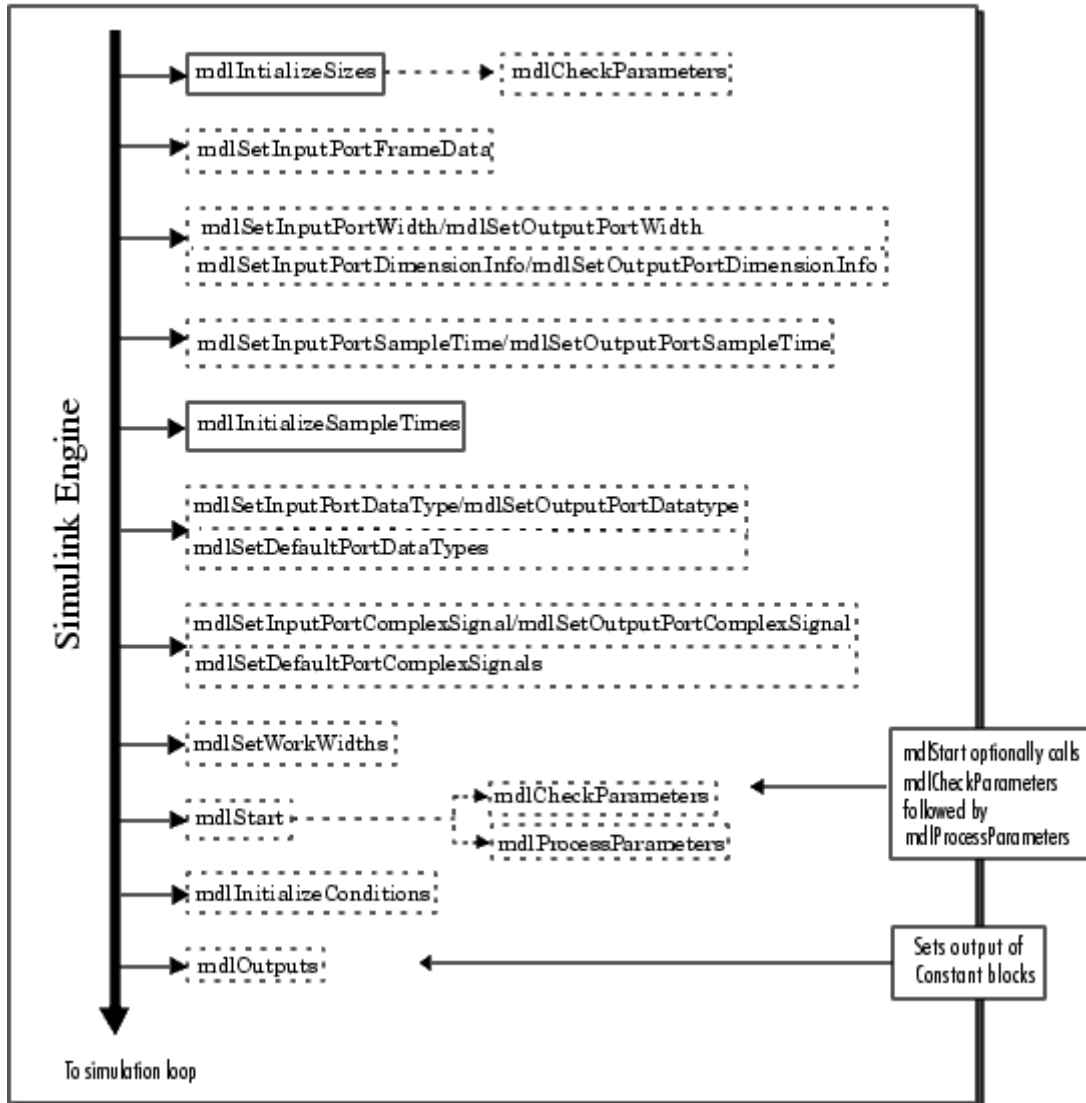
It is helpful in writing C MEX-file S-functions to understand how Simulink interacts with S-functions. This section examines the interaction from two perspectives: a process perspective, i.e., at which points in a simulation Simulink invokes the S-function, and a data perspective, i.e., how Simulink and the S-function exchange information during a simulation.

Process View

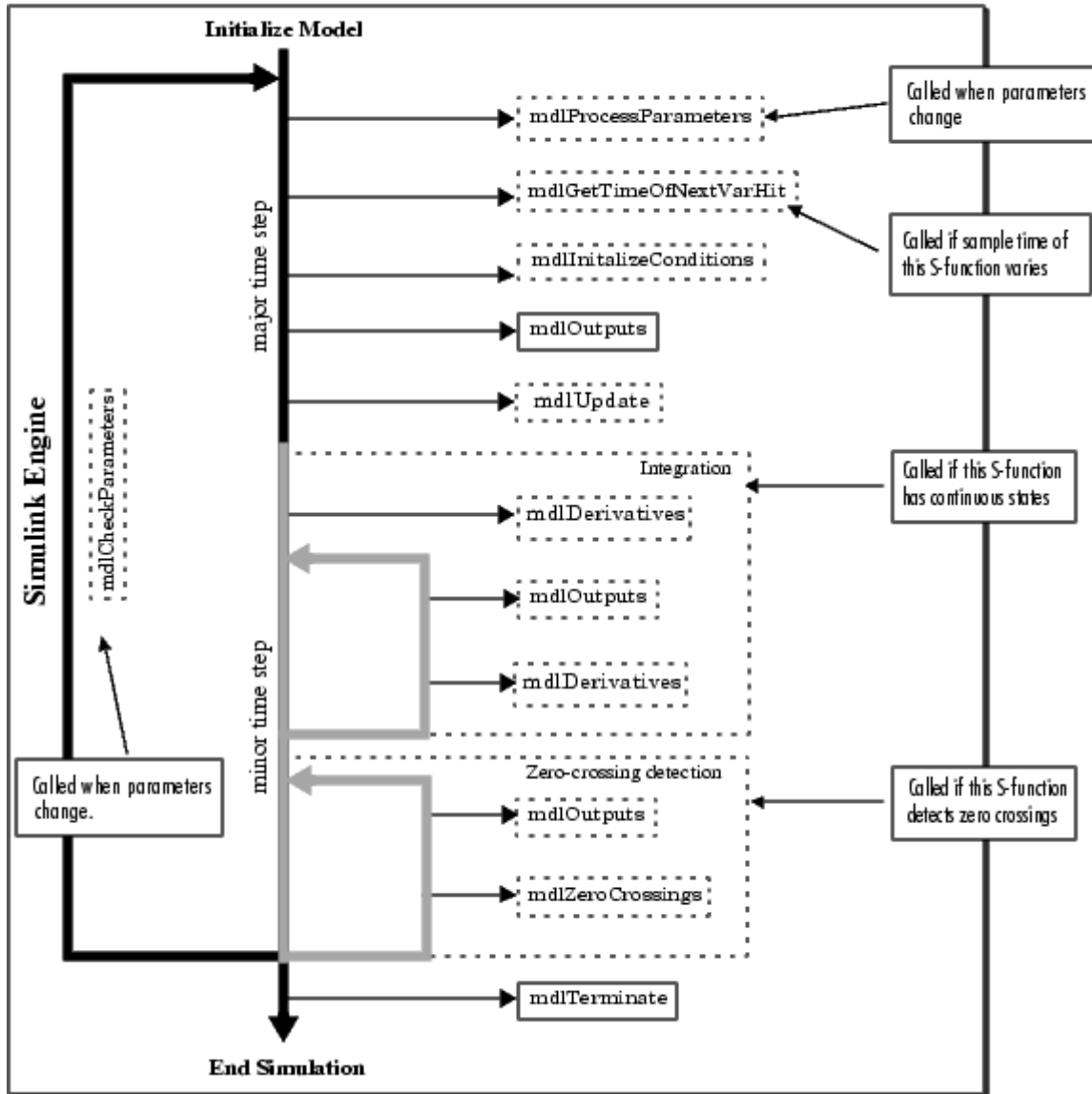
The following figures show the order in which Simulink invokes an S-function’s callback methods. Solid rectangles indicate callbacks that always occur during model initialization and/or at every time step. Dotted rectangles indicate callbacks that may occur during initialization and/or at some or all time steps during the simulation loop. See the documentation for each callback method in Chapter 8, “S-Function Callback Methods — Alphabetical List” to determine the exact circumstances under which Simulink invokes the callback.

Note The process view diagram represents the execution of S-functions that contain continuous and discrete states, enable zero-crossing detection, and reside in a model that uses a variable-step solver. Different solvers omit certain steps in the diagram. For a better understanding on how Simulink executes your particular S-function, use the Simulink debugger. See “Simulink Debugger” in “Using Simulink” for more information.

Model Initialization



Simulation Loop



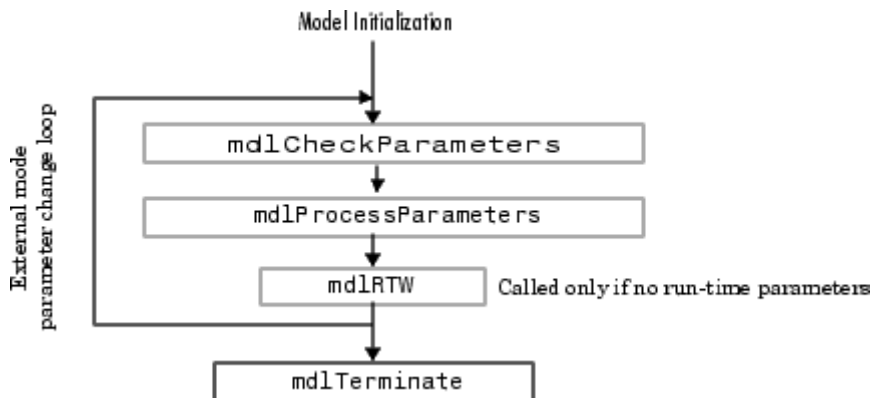
Calling Structure for Real-Time Workshop

When generating code, Real-Time Workshop does not go through the entire calling sequence outlined above. After initializing the model as outlined in the preceding section, Simulink calls `mdlRTW`, an S-function routine unique to Real-Time Workshop, `mdlTerminate`, and exits.

For more information about Real-Time Workshop and how it interacts with S-functions, see the Real-Time Workshop documentation and the “Real-Time Workshop Target Language Compiler Reference Guide”.

Alternate Calling Structure for External Mode

When you are running Simulink in external mode, the calling sequence for S-function routines changes. This picture shows the correct sequence for external mode.



Simulink calls `mdlRTW` once when it enters external mode and again each time a parameter changes or when you select **Update Diagram** under your model’s **Edit** menu.

Note Running Simulink in external mode requires Real-Time Workshop. For more information about external mode, see the Real-Time Workshop documentation.

Data View

S-function blocks have input and output signals, parameters, and internal states, plus other general work areas. In general, block inputs and outputs are written to, and read from, a block I/O vector. Inputs can also come from

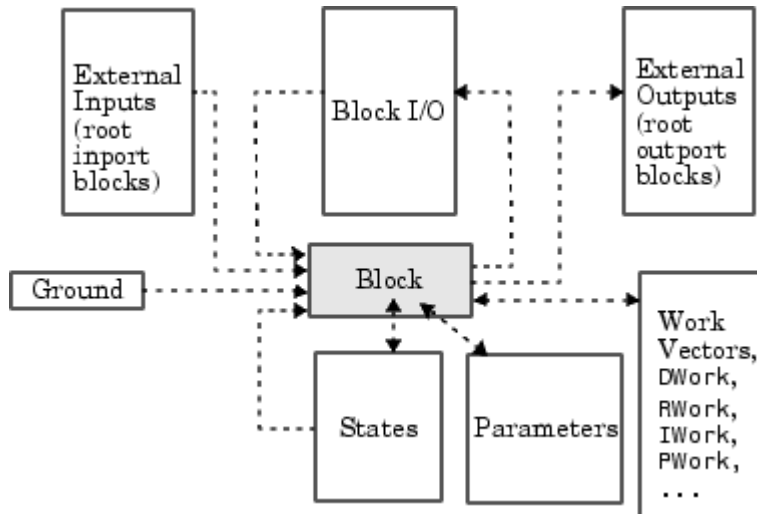
- External inputs via the root input blocks
- Ground if the input signal is unconnected or grounded

Block outputs can also go to the external outputs via the root output blocks. In addition to input and output signals, S-functions can have

- Continuous states
- Discrete states
- Other working areas such as real, integer or pointer work vectors

You can parameterize S-function blocks by passing parameters to them using the S-function block dialog box.

The following figure shows the general mapping between these various types of data.



An S-function's `mdlInitializeSizes` routine sets the sizes of the various signals and vectors. S-function methods called during the simulation loop can determine the sizes and values of the signals.

An S-function method can access input signals in two ways:

- Via pointers
- Using contiguous inputs

Accessing Signals Using Pointers

During the simulation loop, accessing the input signals is performed using

```
InputRealPtrsType uPtrs =  
    ssGetInputPortRealSignalPtrs(S,portIndex)
```

This is an array of pointers, where *portIndex* starts at 0. There is one for each input port. To access an element of this signal you must use

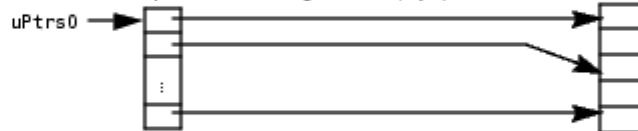
```
*uPtrs[element]
```

as described by this figure.



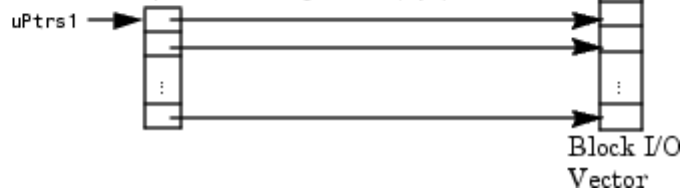
To access Input 1:

```
InputRealPtrsType uPtrs0 = ssGetInputPortRealSignalPtrs(S,0)
```



To access Input 2:

```
InputRealPtrsType uPtrs1 = ssGetInputPortRealSignalPtrs(S,1)
```



Note that input array pointers can point at noncontiguous places in memory. You can retrieve the output signal by using this code.

```
real_T *y = ssGetOutputPortSignal(S,outputPortIndex);
```

Accessing Contiguous Input Signals

An S-function's `mdlInitializeSizes` method can specify that the elements of its input signals must occupy contiguous areas of memory, using `ssSetInputPortRequiredContiguous`. If the inputs are contiguous, other methods can use `ssGetInputPortSignal` to access the inputs.

Accessing Input Signals of Individual Ports

This section describes how to access all input signals of a particular port and write them to the output port. The preceding figure shows that the input array of pointers can point to noncontiguous entries in the block I/O vector. The output signals of a particular port form a contiguous vector. Therefore, the

correct way to access input elements and write them to the output elements (assuming the input and output ports have equal widths) is to use this code.

```
int_T element;
int_T portWidth = ssGetInputPortWidth(S,inputPortIndex);
InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,inputPortIndex);
real_T *y = ssGetOutputPortSignal(S,outputPortIdx);

for (element=0; element<portWidth; element++) {
    y[element] = *uPtrs[element];
}
```

A common mistake is to try to access the input signals via pointer arithmetic. For example, if you were to place

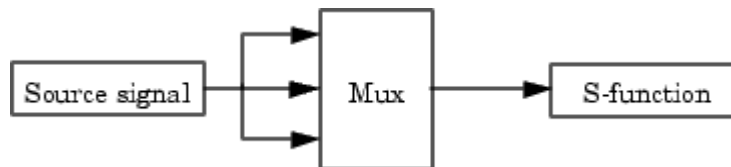
```
real_T *u = *uPtrs; /* Incorrect */
```

just below the initialization of `uPtrs` and replace the inner part of the above loop with

```
*y++ = *u++; /* Incorrect */
```

the code compiles, but the MEX-file might crash Simulink. This is because it is possible to access invalid memory (which depends on how you build your model). When accessing the input signals incorrectly, a crash occurs when the signals entering your S-function block are not contiguous. Noncontiguous signal data occurs when signals pass through virtual connection blocks such as the Mux or Selector blocks.

To verify that you are correctly accessing wide input signals, pass a replicated signal to each input port of your S-function. You do this by creating a Mux block with the number of input ports equal to the width of the desired signal entering your S-function. Then the driving source should be connected to each input port as shown in this figure.



Writing Callback Methods

Writing an S-function basically involves creating implementations of the callback functions that Simulink invokes during a simulation. For guidelines on implementing a particular callback, see the documentation for the callback in Chapter 8, “S-Function Callback Methods — Alphabetical List”. For information on using callbacks to implement specific block features, such as parameters or sample times, see Chapter 7, “Implementing Block Features”.

Using S-Functions in Normal Mode Referenced Models

When a C S-function appears in a referenced model that executes in Normal mode, successful execution is impossible if all of the following are true:

- The S-function has both an `mdlProcessParameters` function and an `mdlStart` function.
- The `mdlProcessParameters` function depends on the `mdlStart` function.
- The referenced model calls `mdlProcessParameters` before calling `mdlStart`.

Execution fails because `mdlProcessParameters` has dependency requirements that `mdlStart` has not satisfied. Automated analysis cannot guard against all possible causes of such failure: you must check your code manually and verify that `mdlProcessParameters` is not in any way dependent on `mdlStart` being called first. Examples of such dependency include:

- Allocating memory in `mdlStart` and using that memory in `mdlProcessParameters`. This is often done using `ssSetUserData` and `ssGetUserData`.
- Initializing any `DWork` or any global memory in `mdlStart` and reading the values in `mdlProcessParameters`.

To remind you to check for any such dependency problems, an error message appears by default for any S-function that is used in a Normal-mode referenced model and contains both an `mdlProcessParameters` function and an `mdlStart` function. The error message does not mean that any dependency problems exist, but only that they might exist.

If you get such an error message, check for any problematic dependencies in the S-function, and recode as needed to eliminate them. When no such dependencies exist, you can use the S-function in a Normal mode referenced model. You can then safely suppress the error message. To certify that the S-function is compliant, and the message is therefore unnecessary, include the following statement in `mdlInitializeSizes`:

```
ssSetModelReferenceNormalModeSupport (S, MDL_START_AND_MDL_PROCESS_PARAMS_OK);
```

For information about referenced models, see “Referencing a Model” in the Simulink documentation, and “Generating Code for Model Referencing” in the Real-Time Workshop documentation.

Debugging C MEX S-Functions

In this section...

“About Debugging C MEX S-Functions” on page 3-85

“Debugging C MEX S-Functions Using Microsoft Visual C/C++ .NET” on page 3-85

“Debugging C MEX S-Functions Using UNIX” on page 3-86

About Debugging C MEX S-Functions

This section contains examples on how to debug C MEX S-functions using one of the following C compilers.

- Microsoft Visual C/C++ .NET compiler (version 7.0)
- UNIX compilers

Refer to your compiler documentation for further information on debugging files. The examples use the Simulink demo model `sfcndemo_timestwo.mdl` and the C MEX S-function `matlabroot/simulink/src/timestwo.c`. Save these files to your working directory before proceeding with the examples.

Debugging C MEX S-Functions Using Microsoft Visual C/C++ .NET

Before beginning the example, save the files `sfcndemo_timestwo.mdl` and `matlabroot/simulink/src/timestwo.c` into your working directory.

- 1 Open the Simulink model `sfcndemo_timestwo.mdl`.
- 2 Create a debuggable version of the MEX-file by compiling the C-file using the `mex` command with the `-g` option.

```
mex -g timestwo.c
```

The `-g` option creates the executable `timestwo.mexw32` with debugging symbols included. At this point, you may want to simulate the `sfcndemo_timestwo` model to ensure it runs properly.

- 3** Without exiting MATLAB, start the Microsoft Development Environment.
- 4** From the Microsoft Development Environment menu bar, select **Tools > Debug Processes**.
- 5** In the **Processes** dialog box that opens:
 - a** Select the MATLAB.exe process in the **Available Processes** list.
 - b** Click **Attach**.
- 6** In the **Attach to Process** dialog box that opens:
 - a** Select **Native** in the list of program types to debug.
 - b** Click **OK**.
You should now be attached to the MATLAB process.
- 7** Click **Close** on the **Processes** dialog box.
- 8** From the Microsoft Development Environment's **File** menu, select **Open > File**. Select the `timestwo.c` source files from the file browser that opens.
- 9** Set a breakpoint on the desired line of code by right-clicking on the line and selecting **Insert Breakpoint** from the context menu. If you have not previously run the model, the breakpoint may show up with a question mark, indicating that the executable is not loaded. Subsequently running the model loads the `.mexw32` file and removes the question mark from the breakpoint.
- 10** Start the simulation from the `sfcndemo_timestwo` Simulink model. You should be running the S-function in the Microsoft Development Environment and can debug the file within that environment.

Debugging C MEX S-Functions Using UNIX

Before beginning the example, save the files `sfcndemo_timestwo.mdl` and `matlabroot/simulink/src/timestwo.c` into your working directory.

- 1** Open the Simulink model `sfcndemo_timestwo.mdl`.
- 2** Create a debuggable version of the MEX-file by compiling the C-file using the `mex` command with the `-g` option


```
mex -g timestwo.c
```

The `-g` option creates the executable `timestwo.mexw32` with debugging symbols included. At this point, you may want to simulate the `sfcndemo_timestwo` model to ensure it runs properly.

3 Exit MATLAB.

4 Start MATLAB in debugging mode using the following command.

```
matlab -D<nameOfDebugger>
```

The `-D` flag starts MATLAB within the specified debugger. For example, to use the `dbx` debugging tool on Solaris, enter the following command.

```
matlab -Ddbx
```

5 Once the debugger has loaded, continue loading MATLAB by typing `run` at the debugger prompt.

```
(dbx) run
Running: matlab
(process id 9375)
```

6 After MATLAB starts, enable debugging by entering the following command at the MATLAB command prompt.

```
dbmex on
```

7 Open the `sfcndemo_timestwo` Simulink model.

8 Simulate the model. This brings you into the debugger.

9 Set breakpoints in the source code, for example:

```
(dbx) stop in mdlOutputs
(2) stop in `timestwo.mexs64`timestwo.c`mdlOutputs
(dbx) file timestwo.c
```

10 Issue the `cont` command to continue.

```
(dbx) cont
```

11 Use your debugger's routines to debug the S-function.

Converting Level 1 C MEX S-Functions to Level 2

In this section...

“Guidelines for Converting Level 1 C MEX S-Functions to Level 2” on page 3-89

“Obsolete Macros” on page 3-92

Guidelines for Converting Level 1 C MEX S-Functions to Level 2

Level 2 S-functions were introduced with Simulink 2.2. Level 1 S-functions refer to S-functions that were written to work with Simulink 2.1 and previous releases. Level 1 S-functions are compatible with Simulink 2.2 and subsequent releases; you can use them in new models without making any code changes. However, to take advantage of new features in S-functions, level 1 S-functions must be updated to level 2 S-functions. Here are some guidelines:

- Start by looking at `simulink/src/sfunctmpl_doc.c`. This template S-function file concisely summarizes level 2 S-functions.
- At the top of your S-function file, add this define:

```
#define S_FUNCTION_LEVEL 2
```

- Update the contents of `mdlInitializeSizes`. In particular, add the following error handling for the number of S-function parameters:

```
ssSetNumSFcnParams(S, NPARAMS); /*Number of expected parameters*/
if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
    /* Return if number of expected != number of actual parameters */
    return;
}
Set up the inputs using:
if (!ssSetNumInputPorts(S, 1)) return; /*Number of input ports */
ssSetInputPortWidth(S, 0, width);      /* Width of input
                                         port one (index 0)*/
ssSetInputPortDirectFeedThrough(S, 0, 1); /* Direct feedthrough
                                         or port one */
ssSetInputPortRequiredContiguous(S, 0);
```

```
Set up the outputs using:  
if (!ssSetNumOutputPorts(S, 1)) return;  
ssSetOutputPortWidth(S, 0, width);    /* Width of output port  
                                         one (index 0) */
```

- If your S-function has a nonempty `mdlInitializeConditions`, update it to the following form:

```
#define MDL_INITIALIZE_CONDITIONS  
static void mdlInitializeConditions(SimStruct *S)  
{  
}  
}
```

Otherwise, delete the function.

- Access the continuous states using `ssGetContStates`. The `ssGetX` macro has been removed.
 - Access the discrete states using `ssGetRealDiscStates(S)`. The `ssGetX` macro has been removed.
 - For mixed continuous and discrete state S-functions, the state vector no longer consists of the continuous states followed by the discrete states. The states are saved in separate vectors and hence might not be contiguous in memory.
- The `mdlOutputs` prototype has changed from

```
static void mdlOutputs( real_T *y, const real_T *x,  
                       const real_T *u, SimStruct *S, int_T tid)
```

to

```
static void mdlOutputs(SimStruct *S, int_T tid)
```

Since `y`, `x`, and `u` are not explicitly passed in to level-2 S-functions, you must use

- `ssGetInputPortSignal` to access inputs
- `ssGetOutputPortSignal` to access the outputs
- `ssGetContStates` or `ssGetRealDiscStates` to access the states

- The `mdlUpdate` function prototype has changed from

```
void mdlUpdate(real_T *x, real_T *u, Simstruct *S, int_T tid)
```

to

```
void mdlUpdate(SimStruct *S, int_T tid)
```

- If your S-function has a nonempty `mdlUpdate`, update it to this form:

```
#define MDL_UPDATE
static void mdlUpdate(SimStruct *S, int_T tid)
{
}

```

Otherwise, delete the function.

- If your S-function has a nonempty `mdlDerivatives`, update it to this form:

```
#define MDL_DERIVATIVES
static void mdlDerivatives(SimStruct *S)
{
}

```

Otherwise, delete the function.

- Replace all obsolete `SimStruct` macros. See “Obsolete Macros” on page 3-92 for a complete list of obsolete macros.
- When converting level 1 S-functions to level 2 S-functions, you should build your S-functions with full (i.e., highest) warning levels. For example, if you have `gcc` on a UNIX system, use these options with the `mex` utility.

```
mex CC=gcc CFLAGS=-Wall sfcn.c
```

If your system has `Lint`, use this code.

```
lint -DMATLAB_MEX_FILE -I<matlabroot>/simulink/include
    -Imatlabroot/extern/include sfcn.c
```

On a PC, to use the highest warning levels, you must create a project file inside the integrated development environment (IDE) for the compiler you are using. Within the project file, define `MATLAB_MEX_FILE` and add

```
matlabroot/simulink/include
matlabroot/extern/include
```

to the path (be sure to build with alignment set to 8).

Obsolete Macros

The following macros are obsolete. Each obsolete macro should be replaced with the specified macro.

Obsolete Macro	Replace with
ssGetU(S), ssGetUPtrs(S)	ssGetInputPortSignalPtrs(S,port), ssGetInputPortSignal(S,port)
ssGetY(S)	ssGetOutputPortRealSignal(S,port)
ssGetX(S)	ssGetContStates(S), ssGetRealDiscStates(S)
ssGetStatus(S)	Normally not used, but ssGetErrorStatus(S) is available.
ssSetStatus(S,msg)	ssSetErrorStatus(S,msg)
ssGetSizes(S)	Specific call for the wanted item (i.e., ssGetNumContStates(S))
ssGetMinStepSize(S)	No longer supported.
ssGetPresentTimeEvent(S,sti)	ssGetTaskTime(S,sti)
ssGetSampleTimeEvent(S,sti)	ssGetSampleTime(S,sti)
ssSetSampleTimeEvent(S,t)	ssSetSampleTime(S,sti,t)
ssGetOffsetTimeEvent(S,sti)	ssGetOffsetTime(S,sti)
ssSetOffsetTimeEvent(S,sti,t)	ssSetOffsetTime(S,sti,t)
ssIsSampleHitEvent(S,sti,tid)	ssIsSampleHit(S,sti,tid)
ssGetNumInputArgs(S)	ssGetNumSFcnParams(S)
ssSetNumInputArgs(S, numInputArgs)	ssSetNumSFcnParams(S,numInputArgs)
ssGetNumArgs(S)	ssGetSFcnParamsCount(S)
ssGetArg(S, argNum)	ssGetSFcnParam(S, argNum)

Obsolete Macro	Replace with
ssGetNumInputs	ssGetNumInputPorts(S) and ssGetInputPortWidth(S, <i>port</i>)
ssSetNumInputs	ssSetNumInputPorts(S, <i>nInputPorts</i>) and ssSetInputPortWidth(S, <i>port</i> , <i>val</i>)
ssGetNumOutputs	ssGetNumOutputPorts(S) and ssGetOutputPortWidth(S, <i>port</i>)
ssSetNumOutputs	ssSetNumOutputPorts(S, <i>nOutputPorts</i>) and ssSetOutputPortWidth(S, <i>port</i> , <i>val</i>)

Creating C++ S-Functions

The procedure for creating C++ S-functions is nearly the same as that for creating C S-functions (see Chapter 3, “Writing S-Functions in C”). The following sections explain the differences.

Source File Format (p. 4-2)	Explains the differences between the source file structure of a C++ S-function and a C S-function.
Making C++ Objects Persistent (p. 4-6)	How to create C++ objects that persist across invocations of the S-function.
Building C++ S-Functions (p. 4-8)	How to build a C++ S-function.

Source File Format

The format of the C++ source for an S-function is nearly identical to that of the source for an S-function written in C. The main difference is that you must tell the C++ compiler to use C calling conventions when compiling the callback methods. This is necessary because the Simulink simulation engine assumes that callback methods obey C calling conventions.

To tell the compiler to use C calling conventions when compiling the callback methods, wrap the C++ source for the S-function callback methods in an `extern "C"` statement. The C++ version of the `sfun_counter` S-function example (`matlabroot/simulink/src/sfun_counter_cpp.cpp`) illustrates usage of the `extern "C"` directive to ensure that the compiler generates Simulink-compatible callback methods:

```
/* File   : sfun_counter_cpp.cpp
 * Abstract:
 *
 * Example of an C++ S-function which stores an C++ object in
 * the pointers vector PWork.
 *
 * Copyright 1990-2005 The MathWorks, Inc.
 */

#include "iostream.h"

class counter {
    double x;
public:
    counter() {
        x = 0.0;
    }
    double output(void) {
        x = x + 1.0;
        return x;
    }
};

#ifdef __cplusplus
```

```
extern "C" { // use the C fcn-call standard for all functions
#endif      // defined within this scope

#define S_FUNCTION_LEVEL 2
#define S_FUNCTION_NAME  sfun_counter_cpp

/*
 * Need to include simstruc.h for the definition of the SimStruct and
 * its associated macro definitions.
 */
#include "simstruc.h"

/*=====
 * S-function methods *
 *=====*/

/* Function: mdlInitializeSizes =====
 * Abstract:
 *   The sizes information is used by Simulink to determine the S-function
 *   block's characteristics (number of inputs, outputs, states, etc.).
 */
static void mdlInitializeSizes(SimStruct *S)
{
    /* See sfuntmpl_doc.c for more details on the macros below */

    ssSetNumSFcnParams(S, 1); /* Number of expected parameters */
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
        /* Return if number of expected != number of actual parameters */
        return;
    }

    ssSetNumContStates(S, 0);
    ssSetNumDiscStates(S, 0);

    if (!ssSetNumInputPorts(S, 0)) return;

    if (!ssSetNumOutputPorts(S, 1)) return;
    ssSetOutputPortWidth(S, 0, 1);

    ssSetNumSampleTimes(S, 1);
}
```

```
    ssSetNumRWork(S, 0);
    ssSetNumIWork(S, 0);
    ssSetNumPWork(S, 1); // reserve element in the pointers vector
    ssSetNumModes(S, 0); // to store a C++ object
    ssSetNumNonsampledZCs(S, 0);

    ssSetOptions(S, 0);
}

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   This function is used to specify the sample time(s) for your
 *   S-function. You must register the same number of sample times as
 *   specified in ssSetNumSampleTimes.
 */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, mxGetScalar(ssGetSFcnParam(S, 0)));
    ssSetOffsetTime(S, 0, 0.0);
}

#define MDL_START /* Change to #undef to remove function */
#if defined(MDL_START)
/* Function: mdlStart =====
 * Abstract:
 *   This function is called once at start of model execution. If you
 *   have states that should be initialized once, this is the place
 *   to do it.
 */
static void mdlStart(SimStruct *S)
{
    ssGetPWork(S)[0] = (void *) new counter; // store new C++ object in the
                                           // pointers vector
}
#endif /* MDL_START */

/* Function: mdlOutputs =====
 * Abstract:
 *   In this function, you compute the outputs of your S-function
 *   block. Generally outputs are placed in the output vector, ssGetY(S).
```

```

*/
static void mdlOutputs(SimStruct *S, int_T tid)
{
    counter *c = (counter *) ssGetPWork(S)[0]; // retrieve C++ object from
    real_T *y = ssGetOutputPortRealSignal(S,0); // the pointers vector and use
    y[0] = c->output(); // member functions of the
} // object

/* Function: mdlTerminate =====
* Abstract:
* In this function, you should perform any actions that are necessary
* at the termination of a simulation. For example, if memory was
* allocated in mdlStart, this is the place to free it.
*/
static void mdlTerminate(SimStruct *S)
{
    counter *c = (counter *) ssGetPWork(S)[0]; // retrieve and destroy C++
    delete c; // object in the termination
} // function
/*=====
* See sfuntmpl_doc.c for the optional S-function methods *
*=====*/

/*=====
* Required S-function trailer *
*=====*/

#ifdef MATLAB_MEX_FILE /* Is this file being compiled as a MEX-file? */
#include "simulink.c" /* MEX-file interface mechanism */
#else
#include "cg_sfun.h" /* Code generation registration function */
#endif

#ifdef __cplusplus
} // end of extern "C" scope
#endif

```

Making C++ Objects Persistent

Your C++ callback methods might need to create persistent C++ objects, that is, objects that continue to exist after the method exits. For example, a callback method might need to access an object created during a previous invocation. Or one callback method might need to access an object created by another callback method. To create persistent C++ objects in your S-function:

- 1 Create a pointer work vector to hold pointers to the persistent object between method invocations:

```
static void mdlInitializeSizes(SimStruct *S)
{
    ...
    ssSetNumPWork(S, 1); // reserve element in the pointers vector
                        // to store a C++ object
    ...
}
```

- 2 Store a pointer to each object that you want to be persistent in the pointer work vector:

```
static void mdlStart(SimStruct *S)
{
    ssGetPWork(S)[0] = (void *) new counter; // store new C++ object in the
                                           // pointers vector
}
```

- 3 Retrieve the pointer in any subsequent method invocation to access the object:

```
static void mdlOutputs(SimStruct *S, int_T tid)
{
    counter *c = (counter *) ssGetPWork(S)[0]; // retrieve C++ object from
    real_T *y = ssGetOutputPortRealSignal(S,0); // the pointers vector and
    y[0] = c->output(); // use member functions of
} // the object
```

4 Destroy the objects when the simulation terminates:

```
static void mdlTerminate(SimStruct *S)
{
    counter *c = (counter *) ssGetPWork(S)[0]; // retrieve and destroy C++
    delete c; // object in the termination
} // function
```

Building C++ S-Functions

Use the MATLAB `mex` command to build C++ S-functions exactly the way you use it to build C S-functions. For example, to build the C++ version of the `sfun_counter` example, enter

```
mex sfun_counter_cpp.cpp
```

at the MATLAB command line.

Note The extension of the source file for a C++ S-function must be `.cpp` to ensure that the compiler treats the file's contents as C++ code.

Creating Ada S-Functions

Introduction (p. 5-2)	Overview of creating Ada S-functions.
Ada S-Function Source File Format (p. 5-4)	Source code structure of an Ada S-function.
Writing Callback Methods in Ada (p. 5-8)	How to use Ada to implement S-function callback methods.
Building an Ada S-Function (p. 5-11)	Compiling and linking an Ada S-function.
Example of an Ada S-Function (p. 5-12)	An Ada version of the <code>times_two</code> S-function example.

Introduction

In this section...
“About Simulink and Ada” on page 5-2
“Ada Compiler Requirements” on page 5-2

About Simulink and Ada

Simulink allows you to use the Ada programming language to create S-functions. Simulink supports Ada S-functions on only the following 32-bit platforms.

- Windows (WIN32)
- Linux (GLNX86)

As with S-functions coded in other programming languages, Simulink interacts with an Ada S-function by invoking callback methods that the S-function implements. Each method performs a predefined task, such as computing block outputs, required to simulate the block whose functionality the S-function defines. Creating an Ada S-function thus entails writing Ada implementations of the callback methods required to simulate the S-function and then compiling and linking the callbacks into a library that Simulink can load and invoke during simulation. The following sections explain how to perform these tasks. Simulink allows you to generate code for Ada S-functions if they are inlined. See “Inlining S-Functions” in the Target Language Compiler documentation for more information.

Ada Compiler Requirements

To build a MEX-file from Ada source code, using the mex tool, you must have previously installed a copy of Version 3.12 (or higher) of the GNAT Ada95 compiler on your system. You can obtain the latest Windows (WIN32) and GNU-Linux (GLNX86) versions of the compiler at the GNAT ftp site (<ftp://cs.nyu.edu/pub/gnat>). You can purchase a professional version from <http://www.adacore.com>. Make sure that the compiler executable is in the MATLAB command path so that the mex tool can find it.

The GNAT Ada95 compiler package used to include `gnatdll.exe`, a tool for building DLLs on Windows. This tool, which is required to build Ada MEX-files on Windows, now comes as part of a separate `gnatwin` package containing Windows-specific files. If you want to build Ada S-functions on a Windows system, you must download and install the `gnatwin` package as well as the GNAT Ada95 compiler.

Ada S-Function Source File Format

In this section...

“Ada S-Function Specification” on page 5-4

“Ada S-Function Body” on page 5-5

Ada S-Function Specification

To create an Ada S-function, you must create an Ada package that implements the callback methods required to simulate the S-function. The S-function package comprises a specification and a body.

The specification specifies the methods that the Ada S-function uses and implements. The specification must specify that the Ada S-function uses the Simulink package, which defines data types and functions that the S-function can use to access the internal data structure (SimStruct) that Simulink uses to store information about the S-function (see Chapter 9, “SimStruct Functions — By Category”). The specification and body of the Simulink package reside in the *matlabroot/simulink/ada/interface/* directory.

The specification should also specify each callback method that the S-function implements as an Ada procedure exported to C. The following is an example of an Ada S-function specification that meets these requirements.

```
-- The Simulink API for Ada S-Function
with Simulink; use Simulink;

package Times_Two is

  -- The S_FUNCTION_NAME has to be defined as a constant
  -- string.
  S_FUNCTION_NAME : constant String := "times_two";

  -- Every S-Function is required to have the
  -- "mdlInitializeSizes" method.
  -- This method needs to be exported as shown below, with the
  -- exported name being "mdlInitializeSizes".
  --
```

```

    procedure mdlInitializeSizes(S : in SimStruct);
    pragma Export(C, mdlInitializeSizes, "mdlInitializeSizes");
    procedure mdlOutputs(S : in SimStruct; TID : in Integer);
    pragma Export(C, mdlOutputs, "mdlOutputs");

end Times_Two;

```

Ada S-Function Body

The Ada S-Function body provides the implementations of the S-function callback methods, as illustrated in the following example.

```

with Simulink; use Simulink;
with Ada.Exceptions; use Ada.Exceptions;

package body Times_Two is

    -- Function: mdlInitializeSizes -----
    -- Abstract:
    --     Setup the input and output port attributes for this
    --     S-Function.
    --
    procedure mdlInitializeSizes(S : in SimStruct) is

begin
    -- Set the input port attributes
    --
    ssSetNumInputPorts(          S, 1);
    ssSetInputPortWidth(        S, 0, DYNAMICALLY_SIZED);
    ssSetInputPortDataType(     S, 0, SS_DOUBLE);
    ssSetInputPortDirectFeedThrough(S, 0, TRUE);
    ssSetInputPortOverWritable(  S, 0, FALSE);
    ssSetInputPortOptimizationLevel(S, 0, 3);

    -- Set the output port attributes
    --
    ssSetNumOutputPorts(        S, 1);
    ssSetOutputPortWidth(       S, 0, DYNAMICALLY_SIZED);
    ssSetOutputPortDataType(    S, 0, SS_DOUBLE);
    ssSetOutputPortOptimizationLevel(S, 0, 3);

```

```
-- Set the block sample time.
ssSetSampleTime(          S, INHERITED_SAMPLE_TIME);

exception
when E : others =>
  if ssGetErrorStatus(S) = "" then
    ssSetErrorStatus(S,
      "Exception occurred in mdlInitializeSizes. " &
      "Name: " & Exception_Name(E) & ", " &
      "Message: " & Exception_Message(E) &
      " and " & "Information: " &
      Exception_Information(E));
  end if;
end mdlInitializeSizes;

-- Function: mdlOutputs -----
-- Abstract:
--   Compute the S-Function's output,
--   given its input:  $y = 2 * u$ 
--
procedure mdlOutputs(S : in SimStruct; TID : in Integer) is

  uWidth : Integer := ssGetInputPortWidth(S,0);
  U      : array(0 .. uWidth-1) of Real_T;
  for U'Address use ssGetInputPortSignalAddress(S,0);

  yWidth : Integer := ssGetOutputPortWidth(S,0);
  Y      : array(0 .. yWidth-1) of Real_T;
  for Y'Address use ssGetOutputPortSignalAddress(S,0);

begin
  if uWidth = 1 then
    for Idx in 0 .. yWidth-1 loop
      Y(Idy) := 2.0 * U(0);
    end loop;
  else
    for Idx in 0 .. yWidth-1 loop
      Y(Idy) := 2.0 * U(Idy);
    end loop;
  end if;
end;
```

```
        end if;

    exception
    when E : others =>
        if ssGetErrorStatus(S) = "" then
            ssSetErrorStatus(S,
                "Exception occurred in mdlOutputs. " &
                "Name: " & Exception_Name(E) & ", " &
                "Message: " & Exception_Message(E) & " and " &
                "Information: " & Exception_Information(E));
            end if;
        end mdlOutputs;

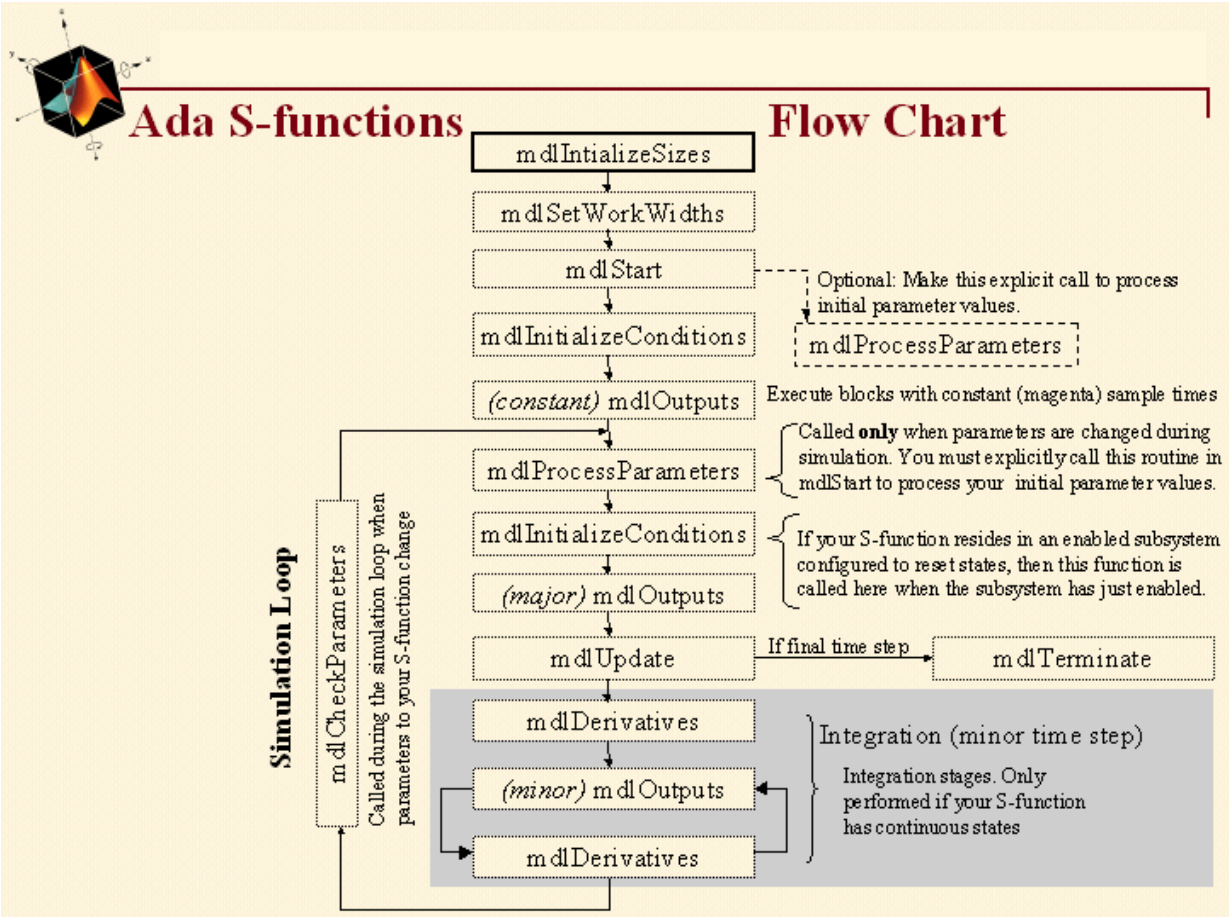
    end Times_Two;
```

Writing Callback Methods in Ada

In this section...
“Callbacks Invoked by Simulink” on page 5-8
“Implementing Callbacks” on page 5-10
“Omitting Optional Callback Methods” on page 5-10
“SimStruct Functions” on page 5-10

Callbacks Invoked by Simulink

Simulink interacts with an Ada S-function by invoking callback methods that the S-function implements. The following diagram shows the callback methods that Simulink invokes when interacting with an Ada S-function during a simulation and the order in which Simulink invokes them.



Note When interacting with Ada S-functions, Simulink invokes only a subset of the callback methods that it invokes for C S-functions. The “Languages Supported” section of the reference page for each callback method specifies whether Simulink invokes that callback when interacting with an Ada S-function.

Implementing Callbacks

Simulink defines in a general way the task of each callback. The S-function is free to perform the task according to the functionality it implements. For example, Simulink specifies that the S-function's `mdlOutputs` method must compute that block's outputs at the current simulation time. It does not specify what those outputs must be. This callback-based API allows you to create S-functions, and hence custom blocks, that meet your requirements.

Chapter 8, “S-Function Callback Methods — Alphabetical List” explains the purpose of each callback and provides guidelines for implementing them. “C S-Function Examples” on page 1-25 provides examples on using these callbacks to implement specific S-function features, such as the ability to handle multiple signal data types.

Omitting Optional Callback Methods

The method `mdlInitializeSizes` is the only callback that an Ada S-function must implement. The source for your Ada S-function needs to include implementations only for callbacks that it must handle. If the source for your S-function does not include an implementation for a particular callback, the `mex` tool that builds the S-function (see “Building an Ada S-Function” on page 5-11) provides a stub implementation.

SimStruct Functions

Simulink provides a set of functions that enable an Ada S-function to access the internal data structure (SimStruct) that Simulink maintains for the S-function. These functions consist of Ada wrappers around the SimStruct macros used to access the SimStruct from a C S-function (see Chapter 9, “SimStruct Functions — By Category”). Simulink provides Ada wrappers for a substantial subset of the SimStruct macros. The “Languages Supported” section of the reference page for a macro specifies whether it has an Ada wrapper.

Building an Ada S-Function

To use your Ada S-function with Simulink, you must build a MATLAB executable (MEX) file from the Ada source code for the S-function. Use the MATLAB `mex` command to perform this step.

The `mex` syntax for building an Ada S-function MEX-file is

```
mex [-v] [-g] -ada SFCN.ads
```

where `SFCN.ads` is the name of the S-function's package specification, `-g` creates a debuggable MEX-file, and `-v` causes Simulink to print each compile step and final link step during the build process. To build the S-function's package body, replace `SFCN.ads` with `SFCN.adb`.

For example, to build the `times_two` S-function example that comes with Simulink, enter the command

```
mex -ada times_two.ads
```

Example of an Ada S-Function

In this section...

“Overview of an Example of an Ada S-Function” on page 5-12

“Times_two Package Specification” on page 5-13

“Times_two Package Body” on page 5-16

“mdlInitializeSizes” on page 5-18

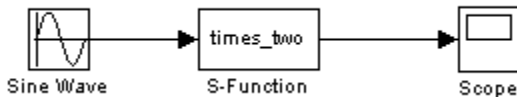
“mdlOutputs” on page 5-18

“Building the Times_two Example” on page 5-19

Overview of an Example of an Ada S-Function

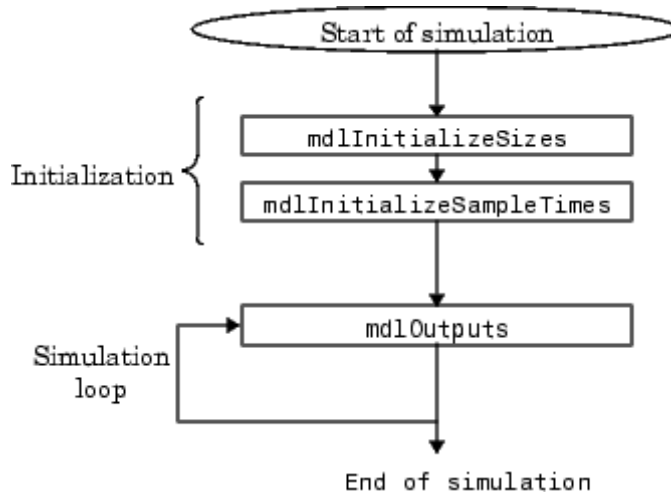
This section presents an example of a basic Ada S-function that you can use as a model when creating your own Ada S-functions. The example is the `times_two` S-function example that comes with Simulink (see `matlabroot/simulink/ada/examples/times_two/times_two.ads` and `matlabroot/simulink/ada/examples/times_two/times_two.adb`). This S-function outputs twice its input.

The following model uses the `times_two` S-function to double the amplitude of a sine wave and plot it in a scope.



The block dialog for the S-function specifies `times_two` as the S-function name; the parameters field is empty.

The `times_two` S-function contains the S-function callback methods shown in this figure.



The source code for the `times_two` S-function comprises two parts:

- Package specification
- Package body

Times_two Package Specification

The `times_two` package specification, `times_two.ads`, contains the following code.

```

-- The Simulink API for Ada S-Function

with Simulink; use Simulink;

package Times_Two is

  -- The S_FUNCTION_NAME has to be defined as a constant string. Note that
  -- the name of the S-Function (ada_times_two) is different from the name
  -- of this package (times_two). We do this so that it is easy to identify
  -- this example S-Function in the MATLAB workspace. Normally you would use
  -- the same name for S_FUNCTION_NAME and the package.
  --
  S_FUNCTION_NAME : constant String := "ada_times_two";

```

```
-- Every S-Function is required to have the "mdlInitializeSizes" method.
-- This method needs to be exported as shown below, with the exported name
-- being "mdlInitializeSizes".
--
procedure mdlInitializeSizes(S : in SimStruct);
pragma Export(C, mdlInitializeSizes, "mdlInitializeSizes");

procedure mdlOutputs(S : in SimStruct; TID : in Integer);
pragma Export(C, mdlOutputs, "mdlOutputs");

end Times_Two;
```

The package specification begins by specifying that the S-function uses the Simulink package.

```
with Simulink; use Simulink;
```

The Simulink package defines Ada procedures for accessing the internal data structure (SimStruct) that Simulink maintains for each S-function (see Chapter 9, “SimStruct Functions — By Category”).

Next the specification specifies the name of the S-function.

```
S_FUNCTION_NAME : constant String := "ada_times_two";
```

The name `ada_times_two` serves to distinguish the MEX-file generated from Ada source from those generated from the `times_two` source coded in other languages.

Finally the specification specifies the callback methods implemented by the `times_two` S-function.

```
procedure mdlInitializeSizes(S : in SimStruct);
pragma Export(C, mdlInitializeSizes, "mdlInitializeSizes");

procedure mdlOutputs(S : in SimStruct; TID : in Integer);
pragma Export(C, mdlOutputs, "mdlOutputs");
```

The specification specifies that the Ada compiler should compile each method as a C-callable function. This is because the Simulink engine assumes that callback methods are C functions.

Note When building an Ada S-function, the MATLAB mex tool uses the package specification to determine the callbacks that the S-function does not implement. It then generates stubs for the nonimplemented methods.

Times_two Package Body

The times_two package body, times_two.adb, contains

```

with Simulink; use Simulink;
with Ada.Exceptions; use Ada.Exceptions;

package body Times_Two is

  -- Function: mdlInitializeSizes -----
  -- Abstract:
  --   Setup the input and output port attributes for this S-Function.
  --
  procedure mdlInitializeSizes(S : in SimStruct) is

  begin
    -- Set the input port attributes
    --
    ssSetNumInputPorts(      S, 1);
    ssSetInputPortWidth(    S, 0, DYNAMICALLY_SIZED);
    ssSetInputPortDataType( S, 0, SS_DOUBLE);
    ssSetInputPortDirectFeedThrough(S, 0, TRUE);
    ssSetInputPortOverWritable(  S, 0, FALSE);
    ssSetInputPortOptimizationLevel(S, 0, 3);

    -- Set the output port attributes
    --
    ssSetNumOutputPorts(      S, 1);
    ssSetOutputPortWidth(    S, 0, DYNAMICALLY_SIZED);
    ssSetOutputPortDataType( S, 0, SS_DOUBLE);
    ssSetOutputPortOptimizationLevel(S, 0, 3);

    -- Set the block sample time.
    ssSetSampleTime(          S, INHERITED_SAMPLE_TIME);

  exception
    when E : others =>
      if ssGetErrorStatus(S) = "" then
        ssSetErrorStatus(S,
          "Exception occurred in mdlInitializeSizes. " &
          "Name: " & Exception_Name(E) & ", " &

```



```

        "Message: " & Exception_Message(E) & " and " &
        "Information: " & Exception_Information(E));
    end if;
end mdlInitializeSizes;

-- Function: mdlOutputs -----
-- Abstract:
--     Compute the S-Function's output, given its input:  $y = 2 * u$ 
--
procedure mdlOutputs(S : in SimStruct; TID : in Integer) is

    uWidth : Integer := ssGetInputPortWidth(S,0);
    U      : array(0 .. uWidth-1) of Real_T;
    for U'Address use ssGetInputPortSignalAddress(S,0);

    yWidth : Integer := ssGetOutputPortWidth(S,0);
    Y      : array(0 .. yWidth-1) of Real_T;
    for Y'Address use ssGetOutputPortSignalAddress(S,0);

begin
    if uWidth = 1 then
        for Idx in 0 .. yWidth-1 loop
            Y(Idx) := 2.0 * U(0);
        end loop;
    else
        for Idx in 0 .. yWidth-1 loop
            Y(Idx) := 2.0 * U(Idx);
        end loop;
    end if;

exception
    when E : others =>
        if ssGetErrorStatus(S) = "" then
            ssSetErrorStatus(S,
                "Exception occurred in mdlOutputs. " &
                "Name: " & Exception_Name(E) & ", " &
                "Message: " & Exception_Message(E) & " and " &
                "Information: " & Exception_Information(E));
        end if;
end if;

```

```
end mdlOutputs;
```

```
end Times_Two;
```

The package body contains implementations of the callback methods needed to implement the `times_two` example.

mdlInitializeSizes

Simulink calls `mdlInitializeSizes` to inquire about the number of input and output ports, the sizes of the ports, and any other objects (such as the number of states) needed by the S-function.

The `times_two` implementation of `mdlInitializeSizes` uses `SimStruct` functions defined in the Simulink package to specify the following size information:

- One input port and one output port

The widths of the input and output port are dynamically sized. This tells Simulink that the S-function can accept a signal of any width. Note that the default handling for dynamically sized S-functions for this case (one input and one output) is that the input and output widths are equal.

- One sample time

Finally the method provides an exception handler to handle any errors that occur in invoking the `SimStruct` functions.

mdlOutputs

Simulink calls `mdlOutputs` at each time step to calculate a block's outputs. The `times_two` implementation of `mdlOutputs` takes the input, multiplies it by 2, and writes the answer to the output.

The `times_two` implementation of the `mdlOutputs` method uses the `SimStruct` functions `ssGetInputPortWidth` and `ssGetInputPortSignalAddress` to access the input signal.

```
uWidth : Integer := ssGetInputPortWidth(S,0);  
U       : array(0 .. uWidth-1) of Real_T;
```

```
for U'Address use ssGetInputPortSignalAddress(S,0);
```

Similarly, the `mdlOutputs` method uses the functions `ssGetOutputPortWidth` and `ssGetOutputPortSignalAddress` to access the output signal.

```
yWidth : Integer := ssGetOutputPortWidth(S,0);  
Y      : array(0 .. yWidth-1) of Real_T;  
for Y'Address use ssGetOutputPortSignalAddress(S,0);
```

Finally the method loops over the inputs to compute the outputs.

Building the `times_two` Example

To build this S-function into Simulink, enter

```
mex -ada times_two.abs
```

at the command line.

Creating Fortran S-Functions

Level 1 Versus Level 2 S-Functions
(p. 6-2)

Overview of approaches to writing Fortran S-functions.

Creating Level 1 Fortran S-Functions (p. 6-3)

Describes a purely Fortran approach to creating an S-function.

Creating Level 2 Fortran S-Functions (p. 6-8)

Describes a hybrid C/Fortran approach to writing an S-function that enables creation of more capable blocks.

Porting Legacy Code (p. 6-19)

How to wrap an S-function around existing Fortran code.

Level 1 Versus Level 2 S-Functions

There are two main strategies to executing Fortran code from Simulink. One is from a Level 1 Fortran-MEX (F-MEX) S-function, the other is from a Level 2 gateway S-function written in C. Each has its advantages and both can be incorporated into code generated by Real-Time Workshop. To have complete code generation with Real-Time Workshop, you must inline the Fortran S-function. See “Inlining S-Functions” in the Target Language Compiler documentation for more information.

The original S-function interface was called the Level 1 API. As the capabilities of Simulink grew, the S-function API was rearchitected into the more extensible Level 2 API. This allows S-functions to have all the capabilities of a full Simulink model (except automatic algebraic loop identification and solving) and to grow as Simulink grows.

Note The Level 1 API supports creation of S-functions having only continuous sample time. If you want to create a Fortran S-function with a discrete sample time, you must use the Level 2 API.

Creating Level 1 Fortran S-Functions

In this section...

“Fortran MEX Template File” on page 6-3

“Example of a Level 1 Fortran S-Function” on page 6-3

“Inline Code Generation Example” on page 6-6

Fortran MEX Template File

A template file for Fortran MEX S-functions is located at *matlabroot/simulink/src/sfuntmpl_fortran.F*. The template file compiles as is and copies the input to the output.

To use the template to create a new Fortran S-function:

- 1 Create a copy under another filename.
- 2 Edit the copy to perform the operations you need.
- 3 Compile the edited file into a MEX-file, using the `mex` command.
- 4 Include the MEX-file in your model, using the S-Function block.

Example of a Level 1 Fortran S-Function

The example file, *matlabroot/simulink/src/sfun_timestwo_for.F*, implements an S-function that multiplies its input by 2.

```

C
C File:  SFUN_TIMESTWO_FOR.F
C
C Abstract:
C     A sample Level 1 FORTRAN representation of a
C     timestwo S-function.
C
C     The basic mex command for this example is:
C
C     >> mex sfun_timestwo_for.F simulink.F
C

```

```
C      Copyright 1990-2002 The MathWorks, Inc.
C
C
C
C=====
C      Function:  SIZES
C
C      Abstract:
C      Set the size vector.
C
C      SIZES returns a vector which determines model
C      characteristics. This vector contains the
C      sizes of the state vector and other
C      parameters. More precisely,
C      SIZE(1) number of continuous states
C      SIZE(2) number of discrete states
C      SIZE(3) number of outputs
C      SIZE(4) number of inputs
C      SIZE(5) number of discontinuous roots in
C              the system
C      SIZE(6) set to 1 if the system has direct
C              feedthrough of its inputs,
C              otherwise 0
C
C=====
C
C      SUBROUTINE SIZES(SIZE)
C      .. Array arguments ..
C      INTEGER*4      SIZE(*)
C      .. Parameters ..
C      INTEGER*4      NSIZES
C      PARAMETER      (NSIZES=6)
C
C      SIZE(1) = 0
C      SIZE(2) = 0
C      SIZE(3) = 1
C      SIZE(4) = 1
C      SIZE(5) = 0
C      SIZE(6) = 1
```



```
        RETURN
        END

C
C=====
C
C      Function:  OUTPUT
C
C      Abstract:
C      Perform output calculations for continuous
C      signals.
C
C=====
C      .. Parameters ..
      SUBROUTINE OUTPUT(T, X, U, Y)
      REAL*8          T
      REAL*8          X(*), U(*), Y(*)

      Y(1) = U(1) * 2.0

      RETURN
      END

C
C=====
C
C      Stubs for unused functions.
C
C=====

      SUBROUTINE INITCOND(X0)
      REAL*8          X0(*)
C --- Nothing to do.
      RETURN
      END

      SUBROUTINE DERIVS(T, X, U, DX)
      REAL*8          T, X(*), U(*), DX(*)
C --- Nothing to do.
      RETURN
```

```
END

SUBROUTINE DSTATES(T, X, U, XNEW)
REAL*8      T, X(*), U(*), XNEW(*)
C --- Nothing to do.
RETURN
END

SUBROUTINE DOUTPUT(T, X, U, Y)
REAL*8      T, X(*), U(*), Y(*)
C --- Nothing to do.
RETURN
END

SUBROUTINE TSAMPL(T, X, U, TS, OFFSET)
REAL*8      T,TS,OFFSET,X(*),U(*)
C --- Nothing to do.
RETURN
END

SUBROUTINE SINGUL(T, X, U, SING)
REAL*8      T, X(*), U(*), SING(*)
C --- Nothing to do.
RETURN
END
```

A Level 1 S-function's input/output is limited to using the REAL*8 data type, (DOUBLE PRECISION), which is equivalent to a double in C. Of course, the internal calculations can use whatever data types you need.

To see how this S-function works, enter

```
sfcndemo_timestwo_for
```

at the MATLAB prompt and run the model.

Inline Code Generation Example

Real-Time Workshop users can use the sample block target file `matlabroot/toolbox/simulink/blocks/tlc_c/sfun_timestwo_for.tlc` to

generate inlined code for `sfcndemo_timestwo_for.mdl`. If you want to learn how to inline your own Fortran MEX-file, see “Inlining S-Functions” in the Real-Time Workshop Target Language Compiler documentation.

Creating Level 2 Fortran S-Functions

In this section...
“About Creating Level 2 Fortran S-Functions” on page 6-8
“Template File” on page 6-8
“C/Fortran Interfacing Tips” on page 6-8
“Constructing the Gateway” on page 6-13
“Example C MEX S-Function Calling Fortran Code” on page 6-16

About Creating Level 2 Fortran S-Functions

To use the features of a level 2 S-function with Fortran code, you must write a skeleton S-function in C that has code for interfacing to Simulink and also calls your Fortran code.

Using the C MEX S-function as a gateway is quite simple if you are writing the Fortran code from scratch. If instead your Fortran code already exists as a stand-alone simulation, there is some work to be done to identify parts of the code that need to be registered with Simulink, such as identifying continuous states if you are using variable-step solvers or getting rid of static variables if you want to have multiple copies of the S-function in a Simulink model (see “Porting Legacy Code” on page 6-19).

Template File

The file `sfuntmpl_gate_fortran.c` contains a template for creating a C MEX-file S-function that invokes a Fortran subroutine in its `mdlOutputs` method. It works with a simple Fortran subroutine if you modify the Fortran subroutine name in the code.

C/Fortran Interfacing Tips

The following are some tips for creating the C-to-Fortran gateway S-function.

MEX Environment

Remember that `mex -setup` needs to find both the MATLAB C and the Fortran compilers, but it can work with only one of these compilers at a time. If you install or change compilers, you must run `mex -setup` between other `mex` commands.

Test the installation and setup using sample MEX-files from the MATLAB C and Fortran MEX examples in `matlabroot/extern/examples/mex`, as well as Simulink examples, which are located in `matlabroot/simulink/src`.

If using a C compiler on Windows, test the `mex` setup using the following commands and the example C source code file, `yprime.c`, in `matlabroot\extern\examples\mex`.

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

If using a Fortran compiler, test the `mex` setup using the following commands and the example Fortran source code files, `yprime.F` and `yprimefg.F`, in `matlabroot\extern\examples\mex`.

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

For more information, see [Building MEX-Files in the MATLAB External Interfaces documentation](#).

Compiler Compatibility

Your C and Fortran compilers need to use the same object format. If you use the compilers explicitly supported by the `mex` command this is not a problem. When you use the C gateway to Fortran, it is possible to use Fortran compilers not supported by the `mex` command, but only if the object file format is compatible with the C compiler format. Common object formats include ELF and COFF.

The compiler must also be configurable so that the caller cleans up the stack instead of the callee. Compaq Visual Fortran (formerly known as Digital Fortran) is one compiler whose default stack cleanup is the callee. However, **Intel** Visual Fortran (the replacement for Compaq Visual Fortran) has the default stack cleanup as the caller.

Symbol Decorations

Symbol decorations can cause run-time errors. For example, g77 decorates subroutine names with a trailing underscore when in its default configuration. You can either recognize this and adjust the C function prototype or alter the Fortran compiler's name decoration policy via command-line switches, if the compiler supports this. See the Fortran compiler manual about altering symbol decoration policies.

If all else fails, use utilities such as `od` (octal dump) to display the symbol names. For example, the command

```
od -s 2 <file>
```

lists strings and symbols in binary (`.obj`) files.

These binary utilities can be obtained for Windows as well. MKS is one company that has commercial versions of powerful UNIX utilities, although most can also be obtained free on the Web. `hexdump` is another common program for viewing binary files. As an example, here is the output of

```
od -s 2 sfun_atmos_for.o
```

on Linux.

```
0000115 E€
0000136 E€
0000271 E€
0000467 `E€@
0000530 `E€
0000575 E€ E 5@
0001267 Cf VC- :C
0001323 :|. -:8~ #8 Kw6
0001353 ?333@
0001364 333
0001414 01.01
0001425 GCC: (GNU) egcs-2.91.66 19990314/Linux
0001522 .symtab
0001532 .strtab
0001542 .shstrtab
0001554 .text
```

```
0001562 .rel.text
0001574 .data
0001602 .bss
0001607 .note
0001615 .comment
0003071 sfun_atmos_for.for
0003101 gcc2_compiled.
0003120 rearth.0
0003131 gmr.1
0003137 htab.2
0003146 ttab.3
0003155 ptab.4
0003164 gtab.5
0003173 atmos_
0003207 exp
0003213 pow_d
```

Note that Atmos has been changed to `atmos_`, which the C program must call to be successful.

With Compaq Visual Fortran and Intel Visual Fortran on 32-bit Windows machines, the symbol is suppressed, so that Atmos becomes ATMOS (no underscore).

Fortran Math Library

Fortran math library symbols might not match C math library symbols. For example, A^B in Fortran calls library function `pow_dd`, which is not in the C math library. In these cases, you must tell `mex` to link in the Fortran math library. For gcc environments, these routines are usually found in `/usr/local/lib/libf2c.a`, `/usr/lib/libf2c.a`, or equivalent.

The `mex` command becomes

```
mex -L/usr/local/lib -lf2c cmex_c_file fortran_object_file
```

Note On UNIX, the `-lf2c` option follows the conventional UNIX library linking syntax, where `-l` is the library option itself and `f2c` is the unique part of the library file's name, `libf2c.a`. Be sure to use the `-L` option for the library search path, because `-I` is only followed while searching for include files.

The `f2c` package can be obtained for Windows and UNIX environments from the Internet. The file `libf2c.a` is usually part of `g77` distributions, or else the file is not needed as the symbols match. In obscure cases, it must be installed separately, but even this is not difficult once the need for it is identified.

On 32-bit Windows machines, using Microsoft Visual C/C++ and Compaq Visual Fortran 6.0 (formerly known as Digital Fortran), this example can be compiled using the following `mex` commands (each command is on one line and `matlabroot` should be replaced with the path to the MATLAB root directory. Note that `mex -setup` must be run to return to the C compiler before executing the second command. `DF_ROOT` is the name of the system's environment variable that points to the Compaq Visual Fortran root directory and may vary on different computers.)

```
mex -v COMPFLAGS#" $COMPFLAGS /iface:cref" -c sfun_atmos_sub.F
-f matlabroot\bin\win32\mexopts\cvf66opts.bat
!mex -v LINKFLAGS#" $LINKFLAGS dformd.lib dfconsol.lib dfport.lib
/LIBPATH:$DF_ROOT\DF98\LIB" sfun_atmos.c sfun_atmos_sub.obj
```

On 32-bit Windows machines, using Microsoft Visual C/C++ and Intel® Visual Fortran 9.0 (formerly known as Compaq Visual Fortran), this example can be compiled using the following `mex` commands (each command is on one line).

```
mex -v -c sfun_atmos_sub.F -f ..\..\bin\win32\mexopts\
intelf90opts.bat
!mex -v -L"%IFORT_COMPILER90%\IA32\LIB" -llibifcoremd
-lifconsol -lifportmd -llibmmd -llibirc sfun_atmos.c
sfun_atmos_sub.obj
```

On 64-bit Windows machines, using Microsoft Visual C/C++ and Intel® Visual Fortran 9.0 (formerly known as Compaq Visual Fortran), this example can be compiled using the following `mex` commands (each command is on one line).

```
mex -v -c sfun_atmos_sub.F -f ..\..\bin\win64\mexopts\
```



```
intelf90opts.bat
!mex -v -L"%IFORT_COMPILER90%\EM64T\LIB" -llibifcoremd
-lifconsol -lifportmd -llibmmd -llibirc sfun_atmos.c
sfun_atmos_sub.obj
```

CFortran

Or you can try using CFortran to create an interface. CFortran is a tool for automated interface generation between C and Fortran modules, in either direction. Search the Web for cfortran or visit

<http://www-zeus.desy.de/~burow/cfortran/>

for downloading.

Obtaining a Fortran Compiler

On Windows, using Visual C/C++ with Fortran is best done with Intel® Visual Fortran, Compaq Visual Fortran, Absoft, Lahey, or other third-party compilers. See Intel (www.intel.com) for Windows and Linux compilers, see Absoft (www.absoft.com) for Windows, Linux, and Sun compilers, and see Lahey (www.lahey.com) for more choices in Windows Fortran compilers.

For Sun (Solaris) and other commercial UNIX platforms, you can purchase the computer vendor's Fortran compiler, a third-party Fortran such as Absoft, or even use the Gnu Fortran port for that platform (if available).

As long as the compiler can output the same object (.o) format as the platform's C compiler, the Fortran compiler will work with the gateway C MEX S-function technique.

Gnu Fortran (g77) can be obtained free for several platforms from many download sites, including [tap://www.redhat.com](http://www.redhat.com) in the download area. A useful keyword on search engines is g77.

Constructing the Gateway

The `mdlInitializeSizes()` and `mdlInitializeSampleTimes()` methods are coded in C. It is unlikely that you will need to call Fortran routines from

these S-function methods. In the simplest case, the Fortran is called only from `mdlOutputs()`.

Simple Case

The Fortran code must at least be callable in one-step-at-a-time fashion. If the code doesn't have any states, it can be called from `mdlOutputs()` and no `mdlDerivatives()` or `mdlUpdate()` method is required.

Code with States

If the code has states, you must decide whether the Fortran code can support a variable-step solver or not. For fixed-step solver only support, the C gateway consists of a call to the Fortran code from `mdlUpdate()`, and outputs are cached in an S-function `DWork` vector so that subsequent calls by Simulink into `mdlOutputs()` will work properly and the Fortran code won't be called until the next invocation of `mdlUpdate()`. In this case, the states in the code can be stored however you like, typically in the work vector or as discrete states in Simulink.

If instead the code needs to have continuous time states with support for variable-step solvers, the states must be registered and stored with Simulink as doubles. You do this in `mdlInitializeSizes()` (registering states), then the states are retrieved and sent to the Fortran code whenever you need to execute it. In addition, the main body of code has to be separable into a call form that can be used by `mdlDerivatives()` to get derivatives for the state integration and also by the `mdlOutputs()` and `mdlUpdate()` methods as appropriate.

Setup Code

If there is a lengthy setup calculation, it is best to make this part of the code separable from the one-step-at-a-time code and call it from `mdlStart()`. This can either be a separate SUBROUTINE called from `mdlStart()` that communicates with the rest of the code through COMMON blocks or argument I/O, or it can be part of the same piece of Fortran code that is isolated by an IF-THEN-ELSE construct. This construct can be triggered by one of the input arguments that tells the code if it is to perform either the setup calculations or the one-step calculations.

SUBROUTINE Versus PROGRAM

To be able to call Fortran from Simulink directly without having to launch processes, etc., you must convert a Fortran PROGRAM into a SUBROUTINE. This consists of three steps. The first is trivial; the second and third can take a bit of examination.

- 1** Change the line PROGRAM to SUBROUTINE subName.

Now you can call it from C using C function syntax.

- 2** Identify variables that need to be inputs and outputs and put them in the SUBROUTINE argument list or in a COMMON block.

It is customary to strip out all hard-coded cases and output dumps. In the Simulink environment, you want to convert inputs and outputs into block I/O.

- 3** If you are converting a stand-alone simulation to work inside Simulink, identify the main loop of time integration and remove the loop and, if you want Simulink to integrate continuous states, remove any time integration code. Leave time integrations in the code if you intend to make a discrete time (sampled) S-function.

Arguments to a SUBROUTINE

Most Fortran compilers generate SUBROUTINE code that passes arguments by reference. This means that the C code calling the Fortran code must use only pointers in the argument list.

```
PROGRAM ...
```

becomes

```
SUBROUTINE somename( U, X, Y )
```

A SUBROUTINE never has a return value. You manage I/O by using some of the arguments for input, the rest for output.

Arguments to a FUNCTION

A FUNCTION has a scalar return value passed by value, so a calling C program should expect this. The argument list is passed by reference (i.e., pointers) as in the SUBROUTINE.

If the result of a calculation is an array, then you should use a subroutine, as a FUNCTION cannot return an array.

Interfacing to COMMON Blocks

While there are several ways for Fortran COMMON blocks to be visible to C code, it is often recommended to use an input/output argument list to a SUBROUTINE or FUNCTION. If the Fortran code has already been written and uses COMMON blocks, it is a simple matter to write a small SUBROUTINE that has an input/output argument list and copies data into and out of the COMMON block.

The procedure for copying in and out of the COMMON block begins with a write of the inputs to the COMMON block before calling the existing SUBROUTINE. The SUBROUTINE is called, then the output values are read out of the COMMON block and copied into the output variables just before returning.

Example C MEX S-Function Calling Fortran Code

The S-function demo `sfcn_demo_atmos.mdl` contains an example of a C MEX S-function calling a Fortran subroutine. The Fortran subroutine `Atmos` is in the file `matlabroot/simulink/src/sfun_atmos_sub.F`. This subroutine calculates the standard atmosphere up to 86 kilometers. The subroutine has four arguments.

```
SUBROUTINE Atmos(alt, sigma, delta, theta)
```

The gateway C MEX S-function, `matlabroot/simulink/src/sfun_atmos.c`, declares the Fortran subroutine.

```
/*
 * Windows uses upper case for Fortran external symbols
 */
#ifdef _WIN32
#define atmos_ ATMOS
#endif
```

```
extern void atmos_(float *alt,
                  float *sigma,
                  float *delta,
                  float *theta);
```

The `mdlOutputs` method calls the Fortran subroutine using pass-by-reference for the arguments.

```
/* call the Fortran routine using pass-by-reference */
atmos_(&falt, &fsigma, &fdelta, &ftheta);
```

To see this example working in the sample model `sfcndemo_atmos.mdl`, enter the following command at the MATLAB prompt.

```
sfcndemo_atmos
```

Building Gateway C MEX S-Functions on a Windows System

On 32-bit Windows systems using Microsoft Visual C/C++ and Compaq Visual Fortran 6.6., you need to use separate commands to compile the Fortran file and then link it to the C gateway file. Each command is on one line.

- 1 Run `mex -setup` and select a Fortran compiler.
- 2 Compile the Fortran file using the following command.

```
mex -v COMPFLAGS#"$COMPFLAGS /iface:cref" -c
sfun_atmos_sub.F -f matlabroot\bin\win32\mexopts\cvf66opts.bat
```

- 3 Rerun `mex -setup` and select a C compiler.
- 4 Link the compiled Fortran subroutine to the gateway C MEX S-function using the following command. `DF_ROOT` is the name of the system's environment variable that points to the Compaq Visual Fortran root directory and may vary on different systems.

```
!mex -v LINKFLAGS#"$LINKFLAGS dformd.lib dfconsol.lib
dfport.lib/LIBPATH:$DF_ROOT\DF98\LIB" sfun_atmos.c
sfun_atmos_sub.obj
```

If the linker finds multiple C libraries, you might need to add the option `/NODEFAULTLIB:libc.lib` to the command to avoid an error. For example:

```
!mex -v /NODEFAULTLIB:libc.lib LINKFLAGS#"$LINKFLAGS
dformd.lib dfconsol.lib dfport.lib /LIBPATH:$DF_ROOT\DF98\LIB"
sfun_atmos.c sfun_atmos_sub.obj.
```

Building Gateway C MEX S-Functions on a UNIX System

Build the gateway on UNIX using the command

```
mex sfun_atmos.c sfun_atmos_sub.o
```

On some UNIX systems where the C and Fortran compilers were installed separately (or are not aware of each other), you might need to reference the library `libf2c.a`. To do this, use the `-lf2c` flag.

If the `libf2c.a` library is not on the library path, you need to add the path to the `mex` process explicitly with the `-L` command. For example:

```
mex -L/usr/local/lib/ -lf2c sfun_atmos.c sfun_atmos_sub.o
```

Porting Legacy Code

In this section...
“Find the States” on page 6-19
“Sample Times” on page 6-20
“Multiple Instances” on page 6-20
“Use Flints if Needed” on page 6-20
“Considerations for Real Time” on page 6-20

Find the States

If a variable-step solver is being used, it is critical that all continuous states are identified in the code and put into the Simulink state vector for integration instead of being integrated by the Fortran code. Likewise, all derivative calculations must be made available separately to be called from the `mdlDerivatives()` method in the S-function. Without these steps, any Fortran code with continuous states will not be compatible with variable-step solvers if the S-function is registered as a continuous block with continuous states.

Telltale signs of implicit advancement are incremented variables such as $M=M+1$ or $X=X+0.05$. If the code has many of these constructs and you determine that it is impractical to recode the source so as not to “ratchet forward,” you might need to try another approach using fixed-step solvers.

If it is impractical to find all the implicit states and to separate out the derivative calculations for Simulink, another approach can be used, but you are limited to using fixed-step solvers. The technique here is to call the Fortran code from the `mdlUpdate()` method so the Fortran code is only executed once per Simulink major integration step. Any block outputs must be cached in a work vector so that `mdlOutputs()` can be called as often as needed and output the values from the work vector instead of calling the Fortran routine again (causing it to inadvertently advance time). See `matlabroot/simulink/src/sfuntmpl_gate_fortran.c` for an example that uses `DWork` vectors.

Sample Times

If the code has an implicit step size in its algorithm, coefficients, etc., ensure that you register the proper discrete sample time in the `mdlInitializeSampleTimes()` S-function method and only change the block's output values from the `mdlUpdate()` method.

Multiple Instances

If you plan to have multiple copies of this S-function used in one Simulink model, you need to allocate storage for each copy of the S-function in the model. The recommended approach is to use DWork vectors. See *matlabroot/simulink/include/simstruc.h* and *matlabroot/simulink/src/sfuntmpl_doc.c* for details on allocating data-typed work vectors.

Use Flints if Needed

Use flints (floating-point ints) to keep track of time. Flints (for IEEE-754 floating-point numerics) have the useful property of not accumulating roundoff error when adding and subtracting flints. Using flint variables in DOUBLE PRECISION storage (with integer values) avoids roundoff error accumulation that would accumulate when floating-point numbers are added together thousands of times.

```
DOUBLE PRECISION F
      :
      :
F = F + 1.0
TIME = 0.003 * F
```

This technique avoids a common pitfall in simulations.

Considerations for Real Time

Since very few Fortran applications are used in a real-time environment, it is common to come across simulation code that is incompatible with a real-time environment. Common failures include unbounded (or large) iterations and sporadic but time-intensive side calculations. You must deal with these directly if you expect to run in real time.

Conversely, it is still perfectly good practice to have iterative or sporadic calculations if the generated code is not being used for a real-time application.

Implementing Block Features

Dialog Parameters (p. 7-2)	How to process parameters passed via the S-function block's dialog box.
Run-Time Parameters (p. 7-7)	How to create and use run-time parameters.
Creating Input and Output Ports (p. 7-16)	How to create input and output ports on a block.
Custom Data Types (p. 7-24)	How to create custom data types for the values of a block's signals and parameters.
Sample Times (p. 7-26)	How to specify the rate or rates at which your block operates.
Work Vectors (p. 7-42)	How to create and use work vectors.
Function-Call Subsystems (p. 7-50)	How to create a function-call subsystem.
Sim Viewing Devices in External Mode (p. 7-55)	How to create a sim viewing device for use in external mode.
Processing Frame-Based Signals (p. 7-56)	How to create an S-function that process frame-based signals.
Handling Errors (p. 7-59)	How to handle errors in an S-function.
S-Function Examples (p. 7-63)	Examples of S-functions.

Dialog Parameters

In this section...

“About Dialog Parameters” on page 7-2

“Tunable Parameters” on page 7-4

About Dialog Parameters

A user can pass parameters to an S-function at the start of and, optionally, during the simulation, using the **S-Function parameters** field of the block’s dialog box. Such parameters are called *dialog box parameters* to distinguish them from run-time parameters created by the S-function to facilitate code generation (see “Run-Time Parameters” on page 7-7). Simulink stores the values of the dialog box parameters in the S-function’s SimStruct structure. Simulink provides callback methods and SimStruct macros that allow the S-function to access and check the parameters and use them in the computation of the block’s output.

If you want your S-function to be able to use dialog parameters, you must perform the following steps when you create the S-function:

- 1 Determine the order in which the parameters are to be specified in the block’s dialog box.
- 2 Access these input arguments in the S-function using the `ssGetSFcnParam` macro.

Specify `S` as the first argument and the relative position of the parameter in the list entered on the dialog box (0 is the first position) as the second argument. The `ssGetSFcnParam` macro returns a pointer to the `mxAarray` containing the parameter. You can use `ssGetDTypeIdFromMxAarray` to get the data type of the parameter.

For example, in `matlabroot/simulink/src/sfun_runtime1.c`, the following `#define` statements at the beginning of the S-function specify the order of three dialog box parameters and access their values on the block’s dialog.

```
#define SIGNS_IDX 0
```

```

#define SIGNS_PARAM(S) ssGetSFcnParam(S,SIGNS_IDX) /* First parameter */

#define GAIN_IDX 1
#define GAIN_PARAM(S) ssGetSFcnParam(S,GAIN_IDX) /* Second parameter */

#define OUT_IDX 2
#define OUT_PARAM(S) ssGetSFcnParam(S,OUT_IDX) /* Third parameter */

```

- 3** In the `mdlInitializeSizes` function, use the `ssSetNumSFcnParams` macro to tell Simulink how many parameters the S-function accepts. Specify `S` as the first argument and the number of parameters you are defining interactively as the second argument. If your S-function implements the `mdlCheckParameters` method, the `mdlInitializeSizes` routine should call `mdlCheckParameters` to check the validity of the initial values of the parameters. For example, the `mdlInitializeSizes` function in `sfun_runtime1.c` begins with the following code.

```

ssSetNumSFcnParams(S, NPARAMS); /* Number of expected parameters */
#ifdef MATLAB_MEX_FILE
    if (ssGetNumSFcnParams(S) == ssGetSFcnParamsCount(S)) {
        mdlCheckParameters(S);
        if (ssGetErrorStatus(S) != NULL) {
            return;
        }
    } else {
        return; /* Parameter mismatch will be reported by Simulink */
    }
#endif

```

When running a simulation, the user must specify the parameters in the **S-Function parameters** field of the block's dialog box in the same order that you defined them in step 1. The user can enter any valid MATLAB expression as the value of a parameter, including literal values, names of workspace variables, function invocations, or arithmetic expressions. Simulink evaluates the expression and passes its value to the S-function.

Note You cannot use the Model Explorer, the S-Function block dialog box, or a mask to tune the parameters of a source S-function, i.e., an S-function that has outputs but no inputs, while a simulation is running. See “Changing Source Block Parameters During Simulation” for more information.

As another example, the following code is part of a device driver S-function. Four input parameters are used: `BASE_ADDRESS_PRM`, `GAIN_RANGE_PRM`, `PROG_GAIN_PRM`, and `NUM_OF_CHANNELS_PRM`. The code uses `#define` statements at the top of the S-function to associate particular input arguments with the parameter names.

```
/* Input Parameters */
#define BASE_ADDRESS_PRM(S)      ssGetSFcnParam(S, 0)
#define GAIN_RANGE_PRM(S)       ssGetSFcnParam(S, 1)
#define PROG_GAIN_PRM(S)        ssGetSFcnParam(S, 2)
#define NUM_OF_CHANNELS_PRM(S)  ssGetSFcnParam(S, 3)
```

When running the simulation, a user enters four variable names or values in the **S-Function parameters** field of the block’s dialog box. The first corresponds to the first expected parameter, `BASE_ADDRESS_PRM(S)`. The second corresponds to the next expected parameter, and so on.

The `mdlInitializeSizes` function contains this statement.

```
ssSetNumSFcnParams(S, 4);
```

Tunable Parameters

Dialog parameters can be either tunable or nontunable. A tunable parameter is a parameter that a user can change while the simulation is running. Use the macro `ssSetSFcnParamTunable` in `mdlInitializeSizes` to specify the tunability of each dialog parameter used by the macro.

Note Dialog box parameters are tunable by default. Nevertheless, it is good programming practice to set the tunability of every parameter, even those that are tunable. If the user enables the simulation diagnostic S-function upgrade needed, Simulink issues the diagnostic whenever it encounters an S-function that fails to specify the tunability of all its parameters.

The `mdlCheckParameters` method enables you to validate changes to tunable parameters during a simulation run. Simulink invokes the `mdlCheckParameters` method whenever a user changes the values of parameters during the simulation loop. This method should check the S-function's dialog parameters to ensure that the changes are valid.

Note The S-function's `mdlInitializeSizes` routine should also invoke the `mdlCheckParameters` method to ensure that the initial values of the parameters are valid.

The example code below is taken from the `mdlInitializeSizes` function found in the example `matlabroot/simulink/src/sfun_runtime1.c`. The code first sets the number of S-function dialog box parameters to three before invoking `mdlCheckParameters`. If the parameter check passes, the tunability of the three S-function dialog box parameters is specified.

```

ssSetNumSFcnParams(S, 3); /* Three dialog box parameters*/

#ifdef MATLAB_MEX_FILE
    if (ssGetNumSFcnParams(S) == ssGetSFcnParamsCount(S)) {
        mdlCheckParameters(S);
        if (ssGetErrorStatus(S) != NULL) {
            return;
        }
    } else {
        return; /* Parameter mismatch will be reported by Simulink */
    }
#endif

ssSetSFcnParamTunable(S,GAIN_IDX,true); /* Tunable */

```

```
ssSetSFcnParamTunable(S,SIGNS_IDX,false); /* Not tunable */  
ssSetSFcnParamTunable(S,OUT_IDX,false); /* Not tunable */
```

The optional `mdlProcessParameters` callback method allows an S-function to process changes to tunable parameters. Simulink invokes this method only if valid parameter changes have occurred in the previous time step. A typical use of this method is to perform computations that depend only on the values of parameters and hence need to be computed only when parameter values change. The method can cache the results of the parameter computations in work vectors or, preferably, as run-time parameters (see “Run-Time Parameters” on page 7-7).

Tuning Parameters in External Mode

When a user tunes parameters during simulation, Simulink invokes the S-function’s `mdlCheckParameters` method to validate the changes and then the S-function’s `mdlProcessParameters` method to give the S-function a chance to process the parameters in some way. Simulink also invokes these methods when running in external mode, but it passes the unprocessed changes on to the S-function target. Thus, if it is essential that your S-function process parameter changes, you need to create a Target Language Compiler (TLC) file that inlines the S-function, including its parameter processing code, during the code generation process. For information on inlining S-functions, see “Inlining S-Functions” in the *Target Language Compiler Reference Guide*.

Run-Time Parameters

In this section...

“About Run-Time Parameters” on page 7-7

“Creating Run-Time Parameters” on page 7-8

“Updating Run-Time Parameters” on page 7-14

“Tuning Runtime Parameters” on page 7-15

About Run-Time Parameters

Simulink allows an S-function to create internal representations of external dialog parameters called *run-time parameters*. Every run-time parameter corresponds to one or more dialog parameters and can have the same value and data type as its corresponding external parameters or a different value or data type. If a run-time parameter differs in value or data type from its external counterpart, the dialog parameter is said to have been transformed to create the run-time parameter. The value of a run-time parameter that corresponds to multiple dialog parameters is typically a function of the values of the dialog parameters. Simulink allocates and frees storage for run-time parameters and provides functions for updating and accessing them, thus eliminating the need for S-functions to perform these tasks.

Run-time parameters facilitate the following kinds of S-function operations:

- Computed parameters

Often the output of a block is a function of the values of several dialog parameters. For example, suppose a block has two parameters, the volume and density of some object, and the output of the block is a function of the input signal and the mass of the object. In this case, the mass can be viewed as a third internal parameter computed from the two external parameters, volume and density. An S-function can create a run-time parameter corresponding to the computed weight, thereby eliminating the need to provide special case handling for weight in the output computation. See “Creating Run-Time Parameters from Multiple S-Function Parameters” on page 7-10 for more information.

- Data type conversions

Often a block needs to change the data type of a dialog parameter to facilitate internal processing. For example, suppose that the output of the block is a function of the input and a parameter and the input and parameter are of different data types. In this case, the S-function can create a run-time parameter that has the same value as the dialog parameter but has the data type of the input signal, and use the run-time parameter in the computation of the output.

- Code generation

During code generation, Real-Time Workshop writes all run-time parameters automatically to the *model.rtw* file, eliminating the need for the S-function to perform this task via an mdlRTW method.

The following Simulink model contains three example S-functions that create run-time parameters:

```
matlabroot/toolbox/simulink/simdemos/simfeatures/sfcdemo_runtime.mdl
```

Creating Run-Time Parameters

An S-function can create run-time parameters all at once or one by one.

Creating Run-Time Parameters All at Once

Use the SimStruct function `ssRegAllTunableParamsAsRunTimeParams` in `mdlSetWorkWidths` to create run-time parameters corresponding to all tunable parameters. This function requires that you pass it an array of names, one for each run-time parameter. Real-Time Workshop uses this name as the name of the parameter during code generation. The S-function *matlabroot/simulink/src/sfun_runtime1.c* shows how to create run-time parameters all at once.

Note The first four characters of the names of a block's run-time parameters must be unique. If they are not, Simulink signals an error. For example, trying to register a parameter named `param2` triggers an error if a parameter named `param1` already exists. This restriction allows Real-time Workshop to generate variable names that are unique within a pre-specified number of characters.

This approach to creating run-time parameters assumes that there is a one-to-one correspondence between an S-function's run-time parameters and its tunable dialog parameters. This might not be the case. For example, an S-function might want to use a computed parameter whose value is a function of several dialog parameters. In such cases, the S-function might need to create the run-time parameters individually. See “Creating Run-Time Parameters from Multiple S-Function Parameters” on page 7-10 for an example.

Creating Run-Time Parameters Individually

To create run-time parameters individually, the S-function's `mdlSetWorkWidths` method should

- 1 Specify the number of run-time parameters it intends to use, using `ssSetNumRunTimeParams`.
- 2 Use `ssRegDlgParamAsRunTimeParam` to register a run-time parameter that corresponds to a single dialog parameter, even if there is a data type transformation, or `ssSetRunTimeParamInfo` to set the attributes of a run-time parameter that corresponds to more than one dialog parameter.

The following example uses `ssRegDlgParamAsRunTimeParam` and is taken from the S-function `matlabroot/simulink/src/sfun_runtime3.c`. This example creates a run-time parameter directly from the dialog parameter and with the same data type as the first input port's signal.

```
static void mdlSetWorkWidths(SimStruct *S)
{
    /* Get data type of input to use for run-time parameter */
    DTypeId      dtId      = ssGetInputPortDataType(S, 0);

    /* Define name of run-time parameter */
    const char_T *rtParamName = "Gain";

    ssSetNumRunTimeParams(S, 1); /* One run-time parameter */
    if (ssGetErrorStatus(S) != NULL) return;
    ssRegDlgParamAsRunTimeParam(S, GAIN_IDX, 0, rtParamName, dtId);
}
#ifdef MDL_SET_WORK_WIDTHS *
```

The next example uses `ssSetRunTimeParamInfo` and is taken from the S-function `matlabroot/simulink/src/sfun_runtime2.c`.

```
static void mdlSetWorkWidths(SimStruct *S)
{
    ssParamRec p; /* Initialize an ssParamRec structure */
    int         dlgP = GAIN_IDX; /* Index of S-function parameter */

    /* Configure run-time parameter information */
    p.name           = "Gain";
    p.nDimensions    = 2;
    p.dimensions     = (int_T *) mxGetDimensions(GAIN_PARAM(S));
    p.dataTypeId     = SS_DOUBLE;
    p.complexSignal  = COMPLEX_NO;
    p.data           = (void *)mxGetPr(GAIN_PARAM(S));
    p.dataAttributes = NULL;
    p.nDlgParamIndices = 1;
    p.dlgParamIndices = &dlgP;
    p.transformed    = false;
    p.outputAsMatrix = false;

    /* Set number of run-time parameters */
    if (!ssSetNumRunTimeParams(S, 1)) return;

    /* Set run-time parameter information */
    if (!ssSetRunTimeParamInfo(S, 0, &p)) return;
}
```

The S-function `sfun_runtime2.c` defines the parameters `GAIN_IDX` and `GAIN_PARAM` as follows, prior to using these parameters in `mdlSetWorkWidths`.

```
#define GAIN_IDX 1
#define GAIN_PARAM(S) ssGetSFcnParam(S,GAIN_IDX)
```

Creating Run-Time Parameters from Multiple S-Function Parameters

Use the `ssSetRunTimeParamInfo` function in `mdlSetWorkWidths` to create run-time parameters as a function of multiple S-function parameters. For example, consider an S-function with two S-function parameters, density and volume. The S-function inputs a force (F) and outputs an acceleration (a). The

`mdlOutputs` method calculates the force using the equation $F=M/a$, where the mass (M) is the product of the density and volume.

The S-function `matlabroot/simulink/src/sfun_runtime4.c` implements this example using a single run-time parameter to store the mass. The S-function begins by defining the run-time parameter data type, as well as variables associated with volume and density.

```
#define RUN_TIME_DATA_TYPE SS_DOUBLE
#if RUN_TIME_DATA_TYPE == SS_DOUBLE
typedef real_T RunTimeDataType;
#endif

#define VOL_IDX 0
#define VOL_PARAM(S) ssGetSFcnParam(S,VOL_IDX)

#define DEN_IDX 1
#define DEN_PARAM(S) ssGetSFcnParam(S,DEN_IDX)
```

The `mdlSetWorkWidths` method then initializes the run-time parameter, as follows.

```
static void mdlSetWorkWidths(SimStruct *S)
{
    ssParamRec p; /* Initialize an ssParamRec structure */
    int         dlg[2]; /* Stores dialog indices */
    real_T vol    = *mxGetPr(VOL_PARAM(S));
    real_T den    = *mxGetPr(DEN_PARAM(S));
    RunTimeDataType *mass;

    /* Initialize dimensions for the run-time parameter as a
     * local variable. Simulink makes a copy of this information
     * to store in the run-time parameter. */
    int_T massDims[2] = {1,1};

    /* Allocate memory for the run-time parameter data. The S-function
     * owns this memory location. Simulink does not copy the data. */
    if ((mass=(RunTimeDataType*)malloc(1)) == NULL) {
        ssSetErrorStatus(S,"Memory allocation error");
        return;
    }
}
```

```
/* Store the pointer to the memory location in the S-function
 * userdata. Since the S-function owns this data, it needs to
 * free the memory during mdlTerminate */
ssSetUserData(S, (void*)mass);

/* Call a local function to initialize the run-time
 * parameter data. Simulink checks that the data is not empty
 * so an initial value must be stored. */
calcMass(mass, vol, den);

/* Specify mass as a function of two S-function dialog parameters */
dlg[0] = VOL_IDX;
dlg[1] = DEN_IDX;

/* Configure run-time parameter information. */
p.name          = "Mass";
p.nDimensions   = 2;
p.dimensions    = massDims;
p.dataTypeId    = RUN_TIME_DATA_TYPE;
p.complexSignal = COMPLEX_NO;
p.data          = mass;
p.dataAttributes = NULL;
p.nDlgParamIndices = 2;
p.dlgParamIndices = &dlg
p.transformed   = RTPARAM_TRANSFORMED;
p.outputAsMatrix = false;

/* Set number of run-time parameters */
if (!ssSetNumRunTimeParams(S, 1)) return;

/* Set run-time parameter information */
if (!ssSetRunTimeParamInfo(S,0,&p)) return;

}
```

The local function `calcMass` updates the run-time parameter value in `mdlSetWorkWidths` and in `mdlProcessParameters`, when the values of density or volume are tuned.

```

/* Function: calcMass =====
 * Abstract:
 *     Local function to calculate the mass as a function of volume
 *     and density.
 */
static void calcMass(RunTimeDataType *mass, real_T vol, real_T den)
{
    *mass = vol * den;
}

```

The `mdlOutputs` method uses the stored mass to calculate the force.

```

/* Function: mdlOutputs =====
 * Abstract:
 *
 *     Output acceleration calculated as input force divided by mass.
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    real_T *y1          = ssGetOutputPortRealSignal(S,0);
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);
    RunTimeDataType *mass =
        (RunTimeDataType *)((ssGetRunTimeParamInfo(S,0))->data);

    /*
     * Output acceleration = force / mass
     */
    y1[0] = (*uPtrs[0]) / *mass;
}

```

Lastly, the `mdlTerminate` method frees the memory allocated for the run-time parameter in `mdlSetWorkWidths`.

```

/* Function: mdlTerminate =====
 * Abstract:
 *     Free the user data.
 */
static void mdlTerminate(SimStruct *S)
{
    /* Free memory used to store the run-time parameter data*/
}

```

```
RunTimeDataType *mass = ssGetUserData(S);
if (mass != NULL) {
    free(mass);
}
}
```

To run the example, open the Simulink model:

```
matlabroot/toolbox/simulink/simdemos/simfeatures/sfcdemo_runtime.mdl
```

Updating Run-Time Parameters

Whenever a user changes the values of an S-function's dialog parameters during a simulation run, Simulink invokes the S-function's `mdlCheckParameters` method to validate the changes. If the changes are valid, Simulink invokes the S-function's `mdlProcessParameters` method at the beginning of the next time step. This method should update the S-function's run-time parameters to reflect the changes in the dialog parameters.

Updating All Parameters at Once

If there is a one-to-one correspondence between the S-function's tunable dialog parameters and the run-time parameters, i.e., the run-time parameters were registered using `ssRegAllTunableParamsAsRunTimeParams`, the S-function can use the SimStruct function `ssUpdateAllTunableParamsAsRunTimeParams` to accomplish this task. This function updates each run-time parameter to have the same value as the corresponding dialog parameter. See *matlabroot/simulink/src/sfun_runtime1.c* for an example.

Updating Parameters Individually

If there is not a one-to-one correspondence between the S-function's dialog and run-time parameters or the run-time parameters are transformed versions of the dialog parameters, the `mdlProcessParameters` method must update each parameter individually. The method used to update the run-time parameter is chosen based on how it was registered.

If a run-time parameter was registered using `ssSetRunTimeParamInfo`, the `mdlProcessParameters` method uses `ssUpdateRunTimeParamData` to update the run-time parameter, as shown in *matlabroot/simulink/src/sfun_runtime2.c*. This function

updates the data field in the parameter's attributes record, `ssParamRec`, with a new value. Note that Simulink does not allow you to directly modify the `ssParamRec`, even though you can obtain a pointer to the `ssParamRec` using `ssGetRunTimeParamInfo`.

If the run-time parameter was registered using `ssRegDlgParamAsRunTimeParam`, the `mdlProcessParameters` method can use `ssUpdateDlgParamAsRunTimeParam` to update the run-time parameter, as is shown in `matlabroot/simulink/src/sfun_runtime3.c`.

Updating Parameters as Functions of Multiple S-Function Parameters

If the run-time parameter was registered as a function of multiple S-function parameters, the `mdlProcessParameters` method uses `ssUpdateRunTimeParamData` to update the run-time parameter.

The S-function `matlabroot/simulink/src/sfun_runtime4.c` provides an example. In the example, the `mdlProcessParameters` method calculates a new value for the run-time parameter and updates the run-time parameter's memory location allocated during the call to `mdlSetWorkWidths`. The `mdlProcessParameters` method then passes the updated run-time parameter's pointer to `ssUpdateRunTimeParamData`.

Tuning Runtime Parameters

Tuning a dialog parameter tunes the corresponding runtime parameter during simulation and in code generated from the model only if the dialog parameter meets the following conditions:

- The S-function marks the dialog parameter tunable, using `ssSetSFcnParamTunable`.
- The dialog parameter is a MATLAB array of values of the standard data types supported by Simulink.

Note that you cannot tune a runtime parameter whose value is a cell array or structure.

Creating Input and Output Ports

In this section...

- “Creating Input Ports” on page 7-16
- “Creating Output Ports” on page 7-20
- “Scalar Expansion of Inputs” on page 7-21
- “Masked Multiport S-Functions” on page 7-23

Creating Input Ports

To create and configure input ports, the `mdlInitializeSizes` method should first specify the number of input ports that the S-function has, using `ssSetNumInputPorts`. Then, for each input port, the method should specify

- The dimensions of the input port (see “Initializing Input Port Dimensions” on page 7-17)

If you want your S-function to inherit its dimensionality from the port to which it is connected, you should specify that the port is dynamically sized in `mdlInitializeSizes` (see “Sizing an Input Port Dynamically” on page 7-18).

- Whether the input port allows scalar expansion of inputs (see “Scalar Expansion of Inputs” on page 7-21)
- Whether the input port has direct feedthrough, using `ssSetInputPortDirectFeedThrough`

A port has direct feedthrough if the input is used in either the `mdlOutputs` or `mdlGetTimeOfNextVarHit` functions. The direct feedthrough flag for each input port can be set to either 1=yes or 0=no. It should be set to 1 if the input, `u`, is used in the `mdlOutputs` or `mdlGetTimeOfNextVarHit` routine. Setting the direct feedthrough flag to 0 tells Simulink that `u` is not used in either of these S-function routines. Violating this leads to unpredictable results.

- The data type of the input port, if not the default double

Use `ssSetInputPortDataType` to set the input port’s data type. If you want the data type of the port to depend on the data type of the port to which

it is connected, specify the data type as `DYNAMICALLY_TYPED`. In this case, you must provide implementations of the `mdlSetInputPortDataType` and `mdlSetDefaultPortDataTypes` methods to enable the data type to be set correctly during signal propagation.

- The numeric type of the input port, if the port accepts complex-valued signals

Use `ssSetInputPortComplexSignal` to set the input port's numeric type. If you want the numeric type of the port to depend on the numeric type of the port to which it is connected, specify the numeric type as `inherited`. In this case, you must provide implementations of the `mdlSetInputPortComplexSignal` and `mdlSetDefaultPortComplexSignals` methods to enable the numeric type to be set correctly during signal propagation.

You can configure additional input port properties using other S-function macros. See “Input and Output Ports” on page 9-6 in the “SimStruct Macros and Functions Listed by Usage” section for more information.

Note The `mdlInitializeSizes` method must specify the number of ports before setting any properties. If it attempts to set a property of a port that doesn't exist, it is accessing invalid memory and a segmentation violation occurs.

Initializing Input Port Dimensions

The following options exist for setting the input port dimensions:

- If the input signal must be one-dimensional and the input port width is w , use

```
ssSetInputPortWidth(S, inputPortIdx, w)
```

- If the input signal must be a matrix of dimension m -by- n , use

```
ssSetInputPortMatrixDimensions(S, inputPortIdx, m, n)
```

- Otherwise, if the input signal can have either one or two dimensions, use

```
ssSetInputPortDimensionInfo(S, inputPortIdx, dimsInfo)
```

You can use this function to fully or partially initialize the port dimensions (see next section).

Sizing an Input Port Dynamically

If your S-function does not require that an input signal have a specific dimensionality, you might want to set the dimensionality of the input port to match the dimensionality of the signal connected to the port. To dimension an input port dynamically, your S-function should

- Specify some or all of the dimensions of the input port as dynamically sized in `mdlInitializeSizes`.

If the input port can accept a signal of any dimensionality, use

```
ssSetInputPortDimensionInfo(S, inputPortIdx, DYNAMIC_DIMENSION)
```

to set the dimensionality of the input port.

If the input port can accept only vector (1-D) signals but the signals can be of any size, use

```
ssSetInputPortWidth(S, inputPortIdx, DYNAMICALLY_SIZED)
```

to specify the dimensionality of the input port.

If the input port can accept only matrix signals but can accept any row or column size, use

```
ssSetInputPortMatrixDimensions(S, inputPortIdx, m, n)
```

where `m` and/or `n` are `DYNAMICALLY_SIZED`.

- Provide an `mdlSetInputPortDimensionInfo` method that sets the dimensions of the input port to the size of the signal connected to it.

Simulink invokes this method during signal propagation when it has determined the dimensionality of the signal connected to the input port.

- Provide an `mdlSetDefaultPortDimensionInfo` method that sets the dimensions of the block's ports to a default value. See

`matlabroot/simulink/src/sfun_dynsize.c` for an example that implements this macro.

Simulink invokes this method during signal propagation when it cannot determine the dimensionality of the signal connected to some or all of the block's input ports. This can happen, for example, if an input port is unconnected. If the S-function does not provide this method, Simulink sets the dimension of the block's ports to 1-D scalar.

Example: Defining S-Function Input Ports

The following code in `mdlInitializeSizes` configures an S-function with one input port. See “Input and Output Ports” on page 9-6 in the “SimStruct Macros and Functions Listed by Usage” section for more information on the macros used in this example.

```
if (!ssSetNumInputPorts(S, 1)) return;

/* Input has direct feedthrough */
ssSetInputPortDirectFeedThrough(S, 0, 1);

/* Input supports frames: Requires Signal Processing Blockset */
ssSetInputPortFrameData(S, 0, FRAME_YES);

/* Input is a real signal */
ssSetInputPortComplexSignal(S, 0, COMPLEX_NO);

/* Input is a dynamically sized 2-D matrix */
ssSetInputPortMatrixDimensions(S, 0,
    DYNAMICALLY_SIZED, DYNAMICALLY_SIZED);

/* Input inherits its sample time */
ssSetInputPortSampleTime(S, 0, INHERITED_SAMPLE_TIME);

/* Input signal must be contiguous */
ssSetInputPortRequiredContiguous(S, 0, 1);

/* The input port cannot share memory */
ssSetInputPortOverWritable(S, 0, 0);
```

During signal propagation, Simulink calls this S-function's `mdlSetInputPortDimensionInfo` macro to initialize the input port dimensions. In this example, `mdlSetInputPortDimensionInfo` sets the input dimensions to the candidate dimensions passed to the macro by Simulink.

```
#if defined(MATLAB_MEX_FILE)
#define MDL_SET_INPUT_PORT_DIMENSION_INFO
static void mdlSetInputPortDimensionInfo(SimStruct *S,
                                         int_T port,
                                         const DimsInfo_T *dimsInfo)
{
    if(!ssSetInputPortDimensionInfo(S, port, dimsInfo)) return;
}
#endif
```

Creating Output Ports

To create and configure output ports, the `mdlInitializeSizes` method should first specify the number of output ports that the S-function has, using `ssSetNumOutputPorts`. Then, for each output port, the method should specify

- Dimensions of the output port

Simulink provides the following macros for setting the port's dimensions.

- `ssSetOutputPortDimensionInfo`
- `ssSetOutputPortMatrixDimensions`
- `ssSetOutputPortVectorDimension`
- `ssSetOutputPortWidth`

If you want the port's dimensions to depend on block connectivity, set the dimensions to `DYNAMICALLY_SIZED`. The S-function must then provide `mdlSetOutputPortDimensionInfo` and `mdlSetDefaultPortDimensionInfo` methods to ensure that output port dimensions are set to the correct values in code generation. For more detail on how to set up output port dimensions, see "Initializing Input Port Dimensions" on page 7-17. The process you use to set up output ports is identical to the process shown in that section for initializing and dimensioning input ports, but using macros appropriate to output ports.

- Data type of the output port

Use `ssSetOutputPortDataType` to set the output port's data type. If you want the data type of the port to depend on block connectivity, specify the data type as `DYNAMICALLY_TYPED`. In this case, you must provide implementations of the `mdlSetOutputPortDataType` and `mdlSetDefaultPortDataTypes` methods to enable the data type to be set correctly during signal propagation.

- The numeric type of the output port, if the port outputs complex-valued signals

Use `ssSetOutputPortComplexSignal` to set the output port's numeric type. If you want the numeric type of the port to depend on the numeric type of the port to which it is connected, specify the numeric type as `inherited`. In this case, you must provide implementations of the `mdlSetOutputPortComplexSignal` and `mdlSetDefaultPortComplexSignals` methods to enable the numeric type to be set correctly during signal propagation.

See “Creating Input Ports” on page 7-16 for an example showing how to initialize an S-function input port. You use the same procedure to initialize the S-function output ports, but with the corresponding output port macro.

Scalar Expansion of Inputs

Scalar expansion of inputs refers conceptually to the process of expanding scalar input signals to the same dimensions as wide input signals connected to other S-function input ports. This is done by setting each element of the expanded signal to the value of the scalar input. An S-function's `mdlInitializeSizes` method can enable scalar expansion of inputs by setting the `SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION` option, using `ssSetOptions`.

With scalar expansion on, the S-function's `mdlInitializeSizes` method should specify that the input and output ports are dynamically sized. Simulink will use a default method to set the dimensions of the input and output ports. If the block has more than two inputs, the input signals can be scalar or wide signals, where the wide signals all have the same number of elements. In this case, Simulink sets the dimensions of the output ports to the width of the wide input signals and expands the scalar inputs to this width. If the wide inputs are driven by 1-D and 2-D vectors, the output is a 2-D vector signal, and the scalar inputs are expanded to a 2-D vector signal.

If scalar expansion is not on, Simulink assumes that all ports (input and output ports) must have the same dimensions, and it sets all port dimensions to the same dimensions specified by one of the driving blocks.

Note If the S-function specifies or controls the dimensions of its input and output ports either by initializing the dimensions in `mdlInitializeSizes`, using `mdlSetInputPortWidth` and `mdlSetOutputPortWidth`, or using `mdlSetInputPortDimensionInfo`, `mdlSetOutputPortDimensionInfo`, and `mdlSetDefaultPortDimensionInfo`, Simulink ignores the scalar expansion option.

The best way to understand how to use scalar expansion is to consider the example `matlabroot/toolbox/simulink/simdemos/simfeatures/sfcn_demo_sfund_multiport.mdl`. This model contains three S-function blocks, each with multiple input ports. The S-function `matlabroot/simulink/src/sfund_multiport.c` used in these blocks sets the `SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION` option in its `mdlInitializeSizes` method, allowing scalar expansion of the inputs. The S-function specifies that its inputs and outputs are dynamically sized. Therefore, during signal propagation, Simulink sets the width of the input ports to the width of the signal connected to the port, and the width of the output ports to the width of any wide input signal. The `mdlOutputs` method performs an element-by-element sum on the input signals, expanding any scalar inputs, as needed.

```
/* Calculate an element-by-element sum of the input signals.
   yWidth is the width of the output signal. */

for (e1 = 0; e1 < yWidth; e1++) {

    int_T port;
    real_T sum = 0.0;
    for (port = 0; port < nInputPorts; port++) {
        /* Get the input signal value */
        InputRealPtrsType uPtrs =
            ssGetInputPortRealSignalPtrs(S,port);

        if (e1 < ssGetInputPortWidth(S,port)) {
```



```
        /* Input is a wide signal. Use specific element */
        sum = sum + ((real_T)signs[port] * (*uPtrs[el]));

    } else {
        /* Use the scalar value to expand the signal */
        sum = sum + ((real_T)signs[port] * (*uPtrs[0]));
    }
}
}
```

Masked Multiport S-Functions

If you are developing masked multiport S-function blocks whose number of ports varies based on some parameter, and if you want to place them in a Simulink library, you must specify that the mask modifies the appearance of the block. To do this, execute the command

```
set_param(blockname, 'MaskSelfModifiable', 'on')
```

at the MATLAB prompt before saving the library, where *blockname* is the full path to the block. Failure to specify that the mask modifies the appearance of the block means that an instance of the block in a model reverts to the number of ports in the library whenever you load the model or update the library link.

Custom Data Types

An S-function can accept and output user-defined as well as built-in Simulink data types. To use a user-defined data type, the S-function's `mdlInitializeSizes` routine must

- 1 Register the data type, using `ssRegisterDataType`.
- 2 Specify the amount of memory in bytes required to store an instance of the data type, using `ssSetDataTypeSize`.
- 3 Specify the value that represents zero for the data type, using `ssSetDataTypeZero`.

The following code placed at the beginning of `mdlInitializeSizes` sets the size and zero representation of a custom data type named `myDataType`.

```
/* Define variables */
int_T  status;
DTypeId id;

/* Define the structure of the user-defined data type */
typedef struct{
    int8_T  a;
    uint16_T b;
}myStruct;

myStruct tmp;

/* Register the user-defined data types */
id = ssRegisterDataType(S, "myDataType");
if(id == INVALID_DTYPE_ID) return;

/* Set the size of the user-defined data type */
status = ssSetDataTypeSize(S, id, sizeof(tmp));
if(status == 0) return;

/* Set the zero representation */
tmp.a = 0;
tmp.b = 1;
```

```
status = ssSetDataTypeZero(S, id, &tmp);
```

To register a custom data type from a `Simulink.AliastType`, `Simulink.NumericType`, or `Simulink.StructType` object, the S-function's `mdlInitializeSizes` routine must

- 1 Define an integer pointer to hold the data type identifier for the custom data type.
- 2 Register the data type, using `ssRegisterTypeFromNamedObject`.

For example, the following code placed at the beginning of `mdlInitializeSizes` defines a custom data type from a `Simulink.AliasType` object named `u8`. The example then assigns the custom data type to the first output port.

```
int id1;  
ssRegisterTypeFromNamedObject(S, "u8", &id1);  
ssSetOutputPortDataType(S, 0, id1);
```

In addition, you can use the identifier `id1` to assign this data type to S-function parameters, Dwork vectors, and input ports.

Note You cannot generate Real-Time Workshop code for S-functions that contain macros to define custom data types. You must use an inlined S-function that accesses Target Language Compiler functions to generate code with custom data types. See “Inlining S-Functions” in the Real-Time Workshop Target Language Compiler documentation.)

Sample Times

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“Specifying Model Reference Sample Time Inheritance” on page 7-40

About Sample Times

This and the following subsections explain how to specify the sample-time behavior of your function, e.g., whether it inherits its rates from the blocks that drive it or defines its own rates and, if it defines its own rates, what the rates are.

An S-function block can specify its rates (i.e., sample times) as

- Block-based sample times
- Port-based sample times
- Hybrid block-based and port-based sample times

With block-based sample times, the S-function specifies a set of operating rates for the block as a whole during the initialization phase of the simulation. With port-based sample times, the S-function specifies a sample time for each input and output port individually during initialization. During the execution phase, with block-based sample times, the S-function processes all inputs and outputs each time a sample hit occurs for the block. By contrast, with port-based sample times, the block processes a particular port only when a sample hit occurs for that port.

For example, consider two sample rates, 0.5 and 0.25 seconds, respectively:

- In the block-based method, selecting 0.5 and 0.25 would direct the block to execute inputs and outputs at 0.25 second increments.
- In the port-based method, you could set the input port to 0.5 and the output port to 0.25, and the block would process inputs at 2 Hz and outputs at 4 Hz.

You should use port-based sample times if your application requires unequal sample rates for input and output execution or if you don't want the overhead associated with running input and output ports at the highest sample rate of your block.

In some applications, an S-Function block might need to operate internally at one or more sample rates while inputting or outputting signals at other rates. The hybrid block- and port-based method of specifying sample rates allows you to create such blocks.

In typical applications, you specify only one block-based sample time. Advanced S-functions might require the specification of port-based or multiple block sample times.

Block-Based Sample Times

The next two sections discuss how to specify block-based sample times. You must specify information in

- `mdlInitializeSizes`
- `mdlInitializeSampleTimes`

A third section presents a simple example that shows how to specify sample times in `mdlInitializeSampleTimes`. For a detailed example, see *matlabroot/simulink/src/mixedm.c*.

Specifying the Number of Sample Times in `mdlInitializeSizes`

To configure your S-function block for block-based sample times, use

```
ssSetNumSampleTimes(S,numSampleTimes);
```

where `numSampleTimes > 0`. This tells Simulink that your S-function has block-based sample times. Simulink calls `mdlInitializeSampleTimes`, which in turn sets the sample times.

Setting Sample Times and Specifying Function Calls in `mdlInitializeSampleTimes`

`mdlInitializeSampleTimes` specifies two pieces of execution information:

- Sample and offset times — In `mdlInitializeSampleTimes`, you must specify the sampling period and offset for each sample time using `ssSetSampleTime` and `ssSetOffsetTime`. If applicable, you can calculate the appropriate sampling period and offset prior to setting them, for example, by computing the best sample time for the block based on the S-function's dialog parameters obtained using `ssGetSFcnParam`.
- Function calls — In `mdlInitializeSampleTimes`, use `ssSetCallSystemOutput` to specify the output elements that are performing function calls. See `matlabroot/simulink/src/sfun_fcncall.c` for an example and “Function-Call Subsystems” on page 7-50 for an explanation of this S-function.

You specify the sample times as pairs [*sample_time*, *offset_time*], using these macros

```
ssSetSampleTime(S, sampleTimePairIndex, sample_time)
ssSetOffsetTime(S, offsetTimePairIndex, offset_time)
```

where *sampleTimePairIndex* starts at 0.

The valid sample time pairs are (uppercase values are macros defined in `simstruc.h`):

```
[CONTINUOUS_SAMPLE_TIME, 0.0 ]
[CONTINUOUS_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
[discrete_sample_period, offset ]
[VARIABLE_SAMPLE_TIME , 0.0 ]
```

Alternatively, you can specify that the sample time is inherited from the driving block, in which case the S-function can have only one sample time pair,

```
[INHERITED_SAMPLE_TIME, 0.0 ]
```

or

```
[INHERITED_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
```

Note If your S-function inherits its sample time, you should specify whether it is safe to use the S-function in a submodel, i.e., a model referenced by another model. See “Specifying Model Reference Sample Time Inheritance” on page 7-40 for more information.

The following guidelines might help in specifying sample times:

- A continuous function that changes during minor integration steps should register the [CONTINUOUS_SAMPLE_TIME, 0.0] sample time.
- A continuous function that does not change during minor integration steps should register the [CONTINUOUS_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET] sample time.
- A discrete function that changes at a specified rate should register the discrete sample time pair

```
[discrete_sample_period, offset]
```

where

```
discrete_sample_period > 0.0
```

and

```
0.0 <= offset < discrete_sample_period
```

- A discrete function that changes at a variable rate should register the variable-step discrete [VARIABLE_SAMPLE_TIME, 0.0] sample time. The `mdlGetTimeOfNextVarHit` function is called to get the time of the next sample hit for the variable-step discrete task. The `VARIABLE_SAMPLE_TIME` can be used with variable-step solvers only.

If your function has no intrinsic sample time, you must indicate that it is inherited according to the following guidelines:

- A function that changes as its input changes, even during minor integration steps, should register the `[INHERITED_SAMPLE_TIME, 0.0]` sample time.
- A function that changes as its input changes, but doesn't change during minor integration steps (that is, is held during minor steps), should register the `[INHERITED_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]` sample time.

To check for a sample hit during execution (in `mdlOutputs` or `mdlUpdate`), use the `ssIsSampleHit` or `ssIsContinuousTask` macro. For example, if your first sample time is continuous, then you use the following code fragment to check for a sample hit. Note that you get incorrect results if you use `ssIsSampleHit(S,0,tid)`.

```
if (ssIsContinuousTask(S,tid)) {  
}
```

If, for example, you wanted to determine whether the third (discrete) task has a hit, you would use the following code fragment:

```
if (ssIsSampleHit(S,2,tid) {  
}
```

Example: mdlInitializeSampleTimes

This example specifies that there are two discrete sample times with periods of 0.01 and 0.5 seconds.

```
static void mdlInitializeSampleTimes(SimStruct *S)  
{  
    ssSetSampleTime(S, 0, 0.01);  
    ssSetOffsetTime(S, 0, 0.0);  
    ssSetSampleTime(S, 1, 0.5);  
    ssSetOffsetTime(S, 1, 0.0);  
} /* End of mdlInitializeSampleTimes. */
```


Specifying Port-Based Sample Times

If you want your S-function to use port-based sample times, you must specify the number of sample times as port-based in the S-function's `mdlInitializeSizes` method:

```
ssSetNumSampleTimes(S, PORT_BASED_SAMPLE_TIMES)
```

You must also specify the sample time of each input and output port in the S-function's `mdlInitializeSizes` method, using the following macros

```
ssSetInputPortSampleTime(S, idx, period)
ssSetInputPortOffsetTime(S, idx, offset)
ssSetOutputPortSampleTime(S, idx, period)
ssSetOutputPortOffsetTime(S, idx, offset)
```

Note `mdlInitializeSizes` should not contain any `ssSetSampleTime` or `ssSetOffsetTime` calls when you use port-based sample times.

The call to `ssSetNumSampleTimes` can be placed before or after the port-based sample times are actually specified in `mdlInitializeSizes`. However, if `ssSetNumSampleTimes` does not configure the S-function to use port-based sample times, any sample times set on the ports will be ignored.

For any given port, you can specify

- A specific sample time and period

For example, the following code sets the sample time of the S-function's first input port to every 0.1 s starting with the simulation start time.

```
ssSetInputPortSampleTime(S, 0, 0.1);
ssSetInputPortOffsetTime(S, 0, 0);
```

- Inherited sample time, i.e., the port inherits its sample time from the port to which it is connected (see “Specifying Inherited Sample Time for a Port” on page 7-32)
- Constant sample time, i.e., the port's input or output never changes (see “Specifying Constant Sample Time for a Port” on page 7-33)

Note To be usable in a triggered subsystem, all of your S-function's ports must have either inherited or constant sample time (see “Configuring Port-Based Sample Times for Use in Triggered Subsystems” on page 7-34).

Port-based sample times cannot be used with S-functions that have neither input ports nor output ports. If an S-function uses port-based sample times and has no ports, the S-function produces errors when the Simulink model is updated or run. If the number of input or output ports on an S-function is variable, extra protection should be added into the S-function to ensure the total number of ports does not go to zero.

To use port-based sample times in a Level-2 M-file S-function, specify the sample time for each S-function port in the setup method. Use a value of [-1 0] for the `SampleTime` property of each port.

```
block.InputPort(1).SampleTime = [-1 0];  
block.OutputPort(1).SampleTime = [-1 0];
```

The setup method should not specify a sample time for the block when using port-based sample times.

Specifying Inherited Sample Time for a Port

To specify that a port's sample time is inherited, the `mdlInitializeSizes` method should set its period to -1 and its offset to 0. For example, the following code specifies inherited sample time for the S-function's first input port:

```
ssSetInputPortSampleTime(S, 0, -1);  
ssSetInputPortOffsetTime(S, 0, 0);
```

When you specify port-based sample times, Simulink calls `mdlSetInputPortSampleTime` and `mdlSetOutputPortSampleTime` to determine the rates of inherited signals.

Once all rates have been determined, Simulink calls `mdlInitializeSampleTimes`. Even though there is no need to initialize port-based sample times at this point, Simulink invokes this method to give your S-function an opportunity to configure function-call connections. Your S-function must thus provide an implementation for this method regardless

of whether it uses port-based sample times or function-call connections. Although you can provide an empty implementation, you might want to use it to check the appropriateness of the sample times that the block inherited during sample time propagation. Use `ssGetInputPortSampleTime` and `ssGetOutputPortSampleTime` in `mdlInitializeSampleTimes` to obtain the values of the inherited sample times. For example, the following code in `mdlInitializeSampleTimes` checks if the S-function's first input inherited a continuous sample time.

```
if (!ssGetInputPortSampleTime(S,0) {
    ssSetErrorStatus(S,"Cannot inherit a continuous sample time.");
}
```

Note If you specify that your S-function's ports inherit their sample time, you should also specify whether it is safe to use the S-function in a submodel, i.e., a model referenced by another model. See "Specifying Model Reference Sample Time Inheritance" on page 7-40 for more information.

Specifying Constant Sample Time for a Port

If your S-function uses port-based sample times, it can specify that any of its ports has a constant sample time. This means that the signal entering or leaving the port never changes from its initial value at the start of the simulation.

Before specifying constant sample time for an output port whose output depends on the S-function's parameters, the S-function should use `ssGetInlineParameters` to check whether the user has specified the **Inline parameters** option on the **Optimization** pane of the **Configuration parameters** dialog box. If the user has not checked this option, it is possible for the user to change the values the S-function's parameters and hence its outputs during the simulation. In this case, the S-function should not specify a constant sample time for any ports whose outputs depend on the S-function's parameters.

To specify constant sample time for a port, the S-function must perform the following tasks

- Use `ssSetOptions` to tell Simulink that it supports constant port sample times in its `mdlInitializeSizes` method:

```
ssSetOptions(S, SS_OPTION_ALLOW_CONSTANT_PORT_SAMPLE_TIME);
```

Note By setting this option, your S-function is in effect telling Simulink that all of its ports support a constant sample time including ports that inherit their sample times from other blocks. If any of the S-function's inherited sample time ports cannot have a constant sample time, your S-function's `mdlSetInputPortSampleTime` and `mdlSetOutputPortSampleTime` methods must check whether that port has inherited a constant sample time. If the port has inherited a constant sample time, your S-function should throw an error.

- Set the port's period to `inf` and its offset to 0, e.g.,

```
ssSetInputPortSampleTime(S, 0, mxGetInf());  
ssSetInputPortOffsetTime(S, 0, 0);
```

- Check in `mdlOutputs` whether the method's `tid` argument equals `CONSTANT_TID` and if so, set the value of the port's output if it is an output port.

See `sfun_port_constant.c`, the source file for the `sfcndemo_port_constant` demo, for an example of how to create ports with a constant sample time.

Configuring Port-Based Sample Times for Use in Triggered Subsystems

To be usable in a triggered subsystem, your port-based sample time S-function must perform the following tasks.

- Use `ssSetOptions` to tell Simulink in its `mdlInitializeSizes` method that it can run in a triggered subsystem:

```
ssSetOptions(S,  
SS_OPTION_ALLOW_PORT_SAMPLE_TIME_IN_TRIGSS);
```

- Set all of its ports to have either inherited or constant sample time in its `mdlInitializeSizes` method.
- Handle inheritance of a triggered sample time in `mdlSetInputPortSampleTime` and `mdlSetOutputPortSampleTime` methods as follows.

Since the S-function's ports inherit their sample times, Simulink invokes either `mdlSetInputPortSampleTime` or `mdlSetOutputPortSampleTime` during sample time propagation. The macro `ssSampleAndOffsetAreTriggered` can be used in these methods to determine if the S-function resides in a triggered subsystem. If the S-function does reside in a triggered subsystem, whichever method is called must set the sample time and offset of the port for which it is called to `INHERITED_SAMPLE_TIME (-1)`.

Setting a port's sample time and offset both to `INHERITED_SAMPLE_TIME` indicates that the sample time of the port is triggered, i.e., it produces an output or accepts an input only when the subsystem in which it resides is triggered. The method must then also set the sample times and offsets of all of the S-function's other input and output ports to have either triggered or constant sample time, whichever is appropriate, e.g.,

```
static void mdlSetInputPortSampleTime(SimStruct *S,
                                     int_T portIdx,
                                     real_T sampleTime
                                     real_T offsetTime)
{
    /* If the S-function resides in a triggered subsystem,
       the sample time and offset passed to this method
       are both equal to INHERITED_SAMPLE_TIME. Therefore,
       if triggered, the following lines set the sample time
       and offset of the input port to INHERITED_SAMPLE_TIME.*/

    ssSetInputPortSampleTime(S, portIdx, sampleTime);
    ssSetInputPortOffsetTime(S, portIdx, offsetTime);

    /* If triggered, set the output port to inherited, as well */

    if (ssSampleAndOffsetAreTriggered(sampleTime,offsetTime)) {
        ssSetOutputPortSampleTime(S, 0, INHERITED_SAMPLE_TIME);
        ssSetOutputPortOffsetTime(S, 0, INHERITED_SAMPLE_TIME);
    }
}
```

```
        /* Note, if there are additional input and output ports
           on this S-function, they should be set to either
           inherited or constant at this point, as well. */
    }
}
```

There is no way for an S-function residing in a triggered subsystem to predict whether Simulink will call `mdlSetInputPortSampleTime` or `mdlSetOutputPortSampleTime` to set its port sample times. For this reason, both methods must be able to set the sample times of all ports correctly so that one of the methods need only be called once.

- In `mdlUpdate` and `mdlOutputs`, use `ssGetPortBasedSampleTimeBlockIsTriggered` to check whether the S-function resides in a triggered subsystem and if so, use appropriate algorithms for computing its states and outputs.

See `sfun_port_triggered.c`, the source file for the `sfcndemo_port_triggered` demo, for an example of how to create an S-function that can be used in a triggered subsystem.

Hybrid Block-Based and Port-Based Sample Times

The hybrid method of assigning sample times combines the block-based and port-based methods. You first specify, in `mdlInitializeSizes`, the total number of rates at which your block operates, including both internal and input and output rates, using `ssSetNumSampleTimes`.

You then set the `SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED`, using `ssSetOptions`, to tell the simulation engine that you are going to use the port-based method to specify the rates of the input and output ports individually. Next, as in the block-based method, you specify the periods and offsets of all of the block's rates, both internal and external, using

```
ssSetSampleTime
ssSetOffsetTime
```

Finally, as in the port-based method, you specify the rates for each port, using

```
ssSetInputPortSampleTime(S, idx, period)
```

```

ssSetInputPortOffsetTime(S, idx, offset)
ssSetOutputPortSampleTime(S, idx, period)
ssSetOutputPortOffsetTime(S, idx, offset)

```

Note that each of the assigned port rates must be the same as one of the previously declared block rates. For an example S-function, see *matlabroot/simulink/src/mixedm.c*.

Note If you use the `SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED` option, your S-function cannot inherit sample times. Instead, you must specify the rate at which each input and output port runs.

Multirate S-Function Blocks

In a multirate S-Function block, you can encapsulate the code that defines each behavior in the `mdlOutputs` and `mdlUpdate` functions with a statement that determines whether a sample hit has occurred. The `ssIsSampleHit` macro determines whether the current time is a sample hit for a specified sample time. The macro has this syntax:

```
ssIsSampleHit(S, st_index, tid)
```

where `S` is the `SimStruct`, `st_index` identifies a specific sample time index, and `tid` is the task ID (`tid` is an argument to the `mdlOutputs` and `mdlUpdate` functions).

For example, these statements specify three sample times: one for continuous behavior and two for discrete behavior.

```

ssSetSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
ssSetSampleTime(S, 1, 0.75);
ssSetSampleTime(S, 2, 1.0);

```

In the `mdlUpdate` function, the following statement encapsulates the code that defines the behavior for the sample time of 0.75 second.

```

if (ssIsSampleHit(S, 1, tid)) {
}

```

The second argument, 1, corresponds to the second sample time, 0.75 second.

Example of Defining a Sample Time for a Continuous Block

This example defines a sample time for a block that is continuous.

```
/* Initialize the sample time and offset. */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);
}
```

You must add this statement to the `mdlInitializeSizes` function.

```
ssSetNumSampleTimes(S, 1);
```

Example of Defining a Sample Time for a Hybrid Block

This example defines sample times for a hybrid S-Function block.

```
/* Initialize the sample time and offset. */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    /* Continuous state sample time and offset. */
    ssSetSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);

    /* Discrete state sample time and offset. */
    ssSetSampleTime(S, 1, 0.1);
    ssSetOffsetTime(S, 1, 0.025);
}
```

In the second sample time, the offset causes Simulink to call the `mdlUpdate` function at these times: 0.025 second, 0.125 second, 0.225 second, and so on, in increments of 0.1 second.

The following statement, which indicates how many sample times are defined, also appears in the `mdlInitializeSizes` function.


```
ssSetNumSampleTimes(S, 2);
```

Synchronizing Multirate S-Function Blocks

If tasks running at different rates need to share data, you must ensure that data generated by one task is valid when accessed by another task running at a different rate. You can use the `ssIsSpecialSampleHit` macro in the `mdlUpdate` or `mdlOutputs` routine of a multirate S-function to ensure that the shared data is valid. This macro returns true if a sample hit has occurred at one rate and a sample hit has also occurred at another rate in the same time step. It thus permits a higher rate task to provide data needed by a slower rate task at a rate the slower task can accommodate.

Suppose, for example, that your model has an input port operating at one rate, 0, and an output port operating at a slower rate, 1. Further, suppose that you want the output port to output the value currently on the input. The following example illustrates usage of this macro.

```
if (ssIsSampleHit(S, 0, tid) {
    if (ssIsSpecialSampleHit(S, 0, 1, tid) {
        /* Transfer input to output memory. */
        ...
    }
}

if (ssIsSampleHit(S, 1, tid) {
    /* Emit output. */
    ...
}
```

In this example, the first block runs when a sample hit occurs at the input rate. If the hit also occurs at the output rate, the block transfers the input to the output memory. The second block runs when a sample hit occurs at the output rate. It transfers the output in its memory area to the block's output.

Note that higher-rate tasks always run before slower-rate tasks. Thus, the input task in the preceding example always runs before the output task, ensuring that valid data is always present at the output port.

Specifying Model Reference Sample Time Inheritance

If your S-function inherits its sample times from the blocks that drive it, it should specify whether submodels containing your S-function can inherit sample times from their parent model. If the S-function's output does not depend on its inherited sample time, use the `ssSetModelReferenceSampleTimeInheritanceRule` macro to set the S-function's sample time inheritance rule to `USE_DEFAULT_FOR_DISCRETE_INHERITANCE`. Otherwise, set the rule to `DISALLOW_SAMPLE_TIME_INHERITANCE`. Specifying the inheritance rule allows Simulink to disallow sample-time inheritance for submodels that include S-functions whose outputs depend on their inherited sample time and thereby avoid inadvertent simulation errors.

Note If your S-function does not set this flag, Simulink assumes that it does not preclude a submodel containing it from inheriting a sample time. However, Simulink optionally warns the user that the submodel contains S-functions that do not specify a sample-time inheritance rule (see “Blocks That Preclude Sample-Time Inheritance” in the online Simulink help).

If you are uncertain whether an existing S-function's output depends on its inherited sample time, check whether it invokes any of the following C macros:

- `ssGetSampleTime`
- `ssGetInputPortSampleTime`
- `ssGetOutputPortSampleTime`
- `ssGetInputPortOffsetTime`
- `ssGetOutputPortOffsetTime`
- `ssGetSampleTimePtr`
- `ssGetInputPortSampleTimeIndex`
- `ssGetOutputPortSampleTimeIndex`
- `ssGetSampleTimeTaskID`
- `ssGetSampleTimeTaskIDPtr`

or TLC functions:

- `LibBlockSampleTime`
- `CompiledModel.SampleTime`
- `LibBlockInputSignalSampleTime`
- `LibBlockInputSignalOffsetTime`
- `LibBlockOutputSignalSampleTime`
- `LibBlockOutputSignalOffsetTime`

If the S-function does not invoke any of these macros or functions, its output does not depend on its inherited sample time and hence it is safe to use in submodels that inherit their sample time.

Sample-Time Inheritance Rule Example

As an example of an S-function that precludes a submodel from inheriting its sample time, consider an S-function that has the following `mdlOutputs` method:

```
static void mdlOutputs(SimStruct *S, int_T tid) {
    const real_T *u = (const real_T*)
        ssGetInputPortSignal(S,0);
    real_T      *y = ssGetOutputPortSignal(S,0);
    y[0] = ssGetSampleTime(S,tid) * u[0];
}
```

This output of this S-function is its inherited sample time, hence its output depends on its inherited sample time, and hence it is unsafe to use in a submodel. For this reason, this S-function should specify its model reference inheritance rule as follows:

```
ssSetModelReferenceSampleTimeInheritanceRule
(S, DISALLOW_SAMPLE_TIME_INHERITANCE);
```

Work Vectors

In this section...
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“Work Vectors and Zero Crossings” on page 7-44
“Example Involving a Pointer Work Vector” on page 7-47
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About Work Vectors

Work vectors are blocks of memory that an S-function can ask Simulink to allocate to each instance of the S-function in a model. If multiple instances of your S-function can occur in a model, your S-function must use work vectors instead of global or static memory to store instance-specific values of S-function variables. Otherwise, your S-function runs the risk of one instance overwriting data needed by another instance, causing a simulation to fail or produce incorrect results. The ability to keep track of multiple instances of an S-function is called *reentrancy*.

You can create an S-function that is reentrant by using work vectors that Simulink manages for each particular instance of the S-function. Integer, floating-point (real), pointer, and general data types are supported. The number of elements in each vector can be specified dynamically as a function of the number of inputs to the S-function.

Work vectors have several advantages:

- Instance-specific storage for block variables
- Integer, real, pointer, and general data types
- Elimination of static and global variables and the associated multiple instance problems

For example, suppose you'd like to track the previous value of each input signal element entering input port 1 of your S-function. Either the discrete-state vector or the real-work vector could be used for this, depending upon whether the previous value is considered a discrete state (that is, compare the unit

delay and the memory block). If you do not want the previous value to be logged when states are saved, use the real-work vector, `rwork`. To do this, in `mdlInitializeSizes` specify the length of this vector by using `ssSetNumRWork`. Then in either `mdlStart` or `mdlInitializeConditions`, initialize the `rwork` vector using `ssSetRWorkValue`. In `mdlOutputs`, you can retrieve the previous inputs by using `ssGetRWork`. In `mdlUpdate`, update the previous value of the `rwork` vector by using `ssGetInputPortRealSignalPtrs`. See `matlabroot/simulink/src/sfunmem.c` for an example using the `rwork` vector.

Use the macros in this table to specify the length of the work vectors for each instance of your S-function in `mdlInitializeSizes`.

Macros Used in Specifying Vector Widths

Macro	Description
<code>ssSetNumContStates</code>	Width of the continuous-state vector
<code>ssSetNumDiscStates</code>	Width of the discrete-state vector
<code>ssSetNumDWork</code>	Width of the data type work vector
<code>ssSetNumRWork</code>	Width of the real-work vector
<code>ssSetNumIWork</code>	Width of the integer-work vector
<code>ssSetNumPWork</code>	Width of the pointer-work vector
<code>ssSetNumModes</code>	Width of the mode-work vector
<code>ssSetNumNonsampledZCs</code>	Width of the nonsampled zero-crossing vector

Specify vector widths in `mdlInitializeSizes`. There are three choices:

- 0 (the default). This indicates that the vector is not used by your S-function.
- A positive nonzero integer. This is the width of the vector that is available for use by `mdlStart`, `mdlInitializeConditions`, and S-function routines called in the simulation loop.
- The `DYNAMICALLY_SIZED` define. The default behavior for dynamically sized vectors is to set them to the overall block width. Simulink does this

after propagating line widths and sample times. The block width is the width of the signal passing through your block. In general this is equal to the output port width.

If the default behavior of dynamically sized vectors does not meet your needs, use `mdlSetWorkWidths` and the macros listed in *Macros Used in Specifying Vector Widths* on page 7-43, to set the sizes of the work vectors explicitly. `mdlSetWorkWidths` also allows you to set your work vector lengths as functions of the block sample time and/or port widths.

The continuous states are used when you have a state that needs to be integrated by one of the Simulink solvers. When you specify continuous states, you must return the states' derivatives in `mdlDerivatives`. The discrete state vector is used to maintain state information that changes at fixed intervals. Typically the discrete state vector is updated in place in `mdlUpdate`.

The integer, real, and pointer work vectors are storage locations that are not logged by Simulink during simulations. They maintain persistent data between calls to your S-function.

Work Vectors and Zero Crossings

The mode-work vector and the nonsampled zero-crossing vector are typically used with zero crossings. Elements of the mode vector are integer values. You specify the number of mode-vector elements in `mdlInitializeSizes`, using `ssSetNumModes(S, num)`. You can then access the mode vector using `ssGetModeVector`. The mode vector is used to determine how the `mdlOutputs` routine should operate when the solvers are homing in on zero crossings. The zero crossings or state events (i.e., discontinuities in the first derivatives) of some signal, usually a function of an input to your S-function, are tracked by the solver by looking at the nonsampled zero crossings. To register nonsampled zero crossings, set the number of nonsampled zero crossings in `mdlInitializeSizes`, using `ssSetNumNonsampledZCs(S, num)`. Then define the `mdlZeroCrossings` routine to return the nonsampled zero crossings. A zero-crossing example can be found in `matlabroot/simulink/src/sfun_zc_sat.c`. The relevant pieces of this S-function are shown below.

First, `mdlInitializeSizes` specifies the sizes for the mode and nonsampled zero-crossing vectors using the following lines of code.

```

ssSetNumModes(S, DYNAMICALLY_SIZED);
ssSetNumNonsampledZCs(S, DYNAMICALLY_SIZED);

```

Since the number of modes and nonsampled zero crossings is dynamically sized, `mdlSetWorkWidths` must initialize the actual size of these vectors. In this example, shown below, there is one mode vector for each output element and two nonsampled zero crossings for each mode. In general, the number of nonsampled zero crossings needed for each mode depends on the number of events that need to be detected. In this case, each output (mode) needs to detect when it hits the upper or the lower bound, hence two nonsampled zero crossings per mode.

```

static void mdlSetWorkWidths(SimStruct *S)
{
    int nModes;
    int nNonsampledZCs;

    nModes      = numOutput;
    nNonsampledZCs = 2 * numOutput;

    ssSetNumModes(S, nModes);
    ssSetNumNonsampledZCs(S, nNonsampledZCs);
}

```

Next, `mdlOutputs` determines which mode the simulation is running in at the beginning of each major time step. By storing this information in the mode vector, it is then available when calculating outputs at both major and minor time steps.

```

/* Get the mode vector */
int_T *mode = ssGetModeVector(S);

/* Specify three possible mode values.*/
enum { UpperLimitEquation, NonLimitEquation, LowerLimitEquation };

/* Update the mode vector at the beginning of a major time step */
if ( ssIsMajorTimeStep(S) ) {
    for ( iOutput = 0; iOutput < numOutput; iOutput++ ) {
        if ( *uPtrs[uIdx] > *upperLimit ) {
            /* Upper limit is reached. */
            mode[iOutput] = UpperLimitEquation;
        }
    }
}

```

```
    } else if ( *uPtrs[uIdx] < *lowerLimit ) {
        /* Lower limit is reached. */
        mode[iOutput] = LowerLimitEquation;

    } else {
        /* Output is not limited. */
        mode[iOutput] = NonLimitEquation;
    }

    /* Adjust indices to give scalar expansion. */
    uIdx      += uInc;
    upperLimit += upperLimitInc;
    lowerLimit += lowerLimitInc;
}
/* Reset index to input and limits. */
uIdx      = 0;
upperLimit = mxGetPr( P_PAR_UPPER_LIMIT );
lowerLimit = mxGetPr( P_PAR_LOWER_LIMIT );

} /* end IsMajorTimeStep */
```

Output calculations in `mdlOutputs` are finally done based on the values stored in the mode vector.

```
for ( iOutput = 0; iOutput < numOutput; iOutput++ ) {
    if ( mode[iOutput] == UpperLimitEquation ) {
        /* Output upper limit. */
        *y++ = *upperLimit;

    } else if ( mode[iOutput] == LowerLimitEquation ) {
        /* Output lower limit. */
        *y++ = *lowerLimit;

    } else {
        /* Output is equal to input */
        *y++ = *uPtrs[uIdx];
    }
}
```


After outputs are calculated, Simulink calls `mdlZeroCrossings` to determine if a zero crossing has occurred. A zero crossing is detected if any element of the nonsampled zero-crossing vector switches from negative to positive, or positive to negative. If this occurs, the simulation modifies the step size and recalculates the outputs to try to locate the exact zero crossing. For this example, the values for the nonsampled zero-crossing vectors are calculated as shown below.

```
static void mdlZeroCrossings(SimStruct *S)
{
    int_T          iOutput;
    int_T          numOutput = ssGetOutputPortWidth(S,0);
    real_T         *zcSignals = ssGetNonsampledZCs(S);
    InputRealPtrsType uPtrs    = ssGetInputPortRealSignalPtrs(S,0);

    /* Set index and increment for the input signal, upper limit, and lower
     * limit parameters so that each gives scalar expansion if needed. */
    int_T uIdx      = 0;
    int_T uInc      = ( ssGetInputPortWidth(S,0) > 1 );
    const real_T *upperLimit = mxGetPr( P_PAR_UPPER_LIMIT );
    int_T upperLimitInc = ( mxGetNumberOfElements( P_PAR_UPPER_LIMIT ) > 1 );
    const real_T *lowerLimit = mxGetPr( P_PAR_LOWER_LIMIT );
    int_T lowerLimitInc = ( mxGetNumberOfElements( P_PAR_LOWER_LIMIT ) > 1 );

    /*Check if the input has crossed an upper or lower limit */
    for ( iOutput = 0; iOutput < numOutput; iOutput++ ) {
        zcSignals[2*iOutput] = *uPtrs[uIdx] - *upperLimit;
        zcSignals[2*iOutput+1] = *uPtrs[uIdx] - *lowerLimit;

        /* Adjust indices to give scalar expansion if needed */
        uIdx      += uInc;
        upperLimit += upperLimitInc;
        lowerLimit += lowerLimitInc;
    }
}
```

Example Involving a Pointer Work Vector

This example opens a file and stores the FILE pointer in the pointer-work vector.

The following statement, included in the `mdlInitializeSizes` function, indicates that the pointer-work vector is to contain one element.

```
ssSetNumPWork(S, 1) /* pointer-work vector */
```

The following code uses the pointer-work vector to store a `FILE` pointer, returned from the standard I/O function `fopen`.

```
#define MDL_START /* Change to #undef to remove function. */
#if defined(MDL_START)
static void mdlStart(real_T *x0, SimStruct *S)
{
    FILE *fPtr;
    void **PWork = ssGetPWork(S);
    fPtr = fopen("file.data", "r");
    PWork[0] = fPtr;
}
#endif /* MDL_START */
```

This code retrieves the `FILE` pointer from the pointer-work vector and passes it to `fclose` to close the file.

```
static void mdlTerminate(SimStruct *S)
{
    if (ssGetPWork(S) != NULL) {
        FILE *fPtr;
        fPtr = (FILE *) ssGetPWorkValue(S,0);
        if (fPtr != NULL) {
            fclose(fPtr);
        }
        ssSetPWorkValue(S,0,NULL);
    }
}
```

Note If you are using `mdlSetWorkWidths`, any work vectors you use in your S-function should be set to `DYNAMICALLY_SIZED` in `mdlInitializeSizes`, even if the exact value is known before `mdlInitializeSizes` is called. The size to be used by the S-function should be specified in `mdlSetWorkWidths`.

The synopsis is

```
#define MDL_SET_WORK_WIDTHS    /* Change to #undef to remove function. */
#ifdef MDL_SET_WORK_WIDTHS && defined(MATLAB_MEX_FILE)
static void mdlSetWorkWidths(SimStruct *S)
{
}
#endif /* MDL_SET_WORK_WIDTHS */
```

For an example, see *matlabroot/simulink/src/sfun_dynsize.c*.

Memory Allocation

When you are creating an S-function, the available work vectors might not provide enough capability. In this case, you need to allocate memory for each instance of your S-function. The standard MATLAB API memory allocation routines `mxMalloc` and `mxFree` should not be used with C MEX S-functions, because these routines are designed to be used with MEX-files that are called from MATLAB and not Simulink. The correct approach for allocating memory is to use the `stdlib.h` library routines `calloc` and `free`. In `mdlStart`, allocate and initialize the memory

```
UD *ptr = (UD *)calloc(1, sizeof(UD));
```

where `UD`, in this example, is a data structure defined at the beginning of the S-function. Then, place the pointer to it either in pointer-work vector elements

```
ssSetPWorkValue(S, 0, ptr);
```

or attach it as user data.

```
ssSetUserData(S, ptr);
```

In `mdlTerminate`, free the allocated memory. For example, if the pointer was stored in the user data

```
UD *prt = ssGetUserData(S);
free(prt);
```

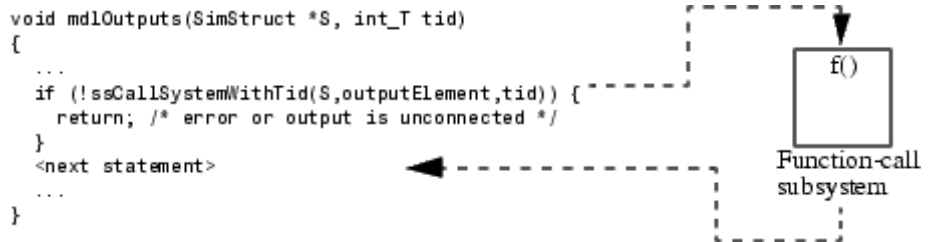
Function-Call Subsystems

You can create a triggered subsystem whose execution is determined by logic internal to an S-function instead of by the value of a signal. A subsystem so configured is called a *function-call subsystem*. To implement a function-call subsystem:

- In the Trigger block, select **function-call** as the **Trigger type** parameter.
- In the S-function, use the `ssEnableSystemWithTid` and `ssDisableSystemWithTid` to enable or disable the triggered subsystem and the `ssCallSystemWithTid` macro to call the triggered subsystem.
- In the model, connect the S-Function block output directly to the trigger port.

Note Function-call connections can only be performed on the first output port.

Function-call subsystems are not executed directly by Simulink; rather, the S-function determines when to execute the subsystem. When the subsystem completes execution, control returns to the S-function. This figure illustrates the interaction between a function-call subsystem and an S-function.



In this figure, `ssCallSystemWithTid` executes the function-call subsystem that is connected to the first output port element. `ssCallSystemWithTid` returns 0 if an error occurs while executing the function-call subsystem or if the output is unconnected. After the function-call subsystem executes, control is returned to your S-function.

Function-call subsystems can only be connected to S-functions that have been properly configured to accept them.

To configure an S-function to call a function-call subsystem:

- Specify the elements that are to execute the function-call subsystem in `mdlInitializeSampleTimes`. For example:

```
ssSetCallSystemOutput(S,0); /* call on first element */
ssSetCallSystemOutput(S,1); /* call on second element */
```

- Specify in `mdlInitializeSampleTimes` whether you want the S-function to be able to enable or disable the function-call subsystem. Only S-functions that explicitly enable and disable the function-call subsystem can reset the states and outputs of the subsystem, as determined by the function-call subsystem's Trigger and Outport blocks. For example, the code

```
ssSetExplicitFCSSCtrl(S, 1);
```

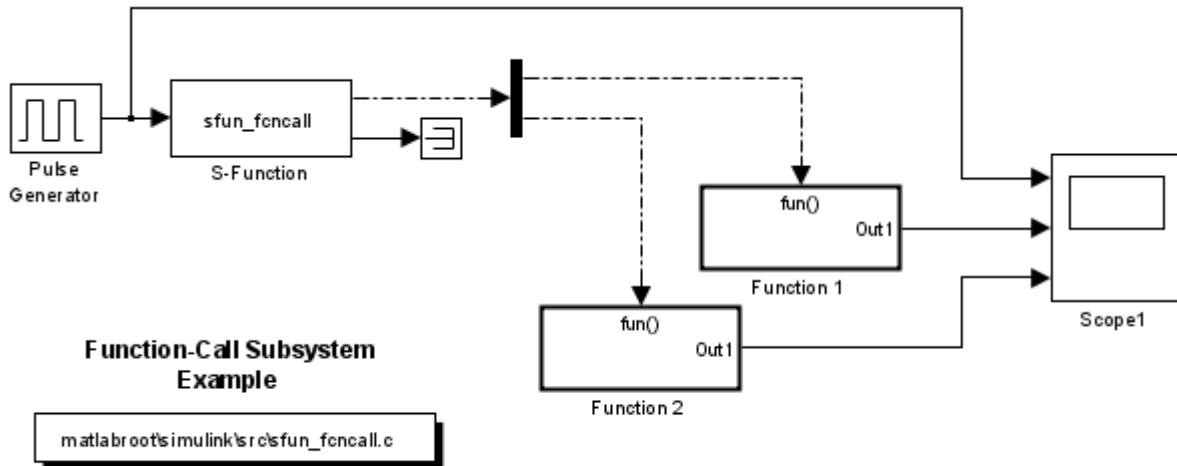
in `mdlInitializeSampleTimes` specifies that the S-function can enable and disable the function-call subsystem. In this case, the S-function must invoke `ssEnableSystemWithTid` before executing the subsystem using `ssCallSystemWithTid`.

- Execute the subsystem in the appropriate `mdlOutputs` or `mdlUpdate` S-function routine. For example:

```
static void mdlOutputs(...)
{
    if (((int)*uPtrs[0]) % 2 == 1) {
        if (!ssCallSystemWithTid(S,0,tid)) {
            /* Error occurred, which will be reported by */
            /*Simulink*/
            return;
        }
    } else {
        if (!ssCallSystemWithTid(S,1,tid)) {
            /* Error occurred, which will be reported by */
            /*Simulink*/
            return;
        }
    }
    ...
}
```

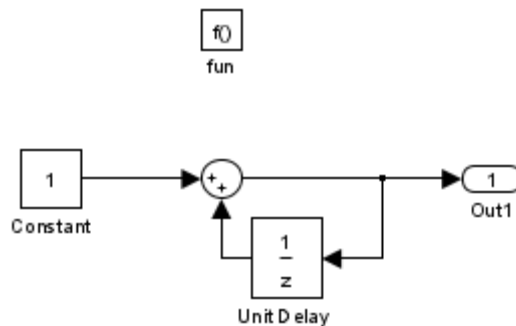
Note Do not use `ssSetOutputPortDataType` or `ssGetOutputPortDataType` on an S-function output that emits function-call signals. Simulink explicitly controls the data type of these output signals.

See `matlabroot/simulink/src/sfun_fcncall.c` for an example that executes a function-call subsystem on the first and second elements of the S-function's first output. The following Simulink model implements this S-function.

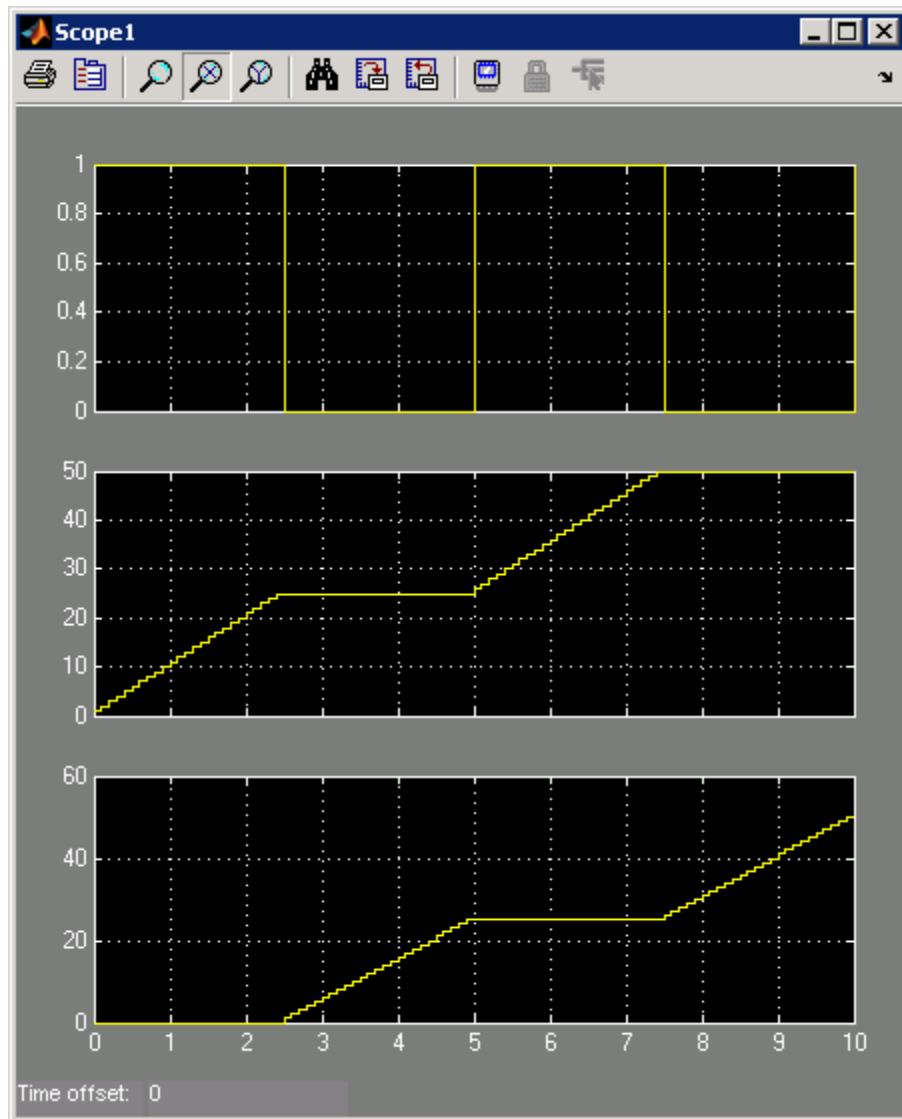


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Each of the function-call subsystems is a simple feedback loop containing a Unit Delay block, as shown below.



When the Pulse Generator emits its upper value, the function-call subsystem connected to the first element of the S-function's first output port is triggered. Similarly, when the Pulse Generator emits its lower value, the function-call subsystem connected to the second element is triggered. The simulation output is shown on the Scope, below.



Function-call subsystems are a powerful modeling construct. You can configure Stateflow® blocks to execute function-call subsystems, thereby extending the capabilities of the blocks. For more information on their use in Stateflow, see the Stateflow documentation.

Sim Viewing Devices in External Mode

A sim viewing device encapsulates processing and viewing of signals received from the target system in external mode. During simulation in external mode, the target system uploads the appropriate input values to the sim viewing device in the Simulink model. The sim viewing device then conditions the input signals as needed and renders the signals on the screen. A sim viewing device runs only on the host, generating no code in the target system and, therefore, allowing extra processing of displayed signals without burdening the generated code.

You can use your S-function as a sim viewing device in external mode if it satisfies the following conditions.

- The S-function has no output ports.
- The S-function contains no states.
- The generated code does not require the conditioned signals produced by the S-function.

To specify the S-function is a sim viewing device, set the `SS_OPTION_SIM_VIEWING_DEVICE` option in the `mdlInitializeSizes` function. For example

```
ssSetOptions(S, SS_OPTION_SIM_VIEWING_DEVICE);
```

External mode compatible S-functions are selected, and the trigger is armed, by using the External Signal & Triggering dialog box. For more information see “External Mode” in the Real-Time Workshop documentation.

Processing Frame-Based Signals

This section explains how to create an S-function that accepts and/or produces frame-based signals. See “Frame-Based Signals” in the “Working with Signals” section of the Signal Processing Blockset documentation for a comprehensive discussion of the use of frame-based signals in Simulink models.

Note Simulating a model containing the S-function that you develop requires a Signal Processing Blockset license.

To accept or produce frame-based signals, an S-function must perform the following tasks:

- The S-function’s `mdlInitializeSizes` callback method must set the port frame status to `FRAME_YES`, `FRAME_NO`, or `FRAME_INHERITED` for each of the S-function’s I/O ports, using the `ssSetInputPortFrameData` and `ssSetOutputPortFrameData` functions. The frame status for a port must be set after the call to `ssSetNumInputPorts` and `ssSetNumOutputPorts`. For example, the following code in `mdlInitializeSizes` specifies that the first input port accepts a frame-based signal while the first output port emits a sample-based signal:

```
ssSetNumInputPorts(S, 1);
ssSetInputPortFrameData(S, 0, FRAME_YES);
ssSetNumOutputPorts(S, 1);
ssSetOutputPortFrameData(S, 0, FRAME_NO);
```

- The S-function should specify the dimensions of the signals that its frame-based ports accept or produce in its `mdlInitializeSizes` or `mdlSetInputPortDimensionInfo` and `mdlSetOutputPortDimensionInfo` callback methods. Note that frame-based signals must be dimensioned as 2-D arrays. For example, the following code in `mdlInitializeSizes` specifies that the first frame-based input port is dynamically sized. This S-function must then also have an `mdlSetInputPortDimensionInfo` callback that sets the specific dimensions of this input port.

```

ssSetNumInputPorts(S, 1);
ssSetInputPortFrameData(S, 0, FRAME_YES);
ssSetInputPortMatrixDimensions(S, 0, DYNAMICALLY_SIZED, DYNAMICALLY_SIZED);

```

- If the frame status of any of the S-function's input ports is inherited, the S-function should define a `mdlSetInputPortFrameData` callback method. Simulink passes the frame status that it assigns to the port, based on frame signal propagation rules, as an argument to this callback method. The callback method should in turn use the `ssSetInputPortFrameData` function to set the port to the assigned status if it is acceptable or signal an error using `ssSetErrorStatus` if it is not. If the frame status of other ports of the S-function depend on the status inherited by one of its input ports, the callback method can also use `ssSetInputPortFrameData` to set the frame status of the other ports based on the status that the input port inherits. A template for the `mdlSetInputPortFrameData` callback is shown below.

```

#if defined(MATLAB_MEX_FILE)
#define MDL_SET_INPUT_PORT_FRAME_DATA
static void mdlSetInputPortFrameData(SimStruct *S,
                                     int_T      portIndex,
                                     Frame_T    frameData)
{
    if(!frameData==FRAME_YES) {
        ssSetErrorStatus(S, "Incorrect frame status");
        return;
    }
    ssSetInputPortFrameData(S, portIndex, frameData); /* Sets frame status */
} /* end mdlSetInputPortFrameData */
#endif

```

- The S-function's `mdlOutputs` method should include code to process the signals. The macro `ssGetInputPortDimensions` can be used in `mdlOutputs` to determine the dimensions of dynamically sized frame-based inputs, as follows:

```

int *dims = ssGetInputPortDimensions(S, 0);
int frameSize = dims[0];
int numChannels = dims[1];

```

See the frame-based A/D converter S-function example (`sfun_frmad.c`) for an example of how to create a frame-based S-function. This S-function is one of several S-functions that manipulate frame-based signals found in the Simulink model `sfendemo_frame.mdl`.

Handling Errors

In this section...

“About Handling Errors” on page 7-59

“Exception Free Code” on page 7-60

“ssSetErrorStatus Termination Criteria” on page 7-61

“Checking Array Bounds” on page 7-62

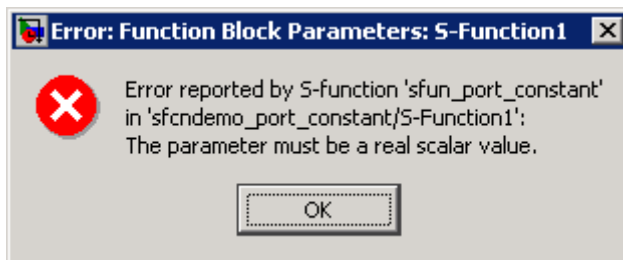
About Handling Errors

When working with S-functions, it is important to handle unexpected events such as invalid parameter values correctly.

If your S-function has parameters whose contents you need to validate, use the following technique to report errors encountered.

```
ssSetErrorStatus(S,"Error encountered due to ...");  
return;
```

In most cases, the error message is displayed in the Simulink Diagnostics Viewer. If the error is encountered in `mdlCheckParameters` as the S-function parameters are being entered into the block dialog, the error dialog shown below is opened. In either case, the error message is displayed along with the name of the S-function and the associated S-function block that invoked the error.



Note that the second argument to `ssSetErrorStatus` must be persistent memory. It cannot be a local variable in your procedure. For example, the following causes unpredictable errors.

```
mdlOutputs()
{
    char msg[256]; /* ILLEGAL: should be "static char */
                /*msg[256];"*/
    sprintf(msg, "Error due to %s", string);
    ssSetErrorStatus(S, msg);
    return;
}
```

Because `ssSetErrorStatus` does not generate exceptions, using it to report errors in your S-function is preferable to using `mexErrMsgTxt`. The `mexErrMsgTxt` function uses exception handling to terminate S-function execution and return control to Simulink. To support exception handling in S-functions, Simulink must set up exception handlers prior to each S-function invocation. This introduces overhead into simulation.

Exception Free Code

You can avoid this overhead by ensuring that your S-function contains entirely *exception free code*. Exception free code refers to code that never long-jumps. Your S-function is not exception free if it contains any routine that, when called, has the potential of long-jumping. For example, `mexErrMsgTxt` throws an exception (i.e., long-jumps) when called, thus ending execution of your S-function. Using `mxCalloc` can cause unpredictable results in the event of a memory allocation error, because `mxCalloc` long-jumps. If memory allocation is needed, use the `stdlib.h` `calloc` routine directly and perform your own error handling.

If you do not call `mexErrMsgTxt` or other API routines that cause exceptions, use the `SS_OPTION_EXCEPTION_FREE_CODE` S-function option. You do this by issuing the following command in the `mdlInitializeSizes` function.

```
ssSetOptions(S, SS_OPTION_EXCEPTION_FREE_CODE);
```

Setting this option increases the performance of your S-function by allowing Simulink to bypass the exception-handling setup that is usually performed

prior to each S-function invocation. You must take extreme care to verify that your code is exception free when using `SS_OPTION_EXCEPTION_FREE_CODE`. If your S-function generates an exception when this option is set, unpredictable results occur.

All `mex*` routines have the potential of long-jumping. Several `mex*` routines also have the potential of long-jumping. To avoid any difficulties, use only the API routines that retrieve a pointer or determine the size of parameters. For example, the following never throw an exception: `mxGetPr`, `mxGetData`, `mxGetNumberOfDimensions`, `mxGetM`, `mxGetN`, and `mxGetNumberOfElements`.

Code in *run-time routines* can also throw exceptions. Run-time routines refer to certain S-function routines that Simulink calls during the simulation loop (see “How Simulink Interacts with C S-Functions” on page 3-74). The run-time routines include

- `mdlGetTimeOfNextVarHit`
- `mdlOutputs`
- `mdlUpdate`
- `mdlDerivatives`

If all run-time routines within your S-function are exception free, you can use this option:

```
ssSetOptions(S, SS_OPTION_RUNTIME_EXCEPTION_FREE_CODE);
```

The other routines in your S-function do not have to be exception free.

ssSetErrorStatus Termination Criteria

If one of your S-function’s callback methods invokes `ssSetErrorStatus` during a simulation, Simulink posts the error and terminates the simulation as soon as the callback method returns. If your S-function’s `SS_OPTION_CALL_TERMINATE_ON_EXIT` option is enabled (see `ssSetOptions`), Simulink invokes your S-function’s `mdlTerminate` method as part of the termination process. Otherwise, Simulink invokes your S-function’s `mdlTerminate` method only if at least one block `mdlStart` method has executed without error during the simulation.

Checking Array Bounds

If your S-function causes otherwise inexplicable errors, the reason might be that the S-function is writing beyond its assigned areas in memory. You can verify this possibility by enabling the Simulink array bounds checking feature. This feature detects any attempt by an S-Function block to write beyond the areas assigned to it for the following types of block data:

- Work vectors (R, I, P, D, and mode)
- States (continuous and discrete)
- Outputs

To enable array bounds checking, select warning or error from the **Array bounds exceeded** options list in the **Debugging** group on the **Diagnostics -Data Validity** pane of the **Configuration Parameters** dialog box or enter the following command at the MATLAB command line.

```
set_param(modelName, 'ArrayBoundsChecking', ValueStr)
```

where `modelName` is the name of the Simulink model and `ValueStr` is either 'none', 'warning', or 'error'.

S-Function Examples

In this section...

“About S-Function Examples” on page 7-63

“Continuous States” on page 7-63

“Discrete States” on page 7-70

“Continuous and Discrete States” on page 7-77

“Variable Sample Time” on page 7-84

“Array Inputs and Outputs” on page 7-90

“Zero-Crossing Detection” on page 7-102

“Discontinuities in Continuous States” on page 7-119

About S-Function Examples

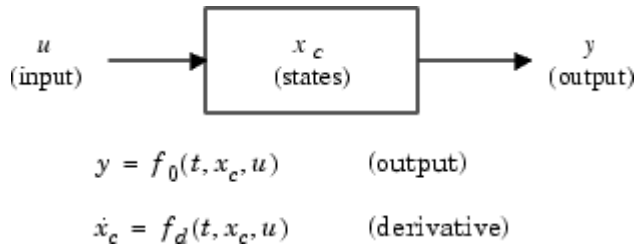
Most S-Function blocks require the handling of states, continuous or discrete. All examples are based on the C MEX-file S-function template `sfuntmpl_basic.c` and on `sfuntmpl_doc.c`, which contains a discussion of the S-function template.

Continuous States

The `matlabroot/simulink/src/csfunc.c` example shows how to model a continuous system with states in a C MEX S-function. The following Simulink model uses this S-function.

`matlabroot/toolbox/simulink/simdemos/simfeatures/sfcndemo_csfunc.mdl`

In continuous state integration, the Simulink solvers integrate a set of continuous states using the following equations.



S-functions that contain continuous states implement a state-space equation. The `mdlOutputs` method contains the output portion and `mdlDerivatives` method contains the derivative portion of the state-space equation. To visualize how the integration works, see the flowchart in “How Simulink Interacts with C S-Functions” on page 3-74. The output equation corresponds to the `mdlOutputs` in the major time step. Next, the example enters the integration section of the flowchart. Here Simulink performs a number of minor time steps during which it calls `mdlOutputs` and `mdlDerivatives`. Each of these pairs of calls is referred to as an *integration stage*. The integration returns with the continuous states updated and the simulation time moved forward. Time is moved forward as far as possible, providing that error tolerances in the state are met. The maximum time step is subject to constraints of discrete events such as the actual simulation stop time and the user-imposed limit.

The `csfunc.c` example specifies that the input port has direct feedthrough. This is because matrix `D` is initialized to a nonzero matrix. If `D` is set equal to a zero matrix in the state-space representation, the input signal is not used in `mdlOutputs`. In this case, the direct feedthrough can be set to 0, which indicates that `csfunc.c` does not require the input signal when executing `mdlOutputs`.

matlabroot/simulink/src/csfunc.c

The S-function begins with `#define` statements for the S-function’s name and level, and a `#include` statement for the `simstruc.h` header. After these statements, the S-function can include or define any other necessary headers, data, etc. The `csfunc.c` example defines the variable `U` as a pointer to the first input port’s signal and initializes static variables for the state-space matrices.

```
/* File      : csfunc.c
 * Abstract:
```

```

*
*   Example C-file S-function for defining a continuous system.
*
*    $x' = Ax + Bu$ 
*    $y = Cx + Du$ 
*
*   For more details about S-functions, see simulink/src/sfunmpl_doc.c.
*
*   Copyright 1990-2007 The MathWorks, Inc.
*/

#define S_FUNCTION_NAME csfunc
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

#define U(element) (*uPtrs[element]) /* Pointer to Input Port0 */

static real_T A[2][2]={ { -0.09, -0.01 } ,
                        { 1 , 0 }
                      };

static real_T B[2][2]={ { 1 , -7 } ,
                        { 0 , -2 }
                      };

static real_T C[2][2]={ { 0 , 2 } ,
                        { 1 , -5 }
                      };

static real_T D[2][2]={ { -3 , 0 } ,
                        { 1 , 0 }
                      };

```

The required S-function method `mdlInitializeSizes` then sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to zero.

- `ssGetSFcnParamsCount` determines how many parameters the user actually entered into the S-function dialog. If the number of user-specified parameters does not match the number returned by `ssGetNumSFcnParams`, the S-function errors out.
- If the S-function parameter count passes, `mdlInitializeSizes` sets the number of continuous and discrete states using `ssSetNumContStates` and `ssSetNumDiscStates`, respectively. This example has two continuous states and zero discrete states.
- Next, the method configures the S-function to have a single input and output port, each with a width of two to match the dimensions of the state-space matrices. The method passes a value of 1 to `ssSetInputPortDirectFeedThrough` to indicate the input port has direct feedthrough.
- `ssSetNumSampleTimes` initializes one sample time, which the `mdlInitializeSampleTimes` function configures later.
- The S-function indicates that no work vectors are used by passing a value of 0 to `ssSetNumRWork`, `ssSetNumIWork`, etc. These lines could be omitted because zero is the default value for all of these macros. However, for clarity, the S-function explicitly sets the number of work vectors.
- Lastly, `ssSetOptions` sets any applicable options. In this case, the only option is `SS_OPTION_EXCEPTION_FREE_CODE`, which stipulates that the code is exception free.

The `mdlInitializeSizes` function for this example is shown below.

```

/*=====
 * S-function methods *
 *=====*/

/* Function: mdlInitializeSizes =====
 * Abstract:
 *   The sizes information is used by Simulink to determine the S-function
 *   block's characteristics (number of inputs, outputs, states, etc.).
 */
static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, 0); /* Number of expected parameters */
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {

```

```

        return; /* Parameter mismatch will be reported by Simulink */
    }

    ssSetNumContStates(S, 2);
    ssSetNumDiscStates(S, 0);

    if (!ssSetNumInputPorts(S, 1)) return;
    ssSetInputPortWidth(S, 0, 2);
    ssSetInputPortDirectFeedThrough(S, 0, 1);

    if (!ssSetNumOutputPorts(S, 1)) return;
    ssSetOutputPortWidth(S, 0, 2);

    ssSetNumSampleTimes(S, 1);
    ssSetNumRWork(S, 0);
    ssSetNumIWork(S, 0);
    ssSetNumPWork(S, 0);
    ssSetNumModes(S, 0);
    ssSetNumNonsampledZCs(S, 0);

    /* Take care when specifying exception free code - see sfuntmpl_doc.c */
    ssSetOptions(S, SS_OPTION_EXCEPTION_FREE_CODE);
}

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's sample rates. The value `CONTINUOUS_SAMPLE_TIME` passed to the `ssSetSampleTime` macro specifies that the S-function's first sample rate is continuous. `ssSetOffsetTime` then specifies an offset time of zero for this sample rate. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   Specify that we have a continuous sample time.
 */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
}

```

```
        ssSetOffsetTime(S, 0, 0.0);
        ssSetModelReferenceSampleTimeDefaultInheritance(S);
    }
```

The optional S-function method `mdlInitializeConditions` initializes the continuous state vector. The `#define` statement before this method is required for Simulink to call this function. In the example below, `ssGetContStates` obtains a pointer to the continuous state vector. The for loop then initializes each state to zero.

```
#define MDL_INITIALIZE_CONDITIONS
/* Function: mdlInitializeConditions =====
 * Abstract:
 *   Initialize both continuous states to zero.
 */
static void mdlInitializeConditions(SimStruct *S)
{
    real_T *x0 = ssGetContStates(S);
    int_T lp;

    for (lp=0;lp<2;lp++) {
        *x0++=0.0;
    }
}
```

The required `mdlOutputs` function computes the output signal of this S-function. The beginning of the function obtains pointers to the first output port, continuous states, and first input port. The S-function uses the data in these arrays to solve the output equation $y=Cx+Du$.

```
/* Function: mdlOutputs =====
 * Abstract:
 *    $y = Cx + Du$ 
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    real_T *y = ssGetOutputPortRealSignal(S,0);
    real_T *x = ssGetContStates(S);
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);
```

```

UNUSED_ARG(tid); /* not used in single tasking mode */

/* y=Cx+Du */
y[0]=C[0][0]*x[0]+C[0][1]*x[1]+D[0][0]*U(0)+D[0][1]*U(1);
y[1]=C[1][0]*x[0]+C[1][1]*x[1]+D[1][0]*U(0)+D[1][1]*U(1);
}

```

The `mdlDerivatives` function calculates the continuous state derivatives. Because this function is an optional method, a `#define` statement must precede the function. The beginning of the function obtains pointers to the S-function's continuous states, state derivatives, and first input port. The S-function uses this data to solve the equation $dx=Ax+Bu$.

```

#define MDL_DERIVATIVES
/* Function: mdlDerivatives =====
 * Abstract:
 *      xdot = Ax + Bu
 */
static void mdlDerivatives(SimStruct *S)
{
    real_T      *dx   = ssGetdX(S);
    real_T      *x    = ssGetContStates(S);
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);

    /* xdot=Ax+Bu */
    dx[0]=A[0][0]*x[0]+A[0][1]*x[1]+B[0][0]*U(0)+B[0][1]*U(1);
    dx[1]=A[1][0]*x[0]+A[1][1]*x[1]+B[1][0]*U(0)+B[1][1]*U(1);
}

```

Simulink requires the S-function to contain an `mdlTerminate` function. In this example, the function is empty.

```

/* Function: mdlTerminate =====
 * Abstract:
 *      No termination needed, but we are required to have this routine.
 */
static void mdlTerminate(SimStruct *S)
{
    UNUSED_ARG(S); /* unused input argument */
}

```

The required S-function trailer includes the files necessary for simulation or code generation, as follows.

```

#ifdef MATLAB_MEX_FILE    /* Is this file being compiled as a MEX-file? */
#include "simulink.c"      /* MEX-file interface mechanism */
#else
#include "cg_sfun.h"      /* Code generation registration function */
#endif

```

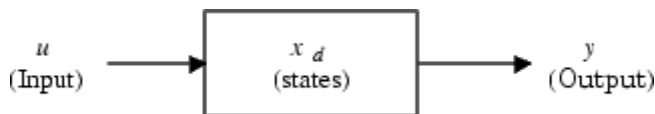
Note The `mdlOutputs` and `mdlTerminate` functions use the `UNUSED_ARG` macro to indicate that an input argument the callback requires is not used. This optional macro is defined in `matlabroot/simulink/include/simstruc_types.h`. If used, you must call this macro once for each input argument that a callback does not use.

Discrete States

The `matlabroot/simulink/src/dsfunc.c` example shows how to model a discrete system in a C MEX S-function. The following Simulink model uses this S-function.

`matlabroot/toolbox/simulink/simdemos/simfeatures/sfcdemo_dsfunc.mdl`

Discrete systems can be modeled by the following set of equations.



$$y = f_0(t, x_d, u) \quad (\text{Output})$$

$$x_{d+1} = f_u(t, x_d, u) \quad (\text{Update})$$

The `dsfunc.c` example implements a discrete state-space equation. The `mdlOutputs` method contains the output portion and the `mdlUpdate` method contains the update portion of the discrete state-space equation. To visualize how the simulation works, see the flowchart in “How Simulink Interacts with C S-Functions” on page 3-74. The output equation above corresponds

to the `mdlOutputs` in the major time step. The preceding update equation corresponds to the `mdlUpdate` in the major time step. If your model does not contain continuous elements, Simulink skips the integration phase and time is moved forward to the next discrete sample hit.

matlabroot/simulink/src/dsfunc.c

The S-function begins with `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. After these statements, the S-function can include or define any other necessary headers, data, etc. The `dsfunc.c` example defines `U` as a pointer to the first input port's signal and initializes static variables for the state-space matrices.

```

/* File      : dsfunc.c
 * Abstract:
 *
 *      Example C-file S-function for defining a discrete system.
 *
 *       $x(n+1) = Ax(n) + Bu(n)$ 
 *       $y(n) = Cx(n) + Du(n)$ 
 *
 *      For more details about S-functions, see simulink/src/sfuntmpl_doc.c.
 *
 * Copyright 1990-2007 The MathWorks, Inc.
 */

#define S_FUNCTION_NAME dsfunc
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

#define U(element) (*uPtrs[element]) /* Pointer to Input Port0 */

static real_T A[2][2]={ { -1.3839, -0.5097 } ,
                        { 1      , 0      }
                        };

static real_T B[2][2]={ { -2.5559, 0      } ,
                        { 0      , 4.2382 }
                        };

```

```
static real_T C[2][2]={ { 0      , 2.0761 } ,  
                        { 0      , 7.7891 }  
                        };  
  
static real_T D[2][2]={ { -0.8141, -2.9334 } ,  
                        { 1.2426, 0      }  
                        };
```

The required S-function method `mdlInitializeSizes` then sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to zero.
- `ssGetSFcnParamsCount` determines how many parameters the user actually entered into the S-function dialog. If the number of user-specified parameters does not match the number returned by `ssSetNumSFcnParams`, the S-function errors out.
- If the S-function parameter count passes, `mdlInitializeSizes` next sets the number of continuous and discrete states using `ssSetNumContStates` and `ssSetNumDiscStates`, respectively. This example has zero continuous states and two discrete states.
- Next, the method configures the S-function to have a single input and output port, each with a width of two to match the dimensions of the state-space matrices. The method passes a value of 1 to `ssSetInputPortDirectFeedThrough` to indicate the input port has direct feedthrough.
- `ssSetNumSampleTimes` initializes one sample time, which the `mdlInitializeSampleTimes` function configures later.
- The S-function indicates that no work vectors are used by passing a value of 0 to `ssSetNumRWork`, `ssSetNumIWork`, etc. These lines could be omitted because zero is the default value for all of these macros. However, for clarity, the S-function explicitly sets the number of work vectors.
- Lastly, `ssSetOptions` sets any applicable options. In this case, the only option is `SS_OPTION_EXCEPTION_FREE_CODE`, which stipulates that the code is exception free.

The mdlInitializeSizes function for this example is shown below.

```

/*=====
 * S-function methods *
 *=====*/

/* Function: mdlInitializeSizes =====
 * Abstract:
 *   The sizes information is used by Simulink to determine the S-function
 *   block's characteristics (number of inputs, outputs, states, etc.).
 */
static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, 0); /* Number of expected parameters */
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
        return; /* Parameter mismatch will be reported by Simulink */
    }

    ssSetNumContStates(S, 0);
    ssSetNumDiscStates(S, 2);

    if (!ssSetNumInputPorts(S, 1)) return;
    ssSetInputPortWidth(S, 0, 2);
    ssSetInputPortDirectFeedThrough(S, 0, 1);

    if (!ssSetNumOutputPorts(S, 1)) return;
    ssSetOutputPortWidth(S, 0, 2);

    ssSetNumSampleTimes(S, 1);
    ssSetNumRWork(S, 0);
    ssSetNumIWork(S, 0);
    ssSetNumPWork(S, 0);
    ssSetNumModes(S, 0);
    ssSetNumNonsampledZCs(S, 0);

    /* Take care when specifying exception free code - see sfuntmpl_doc.c */
    ssSetOptions(S, SS_OPTION_EXCEPTION_FREE_CODE);
}

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's sample rates. A call to `ssSetSampleTime` sets this S-function's first sample period to 1.0. `ssSetOffsetTime` then specifies an offset time of zero for the first sample rate. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   Specify a sample time of 1.0.
 */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, 1.0);
    ssSetOffsetTime(S, 0, 0.0);
    ssSetModelReferenceSampleTimeDefaultInheritance(S);
}

```

The optional S-function method `mdlInitializeConditions` initializes the discrete state vector. The `#define` statement before this method is required for Simulink to call this function. In the example below, `ssGetRealDiscStates` obtains a pointer to the discrete state vector. The for loop then initializes each discrete state to one.

```

#define MDL_INITIALIZE_CONDITIONS
/* Function: mdlInitializeConditions =====
 * Abstract:
 *   Initialize both discrete states to one.
 */
static void mdlInitializeConditions(SimStruct *S)
{
    real_T *x0 = ssGetRealDiscStates(S);
    int_T lp;

    for (lp=0;lp<2;lp++) {
        *x0++=1.0;
    }
}

```

The required `mdlOutputs` function computes the output signal of this S-function. The beginning of the function obtains pointers to the first output port, discrete states, and first input port. The S-function uses the data in these arrays to solve the output equation $y=Cx+Du$.

```

/* Function: mdlOutputs =====
 * Abstract:
 *      y = Cx + Du
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    real_T      *y      = ssGetOutputPortRealSignal(S,0);
    real_T      *x      = ssGetRealDiscStates(S);
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);

    UNUSED_ARG(tid); /* not used in single tasking mode */

    /* y=Cx+Du */
    y[0]=C[0][0]*x[0]+C[0][1]*x[1]+D[0][0]*U(0)+D[0][1]*U(1);
    y[1]=C[1][0]*x[0]+C[1][1]*x[1]+D[1][0]*U(0)+D[1][1]*U(1);
}

```

Simulink calls the `mdlUpdate` function once every major integration time step to update the discrete states' values. Because this function is an optional method, a `#define` statement must precede the function. The beginning of the function obtains pointers to the S-function's discrete states and first input port. The S-function uses the data in these arrays to solve the equation $dx=Ax+Bu$, which is stored in the temporary variable `tempX` before being assigned into the discrete state vector `x`.

```

#define MDL_UPDATE
/* Function: mdlUpdate =====
 * Abstract:
 *      xdot = Ax + Bu
 */
static void mdlUpdate(SimStruct *S, int_T tid)
{
    real_T      tempX[2] = {0.0, 0.0};
    real_T      *x      = ssGetRealDiscStates(S);
    InputRealPtrsType uPtrs      = ssGetInputPortRealSignalPtrs(S,0);

```

```
UNUSED_ARG(tid); /* not used in single tasking mode */

/* xdot=Ax+Bu */
tempX[0]=A[0][0]*x[0]+A[0][1]*x[1]+B[0][0]*U(0)+B[0][1]*U(1);
tempX[1]=A[1][0]*x[0]+A[1][1]*x[1]+B[1][0]*U(0)+B[1][1]*U(1);

x[0]=tempX[0];
x[1]=tempX[1];
}
```

Simulink requires the S-function to contain an `mdlTerminate` function. In this example, the function is empty.

```
/* Function: mdlTerminate =====
 * Abstract:
 *   No termination needed, but we are required to have this routine.
 */
static void mdlTerminate(SimStruct *S)
{
    UNUSED_ARG(S); /* unused input argument */
}
```

The required S-function trailer includes the files necessary for simulation or code generation, as follows.

```
#ifdef MATLAB_MEX_FILE /* Is this file being compiled as a MEX-file? */
#include "simulink.c" /* MEX-file interface mechanism */
#else
#include "cg_sfun.h" /* Code generation registration function */
#endif
```

Note The `mdlOutputs` and `mdlTerminate` functions use the `UNUSED_ARG` macro to indicate that an input argument the callback requires is not used. This optional macro is defined in `matlabroot/simulink/include/simstruc_types.h`. If used, you must call this macro once for each input argument that a callback does not use.

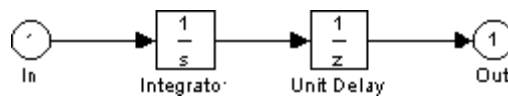
Continuous and Discrete States

The `matlabroot/simulink/src/mixedm.c` example shows a hybrid (a combination of continuous and discrete states) system. The `mixedm.c` example combines elements of `csfunc.c` and `dsfunc.c`. The following Simulink model uses this S-function.

`matlabroot/toolbox/simulink/simdemos/simfeatures/sfcndemo_mixedm.mdl`

If you have a hybrid system, the `mdlDerivatives` method calculates the derivatives of the continuous states of the state vector, x , and the `mdlUpdate` method contains the equations used to update the discrete state vector, xD . The `mdlOutputs` method computes the S-function outputs after checking for sample hits to determine at what point the S-function is being called.

In Simulink block diagram form, the S-function `mixedm.c` looks like



which implements a continuous integrator followed by a discrete unit delay.

`matlabroot/simulink/src/mixedm.c`

The S-function begins with `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. After these statements, the S-function can include or define any other necessary headers, data, etc. The `mixedm.c` example defines `U` as a pointer to the first input port's signal.

```

/* File      : mixedm.c
 * Abstract:
 *
 *      An example S-function illustrating multiple sample times by implementing
 *      integrator -> ZOH(Ts=1second) -> UnitDelay(Ts=1second)
 *      with an initial condition of 1.
 *      (e.g. an integrator followed by unit delay operation).
 *
 *      For more details about S-functions, see simulink/src/sfunmpl_doc.c
 *

```

```
* Copyright 1990-2007 The MathWorks, Inc.
*/

#define S_FUNCTION_NAME mixedm
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

#define U(element) (*uPtrs[element]) /* Pointer to Input Port0 */
```

The required S-function method `mdlInitializeSizes` then sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to zero.
- `ssGetSFcnParamsCount` determines how many parameters the user actually entered into the S-function dialog. If the number of user-specified parameters does not match the number returned by `ssGetNumSFcnParams`, the S-function errors out.
- If the S-function parameter count passes, `mdlInitializeSizes` next sets the number of continuous and discrete states using `ssSetNumContStates` and `ssSetNumDiscStates`, respectively. This example has one continuous state and one discrete state.
- The S-function initializes one floating-point work vector by passing a value of 1 to `ssSetNumRWork`. No other work vectors are initialized.
- Next, the method uses `ssSetNumInputPorts` and `ssSetNumOutputPorts` to configure the S-function to have a single input and output port, each with a width of one. The method passes a value of 1 to `ssSetInputPortDirectFeedThrough` to indicate the input port has direct feedthrough.
- This S-function assigns sample times using a hybrid block-based and port-based method. The macro `ssSetNumSampleTimes` initializes two block-based sample times, which the `mdlInitializeSampleTimes` function configures later. The macros `ssSetInputPortSampleTime` and `ssSetInputPortOffsetTime` initialize the input port to have a continuous sample time with an offset of zero. Similarly, `ssSetOutputPortSampleTime`

and `ssSetOutputPortOffsetTime` initialize the output port sample time to 1 with an offset of zero.

- Lastly, `ssSetOptions` sets two S-function options. `SS_OPTION_EXCEPTION_FREE_CODE` stipulates that the code is exception free and `SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED` indicates a combination of block-based and port-based sample times.

The `mdlInitializeSizes` function for this example is shown below.

```
*=====
* S-function methods *
*=====*/

/* Function: mdlInitializeSizes =====
* Abstract:
*   The sizes information is used by Simulink to determine the S-function
*   block's characteristics (number of inputs, outputs, states, etc.).
*/
static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, 0); /* Number of expected parameters */
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
        return; /* Parameter mismatch will be reported by Simulink */
    }

    ssSetNumContStates(S, 1);
    ssSetNumDiscStates(S, 1);
    ssSetNumRWork(S, 1); /* for zoh output feeding the delay operator */

    if (!ssSetNumInputPorts(S, 1)) return;
    ssSetInputPortWidth(S, 0, 1);
    ssSetInputPortDirectFeedThrough(S, 0, 1);
    ssSetInputPortSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
    ssSetInputPortOffsetTime(S, 0, 0.0);

    if (!ssSetNumOutputPorts(S, 1)) return;
    ssSetOutputPortWidth(S, 0, 1);
    ssSetOutputPortSampleTime(S, 0, 1.0);
    ssSetOutputPortOffsetTime(S, 0, 0.0);
}
```

```

        ssSetNumSampleTimes(S, 2);

        /* Take care when specifying exception free code - see sfuntmpl_doc.c. */
        ssSetOptions(S, (SS_OPTION_EXCEPTION_FREE_CODE |
                        SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED));

    } /* end mdlInitializeSizes */

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's block-based sample rates. The first call to `ssSetSampleTime` specifies that the first sample rate is continuous, with the subsequent call to `ssSetOffsetTime` setting the offset to zero. The second call to this pair of macros sets the second sample time to 1 with an offset of zero. The S-function's port-based sample times set in `mdlInitializeSizes` must all be registered as a block-based sample time. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   Two tasks: One continuous, one with discrete sample time of 1.0.
 */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);

    ssSetSampleTime(S, 1, 1.0);
    ssSetOffsetTime(S, 1, 0.0);
    ssSetModelReferenceSampleTimeDefaultInheritance(S);
} /* end mdlInitializeSampleTimes */

```

The optional S-function method `mdlInitializeConditions` initializes the continuous and discrete state vectors. The `#define` statement before this method is required for Simulink to call this function. In this example, `ssGetContStates` obtains a pointer to the continuous state vector and `ssGetRealDiscStates` obtains a pointer to the discrete state vector. The method then sets all states' initial conditions to one.

```

#define MDL_INITIALIZE_CONDITIONS
/* Function: mdlInitializeConditions =====
 * Abstract:
 *   Initialize both continuous states to one.
 */
static void mdlInitializeConditions(SimStruct *S)
{
    real_T *xC0 = ssGetContStates(S);
    real_T *xD0 = ssGetRealDiscStates(S);

    xC0[0] = 1.0;
    xD0[0] = 1.0;

} /* end mdlInitializeConditions */

```

The required `mdlOutputs` function performs computations based on the current task. The macro `ssIsContinuousTask` checks if the continuous task is executing. If this macro returns true, `ssIsSpecialSampleHit` then checks if the discrete sample rate is also executing. If this macro also returns true, the method sets the value of the floating-point work vector to the current value of the continuous state, via pointers obtained using `ssGetRWork` and `ssGetContStates`, respectively. The `mdlUpdate` method later uses the floating-point work vector as the input to the zero-order hold. Updating the work vector in `mdlOutputs` ensures that the correct values are available during subsequent calls to `mdlUpdate`. Finally, if the S-function is running at its discrete rate, i.e., the call to `ssIsSampleHit` returns true, the method sets the output to the value of the discrete state.

```

/* Function: mdlOutputs =====
 * Abstract:
 *   y = xD, and update the zoh internal output.
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    /* update the internal "zoh" output */
    if (ssIsContinuousTask(S, tid)) {
        if (ssIsSpecialSampleHit(S, 1, 0, tid)) {
            real_T *zoh = ssGetRWork(S);
            real_T *xC = ssGetContStates(S);
            *zoh = *xC;
        }
    }
}

```

```
    }
}

/* y=xD */
if (ssIsSampleHit(S, 1, tid)) {
    real_T *y = ssGetOutputPortRealSignal(S,0);
    real_T *xD = ssGetRealDiscStates(S);
    y[0]=xD[0];
}

} /* end mdlOutputs */
```

Simulink calls the `mdlUpdate` function once every major integration time step to update the discrete states' values. Because this function is an optional method, a `#define` statement must precede the function. The call to `ssIsSampleHit` ensures the body of the method is executed only when the S-function is operating at its discrete rate. If `ssIsSampleHit` returns true, the method obtains pointers to the S-function's discrete state and floating-point work vector and updates the discrete state's value using the value stored in the work vector.

```
#define MDL_UPDATE
/* Function: mdlUpdate =====
 * Abstract:
 *      xD = xC
 */
static void mdlUpdate(SimStruct *S, int_T tid)
{
    UNUSED_ARG(tid); /* not used in single tasking mode */

    /* xD=xC */
    if (ssIsSampleHit(S, 1, tid)) {
        real_T *xD = ssGetRealDiscStates(S);
        real_T *zoh = ssGetRWork(S);
        xD[0]=*zoh;
    }
} /* end mdlUpdate */
```

The `mdlDerivatives` function calculates the continuous state derivatives. Because this function is an optional method, a `#define` statement must precede the function. The function obtains pointers to the S-function's continuous state derivative and first input port then sets the continuous state derivative equal to the value of the first input.

```
#define MDL_DERIVATIVES
/* Function: mdlDerivatives =====
 * Abstract:
 *      xdot = U
 */
static void mdlDerivatives(SimStruct *S)
{
    real_T      *dx   = ssGetX(S);
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);

    /* xdot=U */
    dx[0]=U(0);

} /* end mdlDerivatives */
```

Simulink requires the S-function to contain an `mdlTerminate` function. In this example, the function is empty.

```
/* Function: mdlTerminate =====
 * Abstract:
 *      No termination needed, but we are required to have this routine.
 */
static void mdlTerminate(SimStruct *S)
{
    UNUSED_ARG(S); /* unused input argument */
}

```

The S-function trailer includes the files necessary for simulation or code generation, as follows.

```
#ifdef MATLAB_MEX_FILE /* Is this file being compiled as a MEX-file? */
#include "simulink.c" /* MEX-file interface mechanism */
#else
#include "cg_sfun.h" /* Code generation registration function */
#endif
```

Note The `mdlUpdate` and `mdlTerminate` functions use the `UNUSED_ARG` macro to indicate that an input argument the callback requires is not used. This optional macro is defined in `matlabroot/simulink/include/simstruc_types.h`. If used, you must call this macro once for each input argument that a callback does not use.

Variable Sample Time

The example S-function `matlabroot/simulink/src/vsfunc.c` uses a variable-step sample time. The following Simulink model uses this S-function.

`matlabroot/toolbox/simulink/simdemos/simfeatures/sfcdemo_vsfunc.mdl`

Variable step-size functions require a call to `mdlGetTimeOfNextVarHit`, which is an S-function routine that calculates the time of the next sample hit. S-functions that use the variable-step sample time can be used only with variable-step solvers. The `vsfunc.c` example is a discrete S-function that delays its first input by an amount of time determined by the second input.

The `vsfunc.c` example outputs the input `u` delayed by a variable amount of time. `mdlOutputs` sets the output `y` equal to state `x`. `mdlUpdate` sets the state vector `x` equal to `u`, the input vector. This example calls `mdlGetTimeOfNextVarHit` to calculate and set the time of the next sample hit, that is, the time when `vsfunc.c` is next called. In `mdlGetTimeOfNextVarHit`, the macro `ssGetInputPortRealSignalPtrs` gets a pointer to the input `u`. Then this call is made:

```
ssSetTNext(S, ssGetT(S)(*u[1]));
```

The macro `ssGetT` gets the simulation time `t`. The second input to the block, `(*u[1])`, is added to `t`, and the macro `ssSetTNext` sets the time of the next hit equal to `t+(*u[1])`, delaying the output by the amount of time set in `(*u[1])`.

matlabroot/simulink/src/vsfunc.c

The S-function begins with `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. After these statements, the S-function can include or define any other necessary

headers, data, etc. The `vsfunc.c` example defines `U` as a pointer to the first input port's signal.

```

/* File      : vsfunc.c
 * Abstract:
 *
 *      Variable step S-function example.
 *      This example S-function illustrates how to create a variable step
 *      block in Simulink. This block implements a variable step delay
 *      in which the first input is delayed by an amount of time determined
 *      by the second input:
 *
 *      dt      = u(2)
 *      y(t+dt) = u(t)
 *
 *      For more details about S-functions, see simulink/src/sfuntmpl_doc.c.
 *
 * Copyright 1990-2007 The MathWorks, Inc.
 */

#define S_FUNCTION_NAME vsfunc
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

#define U(element) (*uPtrs[element]) /* Pointer to Input Port0 */

```

The required S-function method `mdlInitializeSizes` then sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to zero.
- `ssGetSFcnParamsCount` determines how many parameters the user actually entered into the S-function dialog. If the number of user-specified parameters does not match the number returned by `ssSetNumSFcnParams`, the S-function errors out.
- If the S-function parameter count passes, `mdlInitializeSizes` next sets the number of continuous and discrete states using `ssSetNumContStates`

and `ssSetNumDiscStates`, respectively. This example has no continuous states and one discrete state.

- Next, the method uses `ssSetNumInputPorts` and `ssSetNumOutputPorts` to configure the S-function to have a single input and output port. Calls to `ssSetInputPortWidth` and `ssSetOutputPortWidth` assign widths to these input and output ports. The method passes a value of 1 to `ssSetInputPortDirectFeedThrough` to indicate the input port has direct feedthrough.
- `ssSetNumSampleTimes` then initializes one sample time, which the `mdlInitializeSampleTimes` function configures later.
- The S-function indicates that no work vectors are used by passing a value of 0 to `ssSetNumRWork`, `ssSetNumIWork`, etc. These lines could be omitted because zero is the default value for all of these macros. However, for clarity, the S-function explicitly sets the number of work vectors.
- Next, `ssGetSimMode` checks if the S-function is being run in a simulation or with Real-Time Workshop. If `ssGetSimMode` returns `SS_SIMMODE_RTWGEN` and `ssIsVariableStepSolver` returns false, indicating use with Real-Time Workshop and a fixed-step solver, then the S-function errors out.
- Lastly, `ssSetOptions` sets any applicable options. In this case, the only option is `SS_OPTION_EXCEPTION_FREE_CODE`, which stipulates that the code is exception free.

The `mdlInitializeSizes` function for this example is shown below.

```
/* Function: mdlInitializeSizes =====
 * Abstract:
 *   The sizes information is used by Simulink to determine the S-function
 *   block's characteristics (number of inputs, outputs, states, etc.).
 */
static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, 0); /* Number of expected parameters */
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
        return; /* Parameter mismatch will be reported by Simulink */
    }

    ssSetNumContStates(S, 0);
    ssSetNumDiscStates(S, 1);
}
```



```

    if (!ssSetNumInputPorts(S, 1)) return;
    ssSetInputPortWidth(S, 0, 2);
    ssSetInputPortDirectFeedThrough(S, 0, 1);

    if (!ssSetNumOutputPorts(S, 1)) return;
    ssSetOutputPortWidth(S, 0, 1);

    ssSetNumSampleTimes(S, 1);
    ssSetNumRWork(S, 0);
    ssSetNumIWork(S, 0);
    ssSetNumPWork(S, 0);
    ssSetNumModes(S, 0);
    ssSetNumNonsampledZCs(S, 0);

    if (ssGetSimMode(S) == SS_SIMMODE_RTWGEN && !ssIsVariableStepSolver(S)) {
        ssSetErrorStatus(S, "S-function vsfunc.c cannot be used with RTW "
            "and Fixed-Step Solvers because it contains variable "
            "sample time");
    }

    /* Take care when specifying exception free code - see sfuntmpl_doc.c */
    ssSetOptions(S, SS_OPTION_EXCEPTION_FREE_CODE);
}

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's sample rates. The input argument `VARIABLE_SAMPLE_TIME` passed to `ssSetSampleTime` specifies that this S-function has a variable-step sample time and `ssSetOffsetTime` specifies an offset time of zero. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model. Because the S-function has a variable-step sample time, `vsfunc.c` must calculate the time of the next sample hit in the `mdlGetTimeOfNextVarHit` method, shown later.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   Variable-Step S-function
 */
static void mdlInitializeSampleTimes(SimStruct *S)

```

```

{
    ssSetSampleTime(S, 0, VARIABLE_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);
    ssSetModelReferenceSampleTimeDefaultInheritance(S);
}

```

The optional S-function method `mdlInitializeConditions` initializes the discrete state vector. The `#define` statement before this method is required for Simulink to call this function. In the example, the method uses `ssGetRealDiscStates` to obtain a pointer to the discrete state vector and sets the state's initial value to zero.

```

#define MDL_INITIALIZE_CONDITIONS
/* Function: mdlInitializeConditions =====
 * Abstract:
 *   Initialize discrete state to zero.
 */
static void mdlInitializeConditions(SimStruct *S)
{
    real_T *x0 = ssGetRealDiscStates(S);

    x0[0] = 0.0;
}

```

The optional `mdlGetTimeOfNextVarHit` method calculates the time of the next sample hit. Because this method is optional, a `#define` statement precedes it. First, this method obtains a pointer to the first input port's signal using `ssGetInputPortRealSignalPtrs`. If the input signal's second element is positive, the macro `ssGetT` gets the simulation time `t`. The macro `ssSetTNext` sets the time of the next hit equal to `t + (*U[1])`, delaying the output by the amount of time specified by the input's second element (`*U[1]`).

```

#define MDL_GET_TIME_OF_NEXT_VAR_HIT
static void mdlGetTimeOfNextVarHit(SimStruct *S)
{
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);

    /* Make sure input will increase time */
    if (U(1) <= 0.0) {
        /* If not, abort simulation */

```

```

        ssSetErrorStatus(S,"Variable step control input must be "
                        "greater than zero");
    return;
}
ssSetTNext(S, ssGetT(S)+U(1));
}

```

The required `mdlOutputs` function computes the S-function's output signal. The function obtains pointers to the first output port and discrete state and then assigns the state's current value to the output.

```

/* Function: mdlOutputs =====
 * Abstract:
 *      y = x
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    real_T *y = ssGetOutputPortRealSignal(S,0);
    real_T *x = ssGetRealDiscStates(S);

    /* Return the current state as the output */
    y[0] = x[0];
}

```

The `mdlUpdate` function updates the discrete state's value. Because this method is optional, a `#define` statement precedes it. The function first obtains pointers to the S-function's discrete state and first input port then assigns the value of the first element of the first input port signal to the state.

```

#define MDL_UPDATE
/* Function: mdlUpdate =====
 * Abstract:
 *      This function is called once for every major integration time step.
 *      Discrete states are typically updated here, but this function is useful
 *      for performing any tasks that should only take place once per integration
 *      step.
 */
static void mdlUpdate(SimStruct *S, int_T tid)
{
    real_T      *x      = ssGetRealDiscStates(S);

```

```
        InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);

        x[0]=U(0);
    }
}
```

Simulink requires the S-functions to contain an `mdlTerminate` function. In this example, the function is empty.

```
/* Function: mdlTerminate =====
 * Abstract:
 *   No termination needed, but we are required to have this routine.
 */
static void mdlTerminate(SimStruct *S)
{
}
}
```

The required S-function trailer includes the files necessary for simulation or code generation, as follows.

```
#ifdef MATLAB_MEX_FILE    /* Is this file being compiled as a MEX-file? */
#include "simulink.c"      /* MEX-file interface mechanism */
#else
#include "cg_sfun.h"       /* Code generation registration function */
#endif
```

Array Inputs and Outputs

The example S-function `matlabroot/simulink/src/sfun_matadd.c` demonstrates how to implement a matrix addition block. The following Simulink model uses this S-function.

`matlabroot/toolbox/simulink/simdemos/simfeatures/sfcndemo_matadd.mdl`

The S-function adds signals of various dimensions to a parameter value entered in the S-function. The S-function accepts and outputs 2-D or n-D signals.

matlabroot/simulink/src/sfun_matadd.c

The S-function begins with `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. After these statements, the S-function includes or defines any other necessary headers, data, etc. This example defines additional variables for the number of S-function parameters, the S-function parameter value, and the flag `EDIT_OK` that indicates if the parameter value can be edited during simulation.

```

/* SFUN_MATADD matrix support example.
 * C-MEX S-function for matrix addition with one input port,
 * one output port, and one parameter.
 *
 * Input Signal: 2-D or n-D array
 * Parameter: 2-D or n-D array
 * Output Signal: 2-D or n-D array
 *
 * Input parameter output
 * -----
 * scalar scalar scalar
 * scalar matrix matrix (input scalar expansion)
 * matrix scalar matrix (parameter scalar expansion)
 * matrix matrix matrix
 *
 * Copyright 1990-2007 The MathWorks, Inc.
 */
#define S_FUNCTION_NAME sfun_matadd
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

enum {PARAM = 0, NUM_PARAMS};

#define PARAM_ARG ssGetSFcnParam(S, PARAM)

#define EDIT_OK(S, ARG) \
    (!((ssGetSimMode(S) == SS_SIMMODE_SIZES_CALL_ONLY) \
    && mxIsEmpty(ARG)))

```

The S-function next implements the `mdlCheckParameters` method to validate the S-function dialog parameters. The `#ifdef` statement checks that the S-function is compiled as a MEX-file, instead of for use with Real-Time Workshop. Because `mdlCheckParameters` is optional, the S-function code contains a `#define` statement to register the method. The body of the function checks that the S-function parameter value is not empty. If the parameter check fails, the S-function errors out with a call to `ssSetErrorStatus`.

```
#ifdef MATLAB_MEX_FILE
#define MDL_CHECK_PARAMETERS
/* Function: mdlCheckParameters =====

* Abstract:
*   Verify parameter settings.
*/
static void mdlCheckParameters(SimStruct *S)
{
    if(EDIT_OK(S, PARAM_ARG)){
        /* Check that parameter value is not empty*/
        if( mxIsEmpty(PARAM_ARG) ) {
            ssSetErrorStatus(S, "Invalid parameter specified. The"
                "parameter must be non-empty");
            return;
        }
    }
} /* end mdlCheckParameters */
#endif
```

The required S-function method `mdlInitializeSizes` then sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to one, as defined by the variable `NUM_PARAMS`.
- If this S-function is compiled as a MEX-file, `ssGetSFcnParamsCount` determines how many parameters the user actually entered into the S-function dialog. If the number of user-specified parameters matches the number returned by `ssGetNumSFcnParams`, the method calls `mdlCheckParameters` to validate the user-entered data. Otherwise, the S-function errors out.

- If the parameter check passes, the S-function specifies that all S-function parameters are tunable using `ssSetSFcnParamTunable`.
- The S-function then invokes `ssAllowSignalsWithMoreThan2D` to allow the S-function to accept n-D signals.
- Next, `ssSetNumOutputPorts` and `ssSetNumInputPorts` specify that the S-function has a single output port and a single input port.
- The S-function uses `ssSetInputPortDimensionInfo` to specify that the input port is dynamically sized. In this case, the S-function needs to implement an `mdlSetInputPortDimensionInfo` method to set the actual input dimension.
- The output dimensions depend on the dimensions of the S-function parameter. If the parameter is a scalar, the call to `ssSetOutputPortDimensionInfo` specifies that the output port dimensions are dynamically sized. If the parameter is a matrix, the output port dimensions are initialized to the dimensions of the S-function parameter. In this case, the macro `DECL_AND_INIT_DIMSINFO` initializes a `dimsInfo` structure. The S-function assigns the width, size, and dimensions of the S-function parameter into the `dimsInfo` structure and then passes this structure to `ssSetOutputPortDimensionInfo` to set the output port dimensions accordingly.
- The S-function specifies that the input port has direct feedthrough by passing a value of 1 to `ssSetInputPortDirectFeedThrough`.
- `ssSetNumSampleTimes` initializes one sample time, to be configured later in the `mdlInitializeSampleTimes` method.
- Lastly, `ssSetOptions` sets any applicable options. In this case, `SS_OPTION_EXCEPTION_FREE_CODE` stipulates that the code is exception free and `SS_OPTION_WORKS_WITH_CODE_REUSE` signifies that this S-function is compatible with the subsystem code reuse feature of Real-Time Workshop.

```

/* Function: mdlInitializeSizes =====
 * Abstract:
 *   Initialize the sizes array
 */
static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, NUM_PARAMS);

```

```
#if defined(MATLAB_MEX_FILE)
    if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
        return; }
    mdlCheckParameters(S);
    if (ssGetErrorStatus(S) != NULL) return;
#endif

{
    int iParam = 0;
    int nParam = ssGetNumSFcnParams(S);

    for ( iParam = 0; iParam < nParam; iParam++ )
    {
        ssSetSFcnParamTunable( S, iParam, SS_PRM_TUNABLE );
    }
}

/* Allow signal dimensions greater than 2 */
ssAllowSignalsWithMoreThan2D(S);

/* Set number of input and output ports */
if (!ssSetNumInputPorts( S,1)) return;
if (!ssSetNumOutputPorts(S,1)) return;

/* Set dimensions of input and output ports */
{
    int_T pWidth = mxGetNumberOfElements(PARAM_ARG);
    /* Input can be a scalar or a matrix signal. */
    if(!ssSetInputPortDimensionInfo(S,0,DYNAMIC_DIMENSION)) {
        return; }

    if( pWidth == 1) {
        /* Scalar parameter: output dimensions are unknown. */
        if(!ssSetOutputPortDimensionInfo(S,0,DYNAMIC_DIMENSION)){
            return; }
        }
    else{
        /*
         * Non-scalar parameter: output dimensions are the same
```



```

    * as the parameter dimensions. To support n-D signals,
    * must use a dimsInfo structure to specify dimensions.
    */
    DECL_AND_INIT_DIMSINFO(di); /*Initializes structure*/
    int_T      pSize = mxGetNumberOfDimensions(PARAM_ARG);
    const int_T *pDims = mxGetDimensions(PARAM_ARG);
    di.width   = pWidth;
    di.numDims = pSize;
    di.dims    = pDims;
    if(!ssSetOutputPortDimensionInfo(S, 0, &di)) return;
    }
}

ssSetInputPortDirectFeedThrough(S, 0, 1);

ssSetNumSampleTimes(S, 1);
ssSetOptions(S,
              SS_OPTION_WORKS_WITH_CODE_REUSE |
              SS_OPTION_EXCEPTION_FREE_CODE);
} /* end mdlInitializeSizes */

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's sample rates. To specify that this S-function inherits its sample time from its driving block, the S-function calls `ssSetSampleTime` with the input argument `INHERITED_SAMPLE_TIME`. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   Initialize the sample times array.
 */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, INHERITED_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);
    ssSetModelReferenceSampleTimeDefaultInheritance(S);
} /* end mdlInitializeSampleTimes */

```

The S-function calls the `mdlSetWorkWidths` method to register its run-time parameters. Because `mdlSetWorkWidths` is an optional method, a `#define` statement precedes it. The method first initializes a name for the run-time parameter and then uses `ssRegAllTunableParamsAsRunTimeParams` to register the run-time parameter.

```

/* Function: mdlSetWorkWidths =====
 * Abstract:
 *   Set up run-time parameter.
 */
#define MDL_SET_WORK_WIDTHS
static void mdlSetWorkWidths(SimStruct *S)
{
    const char_T    *rtParamNames[] = {"Operand"};
    ssRegAllTunableParamsAsRunTimeParams(S, rtParamNames);
} /* end mdlSetWorkWidths */

```

The S-function's `mdlOutputs` method uses a `for` loop to calculate the output as the sum of the input and S-function parameter. The S-function handles n-D arrays of data using a single index into the array.

```

/* Function: mdlOutputs =====
 * Abstract:
 *   Compute the outputs of the S-function.
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    InputRealPtrsType uPtr = ssGetInputPortRealSignalPtrs(S,0);
    real_T            *y   = ssGetOutputPortRealSignal(S,0);
    const real_T      *p   = mxGetPr(PARAM_ARG);

    int_T             uWidth = ssGetInputPortWidth(S,0);
    int_T             pWidth = mxGetNumberOfElements(PARAM_ARG);
    int_T             yWidth = ssGetOutputPortWidth(S,0);
    int               i;

    UNUSED_ARG(tid); /* not used in single tasking mode */

    /*
     * Note1: Matrix signals are stored in column major order.
     * Note2: Access each matrix element by one index not two
    */
}

```

```

*      indices. For example, if the output signal is a
*      [2x2] matrix signal,
*      -      -
*      | y[0]  y[2] |
*      | y[1]  y[3] |
*      -      -
*      Output elements are stored as follows:
*      y[0] --> row = 0, col = 0
*      y[1] --> row = 1, col = 0
*      y[2] --> row = 0, col = 1
*      y[3] --> row = 1, col = 1
*/

for (i = 0; i < yWidth; i++) {
    int_T uIdx = (uWidth == 1) ? 0 : i;
    int_T pIdx = (pWidth == 1) ? 0 : i;

    y[i] = *uPtr[uIdx] + p[pIdx];
}
} /* end mdlOutputs */

```

During signal propagation, the S-function calls the optional `mdlSetInputPortDimensionInfo` method with the candidate input port dimensions stored in `dimsInfo`. The `#if defined` statement checks that the S-function is compiled as a MEX-file. Because `mdlSetInputPortDimensionInfo` is an optional method, a `#define` statement precedes it. In `mdlSetInputPortDimensionInfo`, the S-function uses `ssSetInputPortDimensionInfo` to set the dimensions of the input port to the candidate dimensions. If the call to this macro succeeds, the S-function further checks the candidate dimensions to ensure that the input signal is either a 2-D scalar or a matrix. If this condition is met and the output port dimensions are still dynamically sized, the S-function calls `ssSetOutputPortDimensionInfo` to set the dimension of the output port to the same candidate dimensions. The `ssSetOutputPortDimensionInfo` macro cannot modify the output port dimensions if they are already specified.

```

#if defined(MATLAB_MEX_FILE)
#define MDL_SET_INPUT_PORT_DIMENSION_INFO
/* Function: mdlSetInputPortDimensionInfo =====
* Abstract:

```

```
* This routine is called with the candidate dimensions for
* an input port with unknown dimensions. If the proposed
* dimensions are acceptable, the routine should go ahead and
* set the actual port dimensions. If they are unacceptable
* an error should be generated via ssSetErrorStatus.
* Note that any other input or output ports whose dimensions
* are implicitly defined by virtue of knowing the dimensions
* of the given port can also have their dimensions set.
*/
static void mdlSetInputPortDimensionInfo(SimStruct *S,
    int_T port,
    const DimsInfo_T *dimsInfo)
{
    int_T pWidth = mxGetNumberOfElements(PARAM_ARG);
    int_T pSize = mxGetNumberOfDimensions(PARAM_ARG);
    const int_T *pDims = mxGetDimensions(PARAM_ARG);

    int_T uNumDims = dimsInfo->numDims;
    int_T uWidth = dimsInfo->width;
    int_T *uDims = dimsInfo->dims;

    int_T numDims;
    boolean_T isOk = true;
    int iParam = 0;
    int_T outWidth = ssGetOutputPortWidth(S, 0);

    /* Set input port dimension */
    if(!ssSetInputPortDimensionInfo(S, port, dimsInfo)) return;

    /*
    * The block only accepts 2-D or higher signals. Check
    * number of dimensions. If the parameter and the input
    * signal are non-scalar, their dimensions must be the same.
    */
    isOk = (uNumDims >= 2) && (pWidth == 1 || uWidth == 1 ||
        pWidth == uWidth);
    numDims = (pSize != uNumDims) ? numDims : uNumDims;

    if(isOk && pWidth > 1 && uWidth > 1){
        for ( iParam = 0; iParam < numDims; iParam++ ) {
```

```

        isOk = (pDims[iParam] == uDims[iParam]);
        if(!isOk) break;
    }
}

if(!isOk){
    ssSetErrorStatus(S,"Invalid input port dimensions. The "
        "input signal must be a 2-D scalar signal, or it must "
        "be a matrix with the same dimensions as the parameter "
        "dimensions.");
    return;
}

/* Set the output port dimensions */
if (outWidth == DYNAMICALLY_SIZED){
    if(!ssSetOutputPortDimensionInfo(S,port,dimsInfo) return;
}
} /* end mdlSetInputPortDimensionInfo */

```

During signal propagation, if any output ports have unknown dimensions, the S-function calls the optional `mdlSetOutputPortDimensionInfo` method. Because this method is optional, a `#define` statement precedes it. In `mdlSetOutputPortDimensionInfo`, the S-function uses `ssSetOutputPortDimensionInfo` to set the dimensions of the output port to the candidate dimensions `dimsInfo`. If the call to this macro succeeds, the S-function further checks the candidate dimensions to ensure that the input signal is either a 2-D or n-D matrix. If this condition is not met, the S-function errors out with a call to `ssSetErrorStatus`. Otherwise, the S-function calls `ssSetInputPortDimensionInfo` to set the dimension of the input port to the same candidate dimensions.

```

# define MDL_SET_OUTPUT_PORT_DIMENSION_INFO
/* Function: mdlSetOutputPortDimensionInfo =====
 * Abstract:
 *   This routine is called with the candidate dimensions for
 *   an output port with unknown dimensions. If the proposed
 *   dimensions are acceptable, the routine should go ahead and
 *   set the actual port dimensions. If they are unacceptable
 *   an error should be generated via ssSetErrorStatus.
 *   Note that any other input or output ports whose dimensions

```

```

    *   are implicitly defined by virtue of knowing the dimensions
    *   of the given port can also have their dimensions set.
    */
    */
static void mdlSetOutputPortDimensionInfo(SimStruct      *S,
    int_T          port,
    const DimsInfo_T *dimsInfo)
{
    /*
    * If the block has scalar parameter, the output dimensions
    * are unknown. Set the input and output port to have the
    * same dimensions.
    */
    */
    if(!ssSetOutputPortDimensionInfo(S, port, dimsInfo)) return;

    /* The block only accepts 2-D or n-D signals.
    * Check number of dimensions.
    */
    */
    if (!(dimsInfo->numDims >= 2)){
        ssSetErrorStatus(S, "Invalid output port dimensions. "
            "The output signal must be a 2-D or n-D array (matrix) "
            "signal.");
        return;
    }else{
        /* Set the input port dimensions */
        if(!ssSetInputPortDimensionInfo(S,port,dimsInfo)) return;
    }
} /* end mdlSetOutputPortDimensionInfo */
```

Because the S-function has ports that are dynamically sized, it must provide an `mdlSetDefaultPortDimensionInfo` method. Simulink invokes this method during signal propagation when it cannot determine the dimensionality of the signal connected to the block's input port. This situation can happen, for example, if the input port is unconnected. In this example, the `mdlSetDefaultPortDimensionInfo` method sets the input and output ports dimensions to a scalar.

```

# define MDL_SET_DEFAULT_PORT_DIMENSION_INFO
/* Function: mdlSetDefaultPortDimensionInfo =====
* This routine is called when Simulink is not able to find
* dimension candidates for ports with unknown dimensions.
```

```

*   This function must set the dimensions of all ports with
*   unknown dimensions.
*/
static void mdlSetDefaultPortDimensionInfo(SimStruct *S)
{
    int_T outWidth = ssGetOutputPortWidth(S, 0);
    /* Input port dimension must be unknown. Set it to scalar.*/
    if(!ssSetInputPortMatrixDimensions(S, 0, 1, 1)) return;
    if(outWidth == DYNAMICALLY_SIZED){
        /* Output dimensions are unknown. Set it to scalar. */
        if(!ssSetOutputPortMatrixDimensions(S, 0, 1, 1)) return;
    }
} /* end mdlSetDefaultPortDimensionInfo */
#endif

```

The S-function concludes with the required `mdlTerminate` function. In this example, the function is empty.

```

/* Function: mdlTerminate =====
* Abstract:
*   Called when the simulation is terminated.
*/
static void mdlTerminate(SimStruct *S)
{
    UNUSED_ARG(S); /* unused input argument */
} /* end mdlTerminate */

```

The required S-function's trailer includes the files necessary for simulation or code generation.

```

#ifdef MATLAB_MEX_FILE
    #include "simulink.c"
#else
    #include "cg_sfund.h"
#endif

/* [EOF] sfund_matadd.c */

```

Note The `mdlOutputs` and `mdlTerminate` functions use the `UNUSED_ARG` macro to indicate that an input argument the callback requires is not used. This optional macro is defined in `matlabroot/simulink/include/simstruc_types.h`. You must call this macro once for each input argument that a callback does not use.

Zero-Crossing Detection

The example S-function `matlabroot/simulink/src/sfun_zc_sat.c` demonstrates how to implement a Saturation block. The following Simulink model uses this S-function.

```
matlabroot/toolbox/simulink/simdemos/simfeatures/-  
sfcndemo_sfun_zc_sat.mdl
```

The S-function works with either fixed- or variable-step solvers. When this S-function inherits a continuous sample time and uses a variable-step solver, it uses a zero-crossings algorithm to locate the exact points at which the saturation occurs.

`matlabroot/simulink/src/sfun_zc_sat.c`

The S-function begins with `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. After these statements, the S-function includes or defines any other necessary headers, data, etc. This example defines various parameters associated with the upper and lower saturation bounds.

```
/* File    : sfun_zc_sat.c  
 * Abstract:  
 *  
 * Example of an S-function which has nonsampled zero crossings to  
 * implement a saturation function. This S-function is designed to be  
 * used with a variable or fixed step solver.  
 *  
 * A saturation is described by three equations  
 *  
 * (1)    y = UpperLimit  
 * (2)    y = u
```



```

*      (3)      y = LowerLimit
*
* and a set of inequalities that specify which equation to use
*
*      if                UpperLimit < u      then use (1)
*      if      LowerLimit <= u <= UpperLimit      then use (2)
*      if      u < LowerLimit                then use (3)
*
* A key fact is that the valid equation 1, 2, or 3, can change at
* any instant. Nonsampled zero crossing support helps the variable step
* solvers locate the exact instants when behavior switches from one equation
* to another.
*
* Copyright 1990-2007 The MathWorks, Inc.
*/

#define S_FUNCTION_NAME  sfun_zc_sat
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

/*=====
* General Defines/macros *
*=====*/

/* index to Upper Limit */
#define I_PAR_UPPER_LIMIT 0

/* index to Lower Limit */
#define I_PAR_LOWER_LIMIT 1

/* total number of block parameters */
#define N_PAR      2

/*
* Make access to mxArray pointers for parameters more readable.
*/
#define P_PAR_UPPER_LIMIT  ( ssGetSFcnParam(S,I_PAR_UPPER_LIMIT) )
#define P_PAR_LOWER_LIMIT  ( ssGetSFcnParam(S,I_PAR_LOWER_LIMIT) )

```

This S-function next implements the `mdlCheckParameters` method to check the validity of the S-function dialog parameters. Because this method is optional, a `#define` statement precedes it. The `#if defined` statement checks that this function is compiled as a MEX-file, instead of for use with Real-Time Workshop. The body of the function performs basic checks to ensure that the user entered real vectors of equal length for the upper and lower saturation limits. If the parameter checks fail, the S-function errors out.

```
#define      MDL_CHECK_PARAMETERS
#if defined(MDL_CHECK_PARAMETERS) && defined(MATLAB_MEX_FILE)

/* Function: mdlCheckParameters =====
 * Abstract:
 * Check that parameter choices are allowable.
 */
static void mdlCheckParameters(SimStruct *S)
{
    int_T      i;
    int_T      numUpperLimit;
    int_T      numLowerLimit;
    const char *msg = NULL;

    /*
     * check parameter basics
     */
    for ( i = 0; i < N_PAR; i++ ) {
        if ( mxIsEmpty(  ssGetSFcnParam(S,i) ) ||
             mxIsSparse(  ssGetSFcnParam(S,i) ) ||
             mxIsComplex(  ssGetSFcnParam(S,i) ) ||
             !mxIsNumeric(  ssGetSFcnParam(S,i) ) ) {
            msg = "Parameters must be real vectors.";
            goto EXIT_POINT;
        }
    }

    /*
     * Check sizes of parameters.
     */
    numUpperLimit = mxGetNumberOfElements( P_PAR_UPPER_LIMIT );
```

```

numLowerLimit = mxGetNumberOfElements( P_PAR_LOWER_LIMIT );

if ( ( numUpperLimit != 1          ) &&
      ( numLowerLimit != 1        ) &&
      ( numUpperLimit != numLowerLimit ) ) {
    msg = "Number of input and output values must be equal.";
    goto EXIT_POINT;
}

/*
 * Error exit point
 */
EXIT_POINT:
if (msg != NULL) {
    ssSetErrorStatus(S, msg);
}
}
#endif /* MDL_CHECK_PARAMETERS */

```

The required S-function method `mdlInitializeSizes` sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to two, as defined previously in the variable `N_PAR`.
- If this method is compiled as a MEX-file, `ssGetSFcnParamsCount` determines how many parameters the user actually entered into the S-function dialog. If the number of user-specified parameters matches the number returned by `ssSetNumSFcnParams`, the method calls `mdlCheckParameters` to check the validity of the user-entered data. Otherwise, the S-function errors out.
- If the parameter check passes, the S-function determines the maximum number of elements entered into either the upper or lower saturation limit parameter. This number is needed later to determine the appropriate output width.
- Next, the number of continuous and discrete states is set using `ssSetNumContStates` and `ssSetNumDiscStates`, respectively. This example has no continuous or discrete states.
- The method specifies that the S-function has a single output port using `ssSetNumOutputPorts` and sets the width of this output port

using `ssSetOutputPortWidth`. The output port width is either the maximum number of elements in the upper or lower saturation limit or is dynamically sized. Similar code specifies a single input port and indicates the input port has direct feedthrough by passing a value of 1 to `ssSetInputPortDirectFeedThrough`.

- `ssSetNumSampleTimes` initializes one sample time, which the `mdlInitializeSampleTimes` function configures later.
- The S-function indicates that no work vectors are used by passing a value of 0 to `ssSetNumRWork`, `ssSetNumIWork`, etc. These lines could be omitted because zero is the default value for all of these macros. However, for clarity, the S-function explicitly sets the number of work vectors.
- The method initializes the zero-crossing detection work vectors using `ssSetNumModes` and `ssSetNumNonsampledZCs`. The `mdlSetWorkWidths` method specifies the length of these dynamically sized vectors later.
- Lastly, `ssSetOptions` sets any applicable options. In this case, `SS_OPTION_EXCEPTION_FREE_CODE` stipulates that the code is exception free and `SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION` permits scalar expansion of the input without having to provide an `mdlSetInputPortWidth` function.

The `mdlInitializeSizes` function for this example is shown below.

```
/* Function: mdlInitializeSizes =====
 * Abstract:
 *   Initialize the sizes array.
 */
static void mdlInitializeSizes(SimStruct *S)
{
    int_T numUpperLimit, numLowerLimit, maxNumLimit;

    /*
     * Set and Check parameter count
     */
    ssSetNumSFcnParams(S, N_PAR);

#ifdef MATLAB_MEX_FILE
    if (ssGetNumSFcnParams(S) == ssGetSFcnParamsCount(S)) {
        mdlCheckParameters(S);
        if (ssGetErrorStatus(S) != NULL) {
```

```
        return;
    }
} else {
    return; /* Parameter mismatch will be reported by Simulink */
}
#endif

/*
 * Get parameter size info.
 */
numUpperLimit = mxGetNumberOfElements( P_PAR_UPPER_LIMIT );
numLowerLimit = mxGetNumberOfElements( P_PAR_LOWER_LIMIT );

if (numUpperLimit > numLowerLimit) {
    maxNumLimit = numUpperLimit;
} else {
    maxNumLimit = numLowerLimit;
}

/*
 * states
 */
ssSetNumContStates(S, 0);
ssSetNumDiscStates(S, 0);

/*
 * outputs
 * The upper and lower limits are scalar expanded
 * so their size determines the size of the output
 * only if at least one of them is not scalar.
 */
if (!ssSetNumOutputPorts(S, 1)) return;

if ( maxNumLimit > 1 ) {
    ssSetOutputPortWidth(S, 0, maxNumLimit);
} else {
    ssSetOutputPortWidth(S, 0, DYNAMICALLY_SIZED);
}

/*
```

```
* inputs
* If the upper or lower limits are not scalar then
* the input is set to the same size. However, the
* ssSetOptions below allows the actual width to
* be reduced to 1 if needed for scalar expansion.
*/
if (!ssSetNumInputPorts(S, 1)) return;

ssSetInputPortDirectFeedThrough(S, 0, 1 );

if ( maxNumLimit > 1 ) {
    ssSetInputPortWidth(S, 0, maxNumLimit);
} else {
    ssSetInputPortWidth(S, 0, DYNAMICALLY_SIZED);
}

/*
* sample times
*/
ssSetNumSampleTimes(S, 1);

/*
* work
*/
ssSetNumRWork(S, 0);
ssSetNumIWork(S, 0);
ssSetNumPWork(S, 0);

/*
* Modes and zero crossings:
* If we have a variable-step solver and this block has a continuous
* sample time, then
* o One mode element will be needed for each scalar output
*   in order to specify which equation is valid (1), (2), or (3).
* o Two ZC elements will be needed for each scalar output
*   in order to help the solver find the exact instants
*   at which either of the two possible "equation switches"
*   One will be for the switch from eq. (1) to (2);
*   the other will be for eq. (2) to (3) and vice versa.
```

```

    * otherwise
    *   o No modes and nonsampled zero crossings will be used.
    *
    */
    ssSetNumModes(S, DYNAMICALLY_SIZED);
    ssSetNumNonsampledZCs(S, DYNAMICALLY_SIZED);

    /*
    * options
    *   o No mexFunctions and no problematic mxFunctions are called
    *     so the exception free code option safely gives faster simulations.
    *   o Scalar expansion of the inputs is desired. The option provides
    *     this without the need to write mdlSetOutputPortWidth and
    *     mdlSetInputPortWidth functions.
    */
    ssSetOptions(S, ( SS_OPTION_EXCEPTION_FREE_CODE |
                     SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION));

} /* end mdlInitializeSizes */

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's sample rates. The input argument `INHERITED_SAMPLE_TIME` passed to `ssSetSampleTime` specifies that this S-function inherits its sample time from its driving block. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 *   Specify that the block is continuous.
 */
static void mdlInitializeSampleTimes(SimStruct *S)
{
    ssSetSampleTime(S, 0, INHERITED_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0);
    ssSetModelReferenceSampleTimeDefaultInheritance(S);
}

```

The optional method `mdlSetWorkWidths` initializes the size of the zero-crossing detection work vectors. Because this method is optional, a `#define` statement precedes it. The `#if` defined statement checks that the S-function is being compiled as a MEX-file. Zero-crossing detection can be done only when the S-function is running at a continuous sample rate using a variable-step solver. The `if` statement uses `ssIsVariableStepSolver`, `ssGetSampleTime`, and `ssGetOffsetTime` to determine if this condition is met. If so, the method sets the number of modes equal to the width of the first output port and the number of nonsampled zero crossings to twice this amount. Otherwise, the method sets both values to zero.

```
#define      MDL_SET_WORK_WIDTHS
#ifdef MDL_SET_WORK_WIDTHS && defined(MATLAB_MEX_FILE)
/* Function: mdlSetWorkWidths =====
 * The width of the Modes and the ZCs depends on the width of the output.
 * This width is not always known in mdlInitializeSizes so it is handled
 * here.
 */
static void mdlSetWorkWidths(SimStruct *S)
{
    int nModes;
    int nNonsampledZCs;

    if (ssIsVariableStepSolver(S) &&
        ssGetSampleTime(S,0) == CONTINUOUS_SAMPLE_TIME &&
        ssGetOffsetTime(S,0) == 0.0) {

        int numOutput = ssGetOutputPortWidth(S, 0);

        /*
         * modes and zero crossings
         *   o One mode element will be needed for each scalar output
         *     in order to specify which equation is valid (1), (2), or (3).
         *   o Two ZC elements will be needed for each scalar output
         *     in order to help the solver find the exact instants
         *     at which either of the two possible "equation switches"
         *     One will be for the switch from eq. (1) to (2);
         *     the other will be for eq. (2) to (3) and vice versa.
         */
        nModes          = numOutput;

```



```

        nNonsampledZCs = 2 * numOutput;
    } else {
        nModes          = 0;
        nNonsampledZCs = 0;
    }
    ssSetNumModes(S,nModes);
    ssSetNumNonsampledZCs(S,nNonsampledZCs);
}
#endif /* MDL_SET_WORK_WIDTHS */

```

After declaring variables for the input and output signals, the `mdlOutputs` function uses an `if-else` statement to create blocks of code used to calculate the output signal based on whether the S-function uses a fixed-step or variable-step solver. The `if` statement queries the length of the nonsampled zero-crossing vector. If the length, set in `mdlWorkWidths`, is zero, then no zero-crossing detection is done and the output signals are calculated directly from the input signals. Otherwise, the function uses the mode work vector to determine how to calculate the output signal. If the simulation is at a major time step, i.e., `ssIsMajorTimeStep` returns `true`, `mdlOutputs` determines which mode the simulation is running in, either saturated at the upper limit, saturated at the lower limit, or not saturated. Then, for both major and minor time steps, the function calculates an output based on this mode. If the mode changed between the previous and current time step, then a zero crossing occurred. The `mdlZeroCrossings` function, not `mdlOutputs`, indicates this crossing to the solver.

```

/* Function: mdlOutputs =====
 * Abstract:
 *
 * A saturation is described by three equations
 *
 * (1)    y = UpperLimit
 * (2)    y = u
 * (3)    y = LowerLimit
 *
 * When this block is used with a fixed-step solver or it has a noncontinuous
 * sample time, the equations are used as it
 *
 * Now consider the case of this block being used with a variable-step solver
 * and it has a continuous sample time. Solvers work best on smooth problems.

```

```
* In order for the solver to work without chattering, limit cycles, or
* similar problems, it is absolutely crucial that the same equation be used
* throughout the duration of a MajorTimeStep. To visualize this, consider
* the case of the Saturation block feeding an Integrator block.
*
* To implement this rule, the mode vector is used to specify the
* valid equation based on the following:
*
*   if                UpperLimit < u   then use (1)
*   if   LowerLimit <= u <= UpperLimit   then use (2)
*   if   u < LowerLimit                   then use (3)
*
* The mode vector is changed only at the beginning of a MajorTimeStep.
*
* During a minor time step, the equation specified by the mode vector
* is used without question. Most of the time, the value of u will agree
* with the equation specified by the mode vector. However, sometimes u's
* value will indicate a different equation. Nonetheless, the equation
* specified by the mode vector must be used.
*
* When the mode and u indicate different equations, the corresponding
* calculations are not correct. However, this is not a problem. From
* the ZC function, the solver will know that an equation switch occurred
* in the middle of the last MajorTimeStep. The calculations for that
* time step will be discarded. The ZC function will help the solver
* find the exact instant at which the switch occurred. Using this knowledge,
* the length of the MajorTimeStep will be reduced so that only one equation
* is valid throughout the entire time step.
*/
static void mdlOutputs(SimStruct *S, int_T tid)
{
    InputRealPtrsType uPtrs    = ssGetInputPortRealSignalPtrs(S,0);
    real_T            *y        = ssGetOutputPortRealSignal(S,0);
    int_T             numOutput = ssGetOutputPortWidth(S,0);
    int_T             iOutput;

    /*
     * Set index and increment for input signal, upper limit, and lower limit
     * parameters so that each gives scalar expansion if needed.
     */
}
```

```

int_T uIdx          = 0;
int_T uInc          = ( ssGetInputPortWidth(S,0) > 1 );
const real_T *upperLimit = mxGetPr( P_PAR_UPPER_LIMIT );
int_T upperLimitInc = ( mxGetNumberOfElements( P_PAR_UPPER_LIMIT ) > 1 );
const real_T *lowerLimit = mxGetPr( P_PAR_LOWER_LIMIT );
int_T lowerLimitInc = ( mxGetNumberOfElements( P_PAR_LOWER_LIMIT ) > 1 );

UNUSED_ARG(tid); /* not used in single tasking mode */

if (ssGetNumNonsampledZCs(S) == 0) {
    /*
     * This block is being used with a fixed-step solver or it has
     * a noncontinuous sample time, so we always saturate.
     */
    for (iOutput = 0; iOutput < numOutput; iOutput++) {
        if (*uPtrs[uIdx] >= *upperLimit) {
            *y++ = *upperLimit;
        } else if (*uPtrs[uIdx] > *lowerLimit) {
            *y++ = *uPtrs[uIdx];
        } else {
            *y++ = *lowerLimit;
        }

        upperLimit += upperLimitInc;
        lowerLimit += lowerLimitInc;
        uIdx        += uInc;
    }
} else {
    /*
     * This block is being used with a variable-step solver.
     */
    int_T *mode = ssGetModeVector(S);

    /*
     * Specify indices for each equation.
     */
    enum { UpperLimitEquation, NonLimitEquation, LowerLimitEquation };

    /*

```

```
* Update the Mode Vector ONLY at the beginning of a MajorTimeStep
*/
if ( ssIsMajorTimeStep(S) ) {
    /*
     * Specify the mode, ie the valid equation for each output scalar.
     */
    for ( iOutput = 0; iOutput < numOutput; iOutput++ ) {
        if ( *uPtrs[uIdx] > *upperLimit ) {
            /*
             * Upper limit eq is valid.
             */
            mode[iOutput] = UpperLimitEquation;
        } else if ( *uPtrs[uIdx] < *lowerLimit ) {
            /*
             * Lower limit eq is valid.
             */
            mode[iOutput] = LowerLimitEquation;
        } else {
            /*
             * Nonlimit eq is valid.
             */
            mode[iOutput] = NonLimitEquation;
        }
    }
    /*
     * Adjust indices to give scalar expansion if needed.
     */
    uIdx      += uInc;
    upperLimit += upperLimitInc;
    lowerLimit += lowerLimitInc;
}

/*
 * Reset index to input and limits.
 */
uIdx      = 0;
upperLimit = mxGetPr( P_PAR_UPPER_LIMIT );
lowerLimit = mxGetPr( P_PAR_LOWER_LIMIT );

} /* end IsMajorTimeStep */
```

```

/*
 * For both MinorTimeSteps and MajorTimeSteps calculate each scalar
 * output using the equation specified by the mode vector.
 */
for ( iOutput = 0; iOutput < numOutput; iOutput++ ) {
    if ( mode[iOutput] == UpperLimitEquation ) {
        /*
         * Upper limit eq.
         */
        *y++ = *upperLimit;
    } else if ( mode[iOutput] == LowerLimitEquation ) {
        /*
         * Lower limit eq.
         */
        *y++ = *lowerLimit;
    } else {
        /*
         * Nonlimit eq.
         */
        *y++ = *uPtrs[uIdx];
    }

    /*
     * Adjust indices to give scalar expansion if needed.
     */
    uIdx      += uInc;
    upperLimit += upperLimitInc;
    lowerLimit += lowerLimitInc;
}
} /* end mdlOutputs */

```

The `mdlZeroCrossings` method determines if a zero crossing occurred between the previous and current time step. The method obtains a pointer to the input signal using `ssGetInputPortRealSignalPtrs`. A comparison of this signal's value to the value of the upper and lower saturation limits determines values for the elements of the nonsampled zero-crossing vector. If any element of the nonsampled zero-crossing vector switches from negative to positive, or positive to negative, a zero crossing occurred. In the event of a zero crossing,

Simulink modifies the step size and recalculates the outputs to try to locate the exact zero crossing.

```
#define      MDL_ZERO_CROSSINGS
#if defined(MDL_ZERO_CROSSINGS) && (defined(MATLAB_MEX_FILE) || defined(NRT))

/* Function: mdlZeroCrossings =====
 * Abstract:
 * This will only be called if the number of nonsampled zero crossings is
 * greater than 0 which means this block has a continuous sample time and the
 * model is using a variable-step solver.
 *
 * Calculate zero crossing (ZC) signals that help the solver find the
 * exact instants at which equation switches occur:
 *
 *   if                UpperLimit < u   then use (1)
 *   if  LowerLimit <= u <= UpperLimit   then use (2)
 *   if  u < LowerLimit                   then use (3)
 *
 * The key words are help find. There is no choice of a function that will
 * direct the solver to the exact instant of the change. The solver will
 * track the zero crossing signal and do a bisection style search for the
 * exact instant of equation switch.
 *
 * There is generally one ZC signal for each pair of signals that can
 * switch. The three equations above would break into two pairs (1)&(2)
 * and (2)&(3). The possibility of a "long jump" from (1) to (3) does
 * not need to be handled as a separate case. It is implicitly handled.
 *
 * When ZCs are calculated, the value is normally used twice. When it is
 * first calculated, it is used as the end of the current time step. Later,
 * it will be used as the beginning of the following step.
 *
 * The sign of the ZC signal always indicates an equation from the pair. For
 * S-functions, which equation is associated with a positive ZC and which is
 * associated with a negative ZC doesn't really matter. If the ZC is positive
 * at the beginning and at the end of the time step, this implies that the
 * "positive" equation was valid throughout the time step. Likewise, if the
 * ZC is negative at the beginning and at the end of the time step, this
 * implies that the "negative" equation was valid throughout the time step.
```

```

* Like any other nonlinear solver, this is not foolproof, but it is an
* excellent indicator. If the ZC has a different sign at the beginning and
* at the end of the time step, then a equation switch definitely occurred
* during the time step.
*
* Ideally, the ZC signal gives an estimate of when an equation switch
* occurred. For example, if the ZC signal is -2 at the beginning and +6 at
* the end, then this suggests that the switch occurred
*  $25\% = 100\% \cdot (-2) / (-2 - (+6))$  of the way into the time step. It will almost
* never be true that 25% is perfectly correct. There is no perfect choice
* for a ZC signal, but there are some good rules. First, choose the ZC
* signal to be continuous. Second, choose the ZC signal to give a monotonic
* measure of the "distance" to a signal switch; strictly monotonic is ideal.
*/
static void mdlZeroCrossings(SimStruct *S)
{
    int_T          iOutput;
    int_T          numOutput = ssGetOutputPortWidth(S,0);
    real_T         *zcSignals = ssGetNonsampledZCs(S);
    InputRealPtrsType uPtrs    = ssGetInputPortRealSignalPtrs(S,0);

    /*
    * Set index and increment for the input signal, upper limit, and lower
    * limit parameters so that each gives scalar expansion if needed.
    */
    int_T uIdx      = 0;
    int_T uInc      = ( ssGetInputPortWidth(S,0) > 1 );
    real_T *upperLimit = mxGetPr( P_PAR_UPPER_LIMIT );
    int_T upperLimitInc = ( mxGetNumberOfElements( P_PAR_UPPER_LIMIT ) > 1 );
    real_T *lowerLimit = mxGetPr( P_PAR_LOWER_LIMIT );
    int_T lowerLimitInc = ( mxGetNumberOfElements( P_PAR_LOWER_LIMIT ) > 1 );

    /*
    * For each output scalar, give the solver a measure of "how close things
    * are" to an equation switch.
    */
    for ( iOutput = 0; iOutput < numOutput; iOutput++ ) {

        /* The switch from eq (1) to eq (2)
        *

```

```

*   if                UpperLimit < u   then use (1)
*   if   LowerLimit <= u <= UpperLimit   then use (2)
*
*   is related to how close u is to UpperLimit. A ZC choice
*   that is continuous, strictly monotonic, and is
*   u - UpperLimit
*   or it is negative.
*/
zcSignals[2*iOutput] = *uPtrs[uIdx] - *upperLimit;

/* The switch from eq (2) to eq (3)
*
*   if   LowerLimit <= u <= UpperLimit   then use (2)
*   if   u < LowerLimit                   then use (3)
*
*   is related to how close u is to LowerLimit. A ZC choice
*   that is continuous, strictly monotonic, and is
*   u - LowerLimit.
*/
zcSignals[2*iOutput+1] = *uPtrs[uIdx] - *lowerLimit;

/*
* Adjust indices to give scalar expansion if needed.
*/
uIdx      += uInc;
upperLimit += upperLimitInc;
lowerLimit += lowerLimitInc;
}
}

#endif /* end mdlZeroCrossings */

```

The S-function concludes with the required `mdlTerminate` function. In this example, the function is empty.

```

/* Function: mdlTerminate =====
* Abstract:
*   No termination needed, but we are required to have this routine.
*/
static void mdlTerminate(SimStruct *S)

```



```

{
    UNUSED_ARG(S); /* unused input argument */
}

```

The required S-function trailer includes the files necessary for simulation or code generation, as follows.

```

#ifdef MATLAB_MEX_FILE /* Is this file being compiled as a MEX-file? */
#include "simulink.c" /* MEX-file interface mechanism */
#else
#include "cg_sfun.h" /* Code generation registration function */
#endif

```

Note The `mdlOutputs` and `mdlTerminate` functions use the `UNUSED_ARG` macro to indicate that an input argument the callback requires is not used. This optional macro is defined in `matlabroot/simulink/include/simstruc_types.h`. If used, you must call this macro once for each input argument that a callback does not use.

Discontinuities in Continuous States

The example S-function `matlabroot/simulink/src/stvctf.c` demonstrates a time-varying continuous transfer function. The following Simulink model uses this S-function.

`matlabroot/toolbox/simulink/simdemos/simfeatures/sfcdemo_stvctf.mdl`

The S-function demonstrates how to work with the solvers so that the simulation maintains *consistency*, which means that the block maintains smooth and consistent signals for the integrators although the equations that are being integrated are changing.

matlabroot/simulink/src/stvctf.c

The S-function begins with `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. After these statements, the S-function includes or defines any other necessary headers, data, etc. This example defines parameters for the transfer function's numerator and denominator, which are entered into the S-function's dialog.

The comments at the beginning of this S-function provide additional information on the purpose of the work vectors in this example.

```
/*
 * File : stvctf.c
 * Abstract:
 *   Time Varying Continuous Transfer Function block
 *
 *   This S-function implements a continuous time transfer function
 *   whose transfer function polynomials are passed in via the input
 *   vector. This is useful for continuous time adaptive control
 *   applications.
 *
 *   This S-function is also an example of how to use banks to avoid
 *   problems with computing derivatives when a continuous output has
 *   discontinuities. The consistency checker can be used to verify that
 *   your S-function is correct with respect to always maintaining smooth
 *   and consistent signals for the integrators. By consistent we mean that
 *   two mdlOutputs calls at major time t and minor time t are always the
 *   same. The consistency checker is enabled on the diagnostics page of the
 *   Configuraion parameters dialog box. The update method of this S-function
 *   modifies the coefficients of the transfer function, which cause the
 *   output to "jump." To have the simulation work properly, we need to let
 *   the solver know of these discontinuities by setting
 *   ssSetSolverNeedsReset and then we need to use multiple banks of
 *   coefficients so the coefficients used in the major time step output
 *   and the minor time step outputs are the same. In the simulation loop
 *   we have:
 *   Loop:
 *     o Output in major time step at time t
 *     o Update in major time step at time t
 *     o Integrate (minor time step):
 *       o Consistency check: recompute outputs at time t and compare
 *         with current outputs.
 *       o Derivatives at time t
 *       o One or more Output,Derivative evaluations at time t+k
 *         where k <= step_size to be taken.
 *       o Compute state, x
 *       o t = t + step_size
 *   End_Integrate
```

```

*      End_Loop
*      Another purpose of the consistency checker is to verify that when
*      the solver needs to try a smaller step_size, the recomputing of
*      the output and derivatives at time t doesn't change. Step size
*      reduction occurs when tolerances aren't met for the current step size.
*      The ideal ordering would be to update after integrate. To achieve
*      this we have two banks of coefficients. And the use of the new
*      coefficients, which were computed in update, is delayed until after
*      the integrate phase is complete.
*
* This block has multiple sample times and will not work correctly
* in a multitasking environment. It is designed to be used in
* a single tasking (or variable step) simulation environment.
* Because this block accesses the input signal in both tasks,
* it cannot specify the sample times of the input and output ports
* (SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED).
*
* See simulink/src/sfuntmpl_doc.c.
*
* Copyright 1990-7 The MathWorks, Inc.
*/

#define S_FUNCTION_NAME stvctf
#define S_FUNCTION_LEVEL 2

#include "simstruc.h"

/*
* Defines for easy access to the numerator and denominator polynomials
* parameters
*/
#define NUM(S)  ssGetSFcnParam(S, 0)
#define DEN(S)  ssGetSFcnParam(S, 1)
#define TS(S)   ssGetSFcnParam(S, 2)
#define NPARAMS 3

```

This S-function implements the `mdlCheckParameters` method to check the validity of the S-function dialog parameters. Because this method is optional, a `#define` statement precedes it. The `#if defined` statement checks that this function is compiled as a MEX-file, instead of for use with Real-Time

Workshop. The body of the function performs basic checks to ensure that the user entered real vectors for the numerator and denominator, and that the denominator has a higher order than the numerator. If the parameter check fails, the S-function errors out.

```
#define MDL_CHECK_PARAMETERS
#if defined(MDL_CHECK_PARAMETERS) && defined(MATLAB_MEX_FILE)
/* Function: mdlCheckParameters =====
 * Abstract:
 *   Validate our parameters to verify:
 *   o The numerator must be of a lower order than the denominator.
 *   o The sample time must be a real positive nonzero value.
 */
static void mdlCheckParameters(SimStruct *S)
{
    int_T i;

    for (i = 0; i < NPARAMS; i++) {
        real_T *pr;
        int_T e1;
        int_T nEls;
        if (mxIsEmpty( ssGetSFcnParam(S,i) ||
            mxIsSparse( ssGetSFcnParam(S,i) ||
            mxIsComplex( ssGetSFcnParam(S,i) ||
            !mxIsNumeric( ssGetSFcnParam(S,i) ) ) {
            ssSetErrorStatus(S, "Parameters must be real finite vectors");
            return;
        }
        pr = mxGetPr(ssGetSFcnParam(S,i));
        nEls = mxGetNumberOfElements(ssGetSFcnParam(S,i));
        for (e1 = 0; e1 < nEls; e1++) {
            if (!mxIsFinite(pr[e1])) {
                ssSetErrorStatus(S, "Parameters must be real finite vectors");
                return;
            }
        }
    }
}

if (mxGetNumberOfElements(NUM(S)) > mxGetNumberOfElements(DEN(S)) &&
    mxGetNumberOfElements(DEN(S)) > 0 && *mxGetPr(DEN(S)) != 0.0) {
```

```

        ssSetErrorStatus(S,"The denominator must be of higher order than "
                        "the numerator, nonempty and with first "
                        "element nonzero");
    return;
}

/* xxx verify finite */
if (mxGetNumberOfElements(TS(S)) != 1 || mxGetPr(TS(S))[0] <= 0.0) {
    ssSetErrorStatus(S,"Invalid sample time specified");
    return;
}
}
#endif /* MDL_CHECK_PARAMETERS */

```

The required S-function method `mdlInitializeSizes` then sets up the following S-function characteristics.

- `ssSetNumSFcnParams` sets the number of expected S-function dialog parameters to three, as defined previously in the variable `NPARAMS`.
- If this method is compiled as a MEX-file, `ssGetSFcnParamsCount` determines how many parameters the user entered into the S-function dialog. If the number of user-specified parameters matches the number returned by `ssSetNumSFcnParams`, the method calls `mdlCheckParameters` to check the validity of the user-entered data. Otherwise, the S-function errors out.
- If the parameter check passes, the S-function specifies the number of continuous and discrete states using `ssSetNumContStates` and `ssSetNumDiscStates`, respectively. This example has no discrete states and sets the number of continuous states based on the number of coefficients in the transfer function's denominator.
- Next, `ssSetNumInputPorts` specifies that the S-function has a single input port and sets its width to one plus twice the length of the denominator using `ssSetInputPortWidth`. The method uses the value provided by the third S-function dialog parameter as the input port's sample time. This parameter indicates the rate at which the transfer function is modified during simulation. The S-function specifies that the input port has direct feedthrough by passing a value of 1 to `ssSetInputPortDirectFeedThrough`.
- `ssSetNumOutputPorts` specifies that the S-function has a single output port. The method uses `ssSetOutputPortWidth` to set the width of this output port,

`ssSetOutputPortSampleTime` to specify that the output port has a continuous sample time, and `ssSetOutputPortOffsetTime` to set the offset time to zero.

- `ssSetNumSampleTimes` then initializes two sample times, which the `mdlInitializeSampleTimes` function configures later.
- The method passes a value of four times the number of denominator coefficients to `ssSetNumRWork` to set the length of the floating-point work vector. `ssSetNumIWork` then sets the length of the integer work vector to two. The `RWork` vectors store two banks of transfer function coefficients, while the `IWork` vector indicates which bank in the `RWork` vector is currently in use. The S-function sets the length of all other work vectors to zero. These lines could be omitted because zero is the default value for these macros. However, for clarity, the S-function explicitly sets the number of work vectors.
- Lastly, `ssSetOptions` sets any applicable options. In this case, `SS_OPTION_EXCEPTION_FREE_CODE` stipulates that the code is exception free.

The `mdlInitializeSizes` function for this example is shown below.

```

/* Function: mdlInitializeSizes =====
 * Abstract:
 *   The sizes information is used by Simulink to determine the S-function
 *   block's characteristics (number of inputs, outputs, states, etc.).
 */
static void mdlInitializeSizes(SimStruct *S)
{
    int_T nContStates;
    int_T nCoeffs;

    /* See sfuntmpl_doc.c for more details on the macros below. */

    ssSetNumSFcnParams(S, NPARAMS); /* Number of expected parameters. */
#ifdef MATLAB_MEX_FILE
    if (ssGetNumSFcnParams(S) == ssGetSFcnParamsCount(S)) {
        mdlCheckParameters(S);
        if (ssGetErrorStatus(S) != NULL) {
            return;
        }
    } else {

```

```

        return; /* Parameter mismatch will be reported by Simulink. */
    }
#endif

/*
 * Define the characteristics of the block:
 *
 * Number of continuous states:    length of denominator - 1
 * Inputs port width               2 * (NumContStates+1) + 1
 * Output port width              1
 * DirectFeedThrough:             0 (Although this should be computed.
 *                                 We'll assume coefficients entered
 *                                 are strictly proper).
 * Number of sample times:         2 (continuous and discrete)
 * Number of Real work elements:   4*NumCoeffs
 *                                 (Two banks for num and den coeff's:
 *                                 NumBank0Coeffs
 *                                 DenBank0Coeffs
 *                                 NumBank1Coeffs
 *                                 DenBank1Coeffs)
 * Number of Integer work elements: 2 (indicator of active bank 0 or 1
 *                                 and flag to indicate when banks
 *                                 have been updated).
 *
 * The number of inputs arises from the following:
 *   o 1 input (u)
 *   o the numerator and denominator polynomials each have NumContStates+1
 *     coefficients
 */
nCoeffs      = mxGetNumberOfElements(DEN(S));
nContStates = nCoeffs - 1;

ssSetNumContStates(S, nContStates);
ssSetNumDiscStates(S, 0);

if (!ssSetNumInputPorts(S, 1)) return;
ssSetInputPortWidth(S, 0, 1 + (2*nCoeffs));
ssSetInputPortDirectFeedThrough(S, 0, 0);
ssSetInputPortSampleTime(S, 0, mxGetPr(TS(S))[0]);

```

```

ssSetInputPortOffsetTime(S, 0, 0);

if (!ssSetNumOutputPorts(S,1)) return;
ssSetOutputPortWidth(S, 0, 1);
ssSetOutputPortSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
ssSetOutputPortOffsetTime(S, 0, 0);

ssSetNumSampleTimes(S, 2);

ssSetNumRWork(S, 4 * nCoeffs);
ssSetNumIWork(S, 2);
ssSetNumPWork(S, 0);

ssSetNumModes(S, 0);
ssSetNumNonsampledZCs(S, 0);

/* Take care when specifying exception free code - see sfuntmpl_doc.c */
ssSetOptions(S, (SS_OPTION_EXCEPTION_FREE_CODE));

} /* end mdlInitializeSizes */

```

The required S-function method `mdlInitializeSampleTimes` specifies the S-function's sample rates. The first call to `ssSetSampleTime` specifies that the first sample rate is continuous and the subsequent call to `ssSetOffsetTime` sets the offset to zero. The second call to this pair of macros sets the second sample time to the value of the third S-function parameter with an offset of zero. The call to `ssSetModelReferenceSampleTimeDefaultInheritance` tells the solver to use the default rule to determine if submodels containing this S-function can inherit their sample times from the parent model.

```

/* Function: mdlInitializeSampleTimes =====
 * Abstract:
 * This function is used to specify the sample time(s) for the
 * S-function. This S-function has two sample times. The
 * first, a continuous sample time, is used for the input to the
 * transfer function, u. The second, a discrete sample time
 * provided by the user, defines the rate at which the transfer
 * function coefficients are updated.
 */
static void mdlInitializeSampleTimes(SimStruct *S)

```



```

{
    /*
     * the first sample time, continuous
     */
    ssSetSampleTime(S, 0, CONTINUOUS_SAMPLE_TIME);
    ssSetOffsetTime(S, 0, 0.0);

    /*
     * the second, discrete sample time, is user provided
     */
    ssSetSampleTime(S, 1, mxGetPr(TS(S))[0]);
    ssSetOffsetTime(S, 1, 0.0);
    ssSetModelReferenceSampleTimeDefaultInheritance(S);

} /* end mdlInitializeSampleTimes */

```

The optional S-function method `mdlInitializeConditions` initializes the continuous state vector and the initial numerator and denominator vectors. The `#define` statement before this method is required for Simulink to call this function. The function initializes the continuous states to zero. The numerator and denominator coefficients are initialized from the first two S-function parameters, normalized by the first denominator coefficient. The function sets the value stored in the `IWork` vector to zero, to indicate that the first bank of numerator and denominator coefficients stored in the `RWork` vector is currently in use.

```

#define MDL_INITIALIZE_CONDITIONS
/* Function: mdlInitializeConditions =====
 * Abstract:
 *     Initialize the states, numerator and denominator coefficients.
 */
static void mdlInitializeConditions(SimStruct *S)
{
    int_T i;
    int_T nContStates = ssGetNumContStates(S);
    real_T *x0 = ssGetContStates(S);
    int_T nCoeffs = nContStates + 1;
    real_T *numBank0 = ssGetRWork(S);
    real_T *denBank0 = numBank0 + nCoeffs;
}

```

```
int_T *activeBank    = ssGetIWork(S);

/*
 * The continuous states are all initialized to zero.
 */
for (i = 0; i < nContStates; i++) {
    x0[i]          = 0.0;
    numBank0[i]    = 0.0;
    denBank0[i]    = 0.0;
}
numBank0[nContStates] = 0.0;
denBank0[nContStates] = 0.0;

/*
 * Set up the initial numerator and denominator.
 */
{
    const real_T *numParam  = mxGetPr(NUM(S));
    int          numParamLen = mxGetNumberOfElements(NUM(S));

    const real_T *denParam  = mxGetPr(DEN(S));
    int          denParamLen = mxGetNumberOfElements(DEN(S));
    real_T       den0       = denParam[0];

    for (i = 0; i < denParamLen; i++) {
        denBank0[i] = denParam[i] / den0;
    }

    for (i = 0; i < numParamLen; i++) {
        numBank0[i] = numParam[i] / den0;
    }
}

/*
 * Normalize if this transfer function has direct feedthrough.
 */
for (i = 1; i < nCoeffs; i++) {
    numBank0[i] -= denBank0[i]*numBank0[0];
}
```

```

/*
 * Indicate bank0 is active (i.e. bank1 is oldest).
 */
*activeBank = 0;

} /* end mdlInitializeConditions */

```

The `mdlOutputs` function calculates the S-function output signals when the S-function is simulating in a continuous task, i.e., `ssIsContinuousTask` is true. If the simulation is also at a major time step, `mdlOutputs` checks if the numerator and denominator coefficients need to be updated, as indicated by a switch in the active bank stored in the `IWork` vector. At both major and minor time steps, the S-function calculates the output using the numerator coefficients stored in the active bank.

```

/* Function: mdlOutputs =====
 * Abstract:
 *   The outputs for this block are computed by using a controllable state-
 *   space representation of the transfer function.
 */
static void mdlOutputs(SimStruct *S, int_T tid)
{
    if (ssIsContinuousTask(S,tid)) {
        int            i;
        real_T         *num;
        int            nContStates = ssGetNumContStates(S);
        real_T         *x          = ssGetContStates(S);
        int_T          nCoeffs     = nContStates + 1;
        InputRealPtrsType uPtrs    = ssGetInputPortRealSignalPtrs(S,0);
        real_T         *y          = ssGetOutputPortRealSignal(S,0);
        int_T          *activeBank = ssGetIWork(S);

        /*
         * Switch banks because we've updated them in mdlUpdate and we're no
         * longer in a minor time step.
         */
        if (ssIsMajorTimeStep(S)) {
            int_T *banksUpdated = ssGetIWork(S) + 1;
            if (*banksUpdated) {
                *activeBank = !(*activeBank);
            }
        }
    }
}

```

```

        *banksUpdated = 0;
        /*
        * Need to tell the solvers that the derivatives are no
        * longer valid.
        */
        ssSetSolverNeedsReset(S);
    }
}
num = ssGetRWork(S) + (*activeBank) * (2*nCoeffs);

/*
* The continuous system is evaluated using a controllable state space
* representation of the transfer function. This implies that the
* output of the system is equal to:
*
*
*      y(t) = Cx(t) + Du(t)
*            = [ b1 b2 ... bn]x(t) + b0u(t)
*
* where b0, b1, b2, ... are the coefficients of the numerator
* polynomial:
*
*      B(s) = b0 s^n + b1 s^{n-1} + b2 s^{n-2} + ... + bn-1 s + bn
*/
*y = *num++ * (*uPtrs[0]);
for (i = 0; i < nContStates; i++) {
    *y += *num++ * *x++;
}
}

} /* end mdlOutputs */

```

Although this example has no discrete states, the method still implements the `mdlUpdate` function to update the transfer function coefficients at every major time step. Because this method is optional, a `#define` statement precedes it. The method uses `ssGetInputPortRealSignalPtrs` to obtain a pointer to the input signal. The input signal's values become the new transfer function coefficients, which the S-function stores in the bank of the inactive `RWork` vector. When the `mdlOutputs` function is later called at this major time step, it updates the active bank to be this updated bank of coefficients.

```

#define MDL_UPDATE
/* Function: mdlUpdate =====
 * Abstract:
 *     Every time through the simulation loop, update the
 *     transfer function coefficients. Here we update the oldest bank.
 */
static void mdlUpdate(SimStruct *S, int_T tid)
{
    if (ssIsSampleHit(S, 1, tid)) {
        int_T          i;
        InputRealPtrsType uPtrs      = ssGetInputPortRealSignalPtrs(S,0);
        int_T          uIdx          = 1; /*1st coeff is after signal input*/
        int_T          nContStates   = ssGetNumContStates(S);
        int_T          nCoeffs       = nContStates + 1;
        int_T          bankToUpdate  = !ssGetIWork(S)[0];
        real_T         *num          = ssGetRWork(S)+bankToUpdate*2*nCoeffs;
        real_T         *den          = num + nCoeffs;

        real_T         den0;
        int_T          allZero;

        /*
         * Get the first denominator coefficient. It will be used
         * for normalizing the numerator and denominator coefficients.
         *
         * If all inputs are zero, we probably could have unconnected
         * inputs, so use the parameter as the first denominator coefficient.
         */
        den0 = *uPtrs[uIdx+nCoeffs];
        if (den0 == 0.0) {
            den0 = mxGetPr(DEN(S))[0];
        }

        /*
         * Grab the numerator.
         */
        allZero = 1;
        for (i = 0; (i < nCoeffs) && allZero; i++) {
            allZero &= *uPtrs[uIdx+i] == 0.0;
        }
    }
}

```

```
    }

    if (allZero) { /* if numerator is all zero */
        const real_T *numParam = mxGetPr(NUM(S));
        int_T numParamLen = mxGetNumberOfElements(NUM(S));
        /*
         * Move the input to the denominator input and
         * get the denominator from the input parameter.
         */
        uIdx += nCoeffs;
        num += nCoeffs - numParamLen;
        for (i = 0; i < numParamLen; i++) {
            *num++ = *numParam++ / den0;
        }
    } else {
        for (i = 0; i < nCoeffs; i++) {
            *num++ = *uPtrs[uIdx++] / den0;
        }
    }
}

/*
 * Grab the denominator.
 */
allZero = 1;
for (i = 0; (i < nCoeffs) && allZero; i++) {
    allZero &= *uPtrs[uIdx+i] == 0.0;
}

if (allZero) { /* If denominator is all zero. */
    const real_T *denParam = mxGetPr(DEN(S));
    int_T denParamLen = mxGetNumberOfElements(DEN(S));

    den0 = denParam[0];
    for (i = 0; i < denParamLen; i++) {
        *den++ = *denParam++ / den0;
    }
} else {
    for (i = 0; i < nCoeffs; i++) {
        *den++ = *uPtrs[uIdx++] / den0;
    }
}
```

```

    }

    /*
     * Normalize if this transfer function has direct feedthrough.
     */
    num = ssGetRWork(S) + bankToUpdate*2*nCoeffs;
    den = num + nCoeffs;
    for (i = 1; i < nCoeffs; i++) {
        num[i] -= den[i]*num[0];
    }

    /*
     * Indicate oldest bank has been updated.
     */
    ssGetIWork(S)[1] = 1;
}

} /* end mdlUpdate */

```

The `mdlDerivatives` function calculates the continuous state derivatives. The function uses the coefficients from the active bank to solve a controllable state-space representation of the transfer function.

```

#define MDL_DERIVATIVES
/* Function: mdlDerivatives =====
 * Abstract:
 *     The derivatives for this block are computed by using a controllable
 *     state-space representation of the transfer function.
 */
static void mdlDerivatives(SimStruct *S)
{
    int_T          i;
    int_T          nContStates = ssGetNumContStates(S);
    real_T         *x           = ssGetContStates(S);
    real_T         *dx          = ssGetdX(S);
    int_T          nCoeffs      = nContStates + 1;
    int_T          activeBank    = ssGetIWork(S)[0];
    const real_T   *num          = ssGetRWork(S) + activeBank*(2*nCoeffs);
    const real_T   *den          = num + nCoeffs;
    InputRealPtrsType uPtrs     = ssGetInputPortRealSignalPtrs(S,0);

```

```

/*
 * The continuous system is evaluated using a controllable state-space
 * representation of the transfer function. This implies that the
 * next continuous states are computed using:
 *
 *
 *      dx = Ax(t) + Bu(t)
 *          = [-a1 -a2 ... -an] [x1(t)] + [u(t)]
 *            [ 1  0 ...  0] [x2(t)] + [0]
 *            [ 0  1 ...  0] [x3(t)] + [0]
 *            [ .  . ...  .]  .      + .
 *            [ .  . ...  .]  .      + .
 *            [ .  . ...  .]  .      + .
 *            [ 0  0 ... 1 0] [xn(t)] + [0]
 *
 * where a1, a2, ... are the coefficients of the numerator polynomial:
 *
 *      A(s) = s^n + a1 s^{n-1} + a2 s^{n-2} + ... + an-1 s + an
 */
dx[0] = -den[1] * x[0] + *uPtrs[0];
for (i = 1; i < nContStates; i++) {
    dx[i] = x[i-1];
    dx[0] -= den[i+1] * x[i];
}

} /* end mdlDerivatives */

```

Simulink requires the S-function to contain an mdlTerminate function. In this example, the function is empty.

```

/* Function: mdlTerminate =====
 * Abstract:
 *      Called when the simulation is terminated.
 *      For this block, there are no end of simulation tasks.
 */
static void mdlTerminate(SimStruct *S)
{
    UNUSED_ARG(S); /* unused input argument */
} /* end mdlTerminate */

```


The required S-function trailer includes the files necessary for simulation or code generation, as follows.

```
#ifdef MATLAB_MEX_FILE    /* Is this file being compiled as a MEX-file? */
#include "simulink.c"      /* MEX-file interface mechanism */
#else
#include "cg_sfund.h"      /* Code generation registration function */
#endif
```

Note The `mdlTerminate` function uses the `UNUSED_ARG` macro to indicate that an input argument the callback requires is not used. This optional macro is defined in `matlabroot/simulink/include/simstruc_types.h`. If used, you must call this macro once for each input argument that a callback does not use.

S-Function Callback Methods — Alphabetical List

Every user-written S-function must implement a set of methods, called *callback methods* or simply *callbacks*, that Simulink invokes when simulating a model that contains the S-function. Some callback methods are optional. Simulink invokes an optional callback only if the S-function defines the callback. This section describes the purpose and syntax of all callback methods that an S-function can implement. In each case, the documentation for a callback method indicates whether it is required or optional. For a list of required callback methods, see “Callback Methods That an S-Function Must Implement” on page 3-50.

mdlCheckParameters

Purpose	Check the validity of an S-function's parameters
Required	No
C Syntax	<code>void mdlCheckParameters(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>CheckParameters(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing an S-Function block.
Description	<p>Verifies new parameter settings whenever parameters change or are reevaluated during a simulation. This function is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement to be compatible with Real-Time Workshop targets that support non-inlined S-functions.</p> <p>When a simulation is running, changes to S-function parameters can occur at any time during the simulation loop, that is, either at the start of a simulation step or during a simulation step. When the change occurs during a simulation step, Simulink calls this routine twice to handle the parameter change. The first call during the simulation step is used to verify that the parameters are correct. After verifying the new parameters, the simulation continues using the original parameter values until the next simulation step, at which time the new parameter values are used. Redundant calls are needed to maintain simulation consistency.</p>

Note You cannot access the work, state, input, output, and other vectors in this routine. Use this routine only to validate the parameters. Additional processing of the parameters should be done in `mdlProcessParameters`.

Example

This example checks the first S-function parameter to verify that it is a real nonnegative scalar.

Note Since `mdlCheckParameters` is an optional method, a `#define MDL_CHECK_PARAMETERS` statement precedes the function. Also, since Real-Time Workshop does not support code generation for `mdlCheckParameters`, the function is wrapped in a `#if defined(MATLAB_MEX_FILE)` statement.

```
#define PARAM1(S) ssGetSFcnParam(S,0)
#define MDL_CHECK_PARAMETERS /* Change to #undef to remove function */
#if defined(MDL_CHECK_PARAMETERS) && defined(MATLAB_MEX_FILE)
static void mdlCheckParameters(SimStruct *S)
{
    if (mxGetNumberOfElements(PARAM1(S)) != 1) {
        ssSetErrorStatus(S,"Parameter to S-function must be a scalar");
        return;
    } else if (mxGetPr(PARAM1(S))[0] < 0) {
        ssSetErrorStatus(S, "Parameter to S-function must be nonnegative");
        return;
    }
}
#endif /* MDL_CHECK_PARAMETERS */
```

In addition to the preceding routine, you must add a call to this method from `mdlInitializeSizes` to check parameters during initialization, because `mdlCheckParameters` is only called while the simulation is running. To do this, after setting the number of parameters you expect

mdlCheckParameters

in your S-function by using `ssSetNumSFcnParams`, use this code in `mdlInitializeSizes`:

```
static void mdlInitializeSizes(SimStruct *S)
{
    ssSetNumSFcnParams(S, 1); /* Number of expected parameters */
#ifdef MATLAB_MEX_FILE
    if(ssGetNumSFcnParams(S) == ssGetSFcnParamsCount(S) {
        mdlCheckParameters(S);
        if(ssGetErrorStates(S) != NULL) return;
    } else {
        return; /* Simulink will report a mismatch error. */
    }
#endif
    ...
}
```

Note The macro `ssGetSFcnParamsCount` returns the actual number of parameters entered in the dialog box.

See `matlabroot/simulink/src/sfun_errhdl.c` for an example.

Languages

Ada, C, M

See Also

`mdlProcessParameters`, `ssGetSFcnParamsCount`

Purpose	Compute the S-function's derivatives
Required	No
C Syntax	<code>void mdlDerivatives(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>Derivatives(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block
Description	<p>Simulink invokes this optional method at each time step to compute the derivatives of the S-function's continuous states. This method should store the derivatives in the S-function's state derivatives vector. This method can use <code>ssGetX</code> to get a pointer to the derivatives vector.</p> <p>Each time the <code>mdlDerivatives</code> routine is called, it must explicitly set the values of all derivatives. The derivative vector does not maintain the values from the last call to this routine. The memory allocated to the derivative vector changes during execution.</p>

mdlDerivatives

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#define MDL_DERIVATIVES
#if defined(MDL_DERIVATIVES) && defined(MATLAB_MEX_FILE)
static void mdlDerivatives(SimStruct *S)
{
    /* Add mdlDerivatives code here */
}
#endif
```

The `define` statement makes the `mdlDerivatives` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Example

For an example, see *matlabroot/simulink/src/csfunc.c*. A Level-2 M-file example can be found in *matlabroot/toolbox/simulink/blocks/msfcn_limintm.m*.

Languages

Ada, C, M

See Also

`ssGetdx`

Purpose	Respond to disabling of an enabled system containing this block
Required	No
C Syntax	<code>void mdlDisable(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>Disable(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	Simulink invokes this optional method if this block resides in an enabled subsystem and the enabled subsystem changes from an enabled to a disabled state at the current time step. Your S-function can use this method to perform any actions required by the disabling of the containing subsystem.
Languages	Ada, C, M
See Also	<code>mdlEnable</code>

mdlEnable

Purpose	Respond to enabling of an enabled system containing this block
Required	No
C Syntax	<code>void mdlEnable(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>Enable(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	Simulink invokes this optional method if this block resides in an enabled subsystem and the enabled subsystem changes from a disabled to an enabled state at the current time step. Your S-function can use this method to perform any actions required by the enabling of the containing subsystem.
Languages	Ada, C, M
See Also	<code>mdlDisable</code>

Purpose Specify time of the next sample time hit

Required No

C Syntax `void mdlGetTimeOfNextVarHit(SimStruct *S)`

C Arguments S
SimStruct representing an S-Function block.

Description Simulink invokes this optional method at every major integration step to get the time of the next sample time hit. This method should set the time of next hit, using `ssSetTNext`. The time of the next hit must be greater than the current simulation time as returned by `ssGetT`. The S-function must implement this method if it operates at a discrete, variable-step sample time.

For Level-2 M-file S-functions, use a sample time of -2 to specify a variable sample time. The S-function's output method should then update the `NextTimeHit` property of the instance of the `Simulink.MSFcnRunTimeBlock` class representing the S-function block to set the time of the next sample time hit. See `matlabroot/toolbox/simulink/blocks/msfcn_vs.m` for an example.

For Level-1 M-file S-functions, a flag of 4 is passed to the S-function when the next sample time hit needs to be calculated.

Note The time of the next hit can be a function of the input signals.

Example

```
static void mdlGetTimeOfNextVarHit(SimStruct *S)
{
    time_T offset = getOffset();
    time_T timeOfNextHit = ssGetT(S) + offset;
    ssSetTNext(S, timeOfNextHit);
}
```

mdlGetTimeOfNextVarHit

Languages C, M

See Also mdlInitializeSampleTimes, ssGetT, ssSetTNext

Purpose	Initialize the state vectors of this S-function
Required	No
C Syntax	<code>void mdlInitializeConditions(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>InitializeConditions(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	<p>Simulink invokes this optional method at the beginning of a simulation. It should initialize the continuous and discrete states, if any, of this S-Function block. Use <code>ssGetContStates</code> and/or <code>ssGetDiscStates</code> to get the states. This method can also perform any other initialization activities that this S-function requires.</p> <p>If this S-function resides in an enabled subsystem configured to reset states, Simulink also calls this method when the enabled subsystem restarts execution. This method can use the <code>ssIsFirstInitCond</code> macro to determine whether it is being called for the first time.</p>

mdlInitializeConditions

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#define MDL_INITIALIZE_CONDITIONS
#if defined(MDL_INITIALIZE_CONDITIONS) && defined(MATLAB_MEX_FILE)
static void mdlInitializeConditions(SimStruct *S)
{
    /* Add mdlInitializeConditions code here */
}
#endif
```

The `define` statement makes the `mdlInitializeConditions` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Example

This example is an S-function with both continuous and discrete states. It initializes both sets of states to 1.0.

```
#define MDL_INITIALIZE_CONDITIONS    /*Change to #undef to remove */
/*function*/
#if defined(MDL_INITIALIZE_CONDITIONS)

static void mdlInitializeConditions(SimStruct *S)
{
    int i;
    real_T *xcont    = ssGetContStates(S);
    int_T   nCStates = ssGetNumContStates(S);
    real_T *xdisc    = ssGetRealDiscStates(S);
    int_T   nDStates = ssGetNumDiscStates(S);

    for (i = 0; i < nCStates; i++) {
        *xcont++ = 1.0;
    }
}
```

```
    for (i = 0; i < nDStates; i++) {  
        *xdisc++ = 1.0;  
    }  
  
}  
#endif /* MDL_INITIALIZE_CONDITIONS */
```

For another example that initializes only the continuous states, see *matlabroot/simulink/src/resetint.c*.

Languages

C, C++, M

See Also

mdlStart, ssIsFirstInitCond, ssGetContStates, ssGetDiscStates

mdlInitializeSampleTimes

Purpose Specify the sample rates at which this S-function operates

Required Yes

C Syntax `void mdlInitializeSampleTimes(SimStruct *S)`

C Arguments S
SimStruct representing an S-Function block.

Description This method should specify the sample time and offset time for each sample rate at which this S-function operates via the following paired macros

```
ssSetSampleTime(S, sampleTimeIndex, sample_time)
ssSetOffsetTime(S, offsetTimeIndex, offset_time)
```

where `sampleTimeIndex` runs from 0 to one less than the number of sample times specified in `mdlInitializeSizes` via `ssSetNumSampleTimes`.

If the S-function operates at one or more sample rates, this method can specify any of the following sample time and offset values for a given sample time:

- [CONTINUOUS_SAMPLE_TIME, 0.0]
- [CONTINUOUS_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
- [discrete_sample_period, offset]
- [VARIABLE_SAMPLE_TIME, 0.0]

The uppercase values are macros defined in `simstruc_types.h`.

If the S-function operates at one rate, this method can alternatively set the sample time to one of the following sample/offset time pairs.

- [INHERITED_SAMPLE_TIME, 0.0]

- [INHERITED_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]

If the number of sample times is 0, Simulink assumes that the S-function inherits its sample time from the block to which it is connected, i.e., that the sample time is

```
[INHERITED_SAMPLE_TIME, 0.0]
```

This method can therefore return without doing anything.

Use the following guidelines when specifying sample times.

- A continuous function that changes during minor integration steps should set the sample time to

```
[CONTINUOUS_SAMPLE_TIME, 0.0]
```

- A continuous function that does not change during minor integration steps should set the sample time to

```
[CONTINUOUS_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
```

- A discrete function that changes at a specified rate should set the sample time to

```
[discrete_sample_period, offset]
```

where

```
discrete_sample_period > 0.0
```

and

```
0.0 <= offset < discrete_sample_period
```

- A discrete function that changes at a variable rate should set the sample time to

```
[VARIABLE_SAMPLE_TIME, 0.0]
```

mdlInitializeSampleTimes

Simulink invokes the `mdlGetTimeOfNextVarHit` function to get the time of the next sample hit for the variable-step discrete task.

Note that `VARIABLE_SAMPLE_TIME` requires a variable-step solver.

- To operate correctly in a triggered subsystem or a periodic system, a discrete S-function should

- Specify a single sample time set to

```
[INHERITED_SAMPLE_TIME, 0.0]
```

- Use `ssSetOptions` to set the `SS_OPTION_DISALLOW_CONSTANT_SAMPLE_TIME` simulation option in `mdlInitializeSizes`

- Verify that it was assigned a discrete or triggered sample time in `mdlSetWorkWidths`:

```
if (ssGetSampleTime(S, 0) == CONTINUOUS_SAMPLE_TIME) {  
    ssSetErrorStatus(S,  
        "This block cannot be assigned a continuous sample  
        time");  
}
```

After propagating sample times throughout the block diagram, Simulink assigns the sample time

```
[INHERITED_SAMPLE_TIME, INHERITED_SAMPLE_TIME]
```

to discrete blocks residing in triggered subsystems.

If this function has no intrinsic sample time, it should set its sample time to inherited according to the following guidelines:

- A function that changes as its input changes, even during minor integration steps, should set its sample time to

```
[INHERITED_SAMPLE_TIME, 0.0]
```

A function that changes as its input changes, but doesn't change during minor integration steps (i.e., is held during minor steps) should set its sample time to

```
[INHERITED_SAMPLE_TIME, FIXED_IN_MINOR_STEP_OFFSET]
```

The S-function should use the `ssIsSampleHit` or `ssIsContinuousTask` macros to check for a sample hit during execution (in `mdlOutputs` or `mdlUpdate`). For example, if the block's first sample time is continuous, the function can use the following code fragment to check for a sample hit.

```
if (ssIsContinuousTask(S,tid)) {  
}
```

Note The function receives incorrect results if it uses `ssIsSampleHit(S,0,tid)`.

If the function wants to determine whether the third (discrete) task has a hit, it can use the following code fragment.

```
if (ssIsSampleHit(S,2,tid) {  
}
```

mdlInitializeSampleTimes

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#if defined(MATLAB_MEX_FILE)
static void mdlInitializeSampleTimes(SimStruct *S)
{
    /* Add mdlInitializeSampleTimes code here */
}
#endif
```

The define statement makes the `mdlInitializeSampleTimes` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Languages C

See Also `mdlSetInputPortSampleTime`, `mdlSetOutputPortSampleTime`

Purpose	Specify the number of inputs, outputs, states, parameters, and other characteristics of the S-function
Required	Yes
C Syntax	<code>void mdlInitializeSizes(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>setup(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	<p>This is the first of the S-function's callback methods that Simulink calls. This method should perform the following tasks:</p> <ul style="list-style-type: none">• Specify the number of parameters that this S-function supports, using <code>ssSetNumSFcnParams</code>. Use <code>ssSetSFcnParamTunable(S,paramIdx, 0)</code> when a parameter cannot change during simulation, where <code>paramIdx</code> starts at 0. When a parameter has been specified as not tunable, Simulink issues an error during simulation (or the Real-Time Workshop external mode) if an attempt is made to change the parameter.• Specify the number of states that this function has, using <code>ssSetNumContStates</code> and <code>ssSetNumDiscStates</code>.• Configure the block's input ports. This entails the following tasks:

mdlInitializeSizes

- Specify the number of input ports that this S-function has, using `ssSetNumInputPorts`.
- Specify the dimensions of the input ports.
See `ssSetInputPortDimensionInfo` for more information.
- For each input port, specify whether it has direct feedthrough, using `ssSetInputPortDirectFeedThrough`.

A port has direct feedthrough if the input is used in either the `mdlOutputs` or `mdlGetTimeOfNextVarHit` function. The direct feedthrough flag for each input port can be set to either 1=yes or 0=no. It should be set to 1 if the input, `u`, is used in the `mdlOutputs` or `mdlGetTimeOfNextVarHit` routine. Setting the direct feedthrough flag to 0 tells Simulink that `u` is not used in either of these S-function routines. Violating this leads to unpredictable results.

- Configure the block's output ports.

This entails the following tasks:

- Specify the number of output ports that the block has, using `ssSetNumOutputPorts`.
- Specify the dimensions of the output ports.

See `mdlSetOutputPortDimensionInfo` for more information.

If your S-function outputs are discrete (for example, the outputs only take specific values such as 0, 1, and 2), specify `SS_OPTION_DISCRETE_VALUED_OUTPUT`.

- Set the number of sample times (i.e., sample rates) at which the block operates.

There are two ways of specifying sample times:

- Port-based sample times
- Block-based sample times

See “Sample Times” on page 7-26 for a complete discussion of sample time issues.

For multirate S-functions, the suggested approach to setting sample times is via the port-based sample times method. When you create a multirate S-function, you must take care to verify that, when slower tasks are preempted, your S-function correctly manages data so as to avoid race conditions. When port-based sample times are specified, the block cannot inherit a constant sample time at any port.

- Set the size of the block’s work vectors, using `ssSetNumRWork`, `ssSetNumIWork`, `ssSetNumPWork`, `ssSetNumModes`, `ssSetNumNonsampledZCs`.
- Set the simulation options that this block implements, using `ssSetOptions`.

All options have the form `SS_OPTION_<name>`. See `ssSetOptions` for information on each option. The options should be bitwise OR’d together, as in

```
ssSetOptions(S, (SS_OPTION_name1 | SS_OPTION_name2))
```

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#if defined(MATLAB_MEX_FILE)
static void mdlInitializeSizes(SimStruct *S)
{
    /* Add mdlInitializeSizes code here */
}
#endif
```

The `define` statement makes the `mdlInitializeSizes` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Dynamically Sized Block Features

You can set the parameters `NumContStates`, `NumDiscStates`, `NumInputs`, `NumOutputs`, `NumRWork`, `NumIWork`, `NumPWork`, `NumModes`, and `NumNonsampledZCs` to a fixed nonnegative integer or tell Simulink to size them dynamically:

- `DYNAMICALLY_SIZED` -- Sets lengths of states, work vectors, and so on to values inherited from the driving block. It sets widths to the actual input widths, according to the scalar expansion rules unless you use `mdlSetWorkWidths` to set the widths.
- `0` or positive number -- Sets lengths (or widths) to the specified values. The default is `0`.

Example

```
static void mdlInitializeSizes(SimStruct *S)
{
    int_T nInputPorts = 1; /* number of input ports */
    int_T nOutputPorts = 1; /* number of output ports */
    int_T needsInput = 1; /* direct feed through */
}
```



```
int_T inputPortIdx = 0;
int_T outputPortIdx = 0;

ssSetNumSFcnParams(S, 0); /* Number of expected parameters */
if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
    /*
     * If the number of expected input parameters is not
     * equal to the number of parameters entered in the
     * dialog box, return. Simulink will generate an error
     * indicating that there is a parameter mismatch.
     */
    return;
} else {
    mdlCheckParameters(S);

    if (ssGetErrorStatus(s) != NULL)
        return;
}

ssSetNumContStates( S, 0);
ssSetNumDiscStates( S, 0);

/*
 * Configure the input ports. First set the number of input
 * ports.
 */
if (!ssSetNumInputPorts(S, nInputPorts)) return;
/*
 * Set input port dimensions for each input port index
 * starting at 0.
 */
if (!ssSetInputPortDimensionInfo(S, inputPortIdx,
    DYNAMIC_DIMENSION)) return;
/*
```

mdlInitializeSizes

```
    * Set direct feedthrough flag (1=yes, 0=no).
    */
    ssSetInputPortDirectFeedThrough(S, inputPortIdx, needsInput);

    /*
    * Configure the output ports. First set the number of
    * output ports.
    */
    if (!ssSetNumOutputPorts(S, nOutputPorts)) return;

    /*
    * Set output port dimensions for each output port index
    * starting at 0.
    */
    if (!ssSetOutputPortDimensionInfo(S, outputPortIdx,
        DYNAMIC_DIMENSION)) return;

    /*
    * Set the number of sample times.
    */
    ssSetNumSampleTimes(S, 1);

    /*
    * Set size of the work vectors.
    */
    ssSetNumRWork(S, 0); /* real vector */
    ssSetNumIWork(S, 0); /* integer vector */
    ssSetNumPWork(S, 0); /* pointer vector */
    ssSetNumModes(S, 0); /* mode vector */
    ssSetNumNonsampledZCs(S, 0); /* zero crossings */

    ssSetOptions(S, 0);

} /* end mdlInitializeSizes */
```

Languages Ada, C, M

Purpose	Compute the signals that this block emits
Required	Yes
C Syntax	<code>void mdlOutputs(SimStruct *S, int_T tid)</code>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>tid Task ID.</p>
M Syntax	Outputs(s)
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p>
Description	<p>Simulink invokes this required method at each simulation time step. The method should compute the S-function's outputs at the current time step and store the results in the S-function's output signal arrays.</p> <p>The tid (task ID) argument specifies the task running when the mdlOutputs routine is invoked. You can use this argument in the mdlOutputs routine of a multirate S-Function block to encapsulate task-specific blocks of code (see "Multirate S-Function Blocks" on page 7-37).</p> <p>Use the UNUSED_ARG macro if the S-function does not contain task-specific blocks of code to indicate that the tid input argument is required but not used in the body of the callback. To do this, insert the line</p> <pre>UNUSED_ARG(tid)</pre> <p>after the declarations in mdlOutputs.</p>

mdlOutputs

For an example of an `mdlOutputs` routine that works with multiple input and output ports, see `matlabroot/simulink/src/sfun_multiport.c`.

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#if defined(MATLAB_MEX_FILE)
static void mdlOutputs(SimStruct *S)
{
    /* Add mdlOutputs code here */
}
#endif
```

The `define` statement makes the `mdlOutputs` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Languages

Ada, C, C++, M

See Also

`ssGetOutputPortComplexSignal`, `ssGetOutputPortRealSignal`,
`ssGetOutputPortSignal`

Purpose	Process the S-function's parameters
Required	No
C Syntax	<code>void mdlProcessParameters(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>ProcessParameters(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	<p>This is an optional routine that Simulink calls after <code>mdlCheckParameters</code> changes and verifies parameters. The processing is done at the top of the simulation loop when it is safe to process the changed parameters. This function is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement.</p> <p>The purpose of this routine is to process newly changed parameters. An example is to cache parameter changes in work vectors. Simulink does not call this routine when it is used with Real-Time Workshop. Therefore, if you use this routine in an S-function designed for use with Real-Time Workshop, you must write your S-function so that it doesn't rely on this routine. To do this, you must inline your S-function by using the Target Language Compiler. See <i>Real-Time Workshop Target Language Compiler</i> for information on inlining S-functions.</p> <p>The synopsis is</p> <pre>#define MDL_PROCESS_PARAMETERS /* Change to #undef to remove function */ #if defined(MDL_PROCESS_PARAMETERS) && defined(MATLAB_MEX_FILE) static void mdlProcessParameters(SimStruct *S)</pre>

mdlProcessParameters

```
{
}
#endif /* MDL_PROCESS_PARAMETERS */
```

Example

This example processes a string parameter that `mdlCheckParameters` has verified to be of the form '+++' (where there could be any number of '+' or '-' characters).

```
#define MDL_PROCESS_PARAMETERS /* Change to #undef to remove function */
#if defined(MDL_PROCESS_PARAMETERS) && defined(MATLAB_MEX_FILE)
static void mdlProcessParameters(SimStruct *S)
{
    int_T i;
    char_T *plusMinusStr;
    int_T nInputPorts = ssGetNumInputPorts(S);
    int_T *iwork = ssGetIWork(S);
    if ((plusMinusStr=(char_T*)malloc(nInputPorts+1)) == NULL) {
        ssSetErrorStatus(S,"Memory allocation error in mdlStart");
        return;
    }
    if (mxGetString(SIGNS_PARAM(S),plusMinusStr,nInputPorts+1) != 0) {
        free(plusMinusStr);
        ssSetErrorStatus(S,"mxGetString error in mdlStart");
        return;
    }
    for (i = 0; i < nInputPorts; i++) {
        iwork[i] = plusMinusStr[i] == '+'? 1: -1;
    }
    free(plusMinusStr);
}
#endif /* MDL_PROCESS_PARAMETERS */
```

`mdlProcessParameters` is called from `mdlStart` to load the signs string prior to the start of the simulation loop.

```
#define MDL_START
```

```
#if defined(MDL_START)
static void mdlStart(SimStruct *S)
{
    mdlProcessParameters(S);
}
#endif /* MDL_START */
```

Languages Ada, C, M

See Also mdlCheckParameters

mdlProjection

Purpose	Perturb the solver's solution of a system's states to better satisfy time-invariant solution relationships
Required	No
C Syntax	<code>void mdlProjection(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	Projection(s)
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	<p>This method is intended for use with S-functions that model dynamic systems whose states satisfy time-invariant relationships, such as those resulting from mass or energy conservation or other physical laws. Simulink invokes this method at each time step after the model's solver has computed the S-function's states for that time step. Typically, slight errors in the numerical solution of the states cause the solutions to fail to satisfy solution invariants exactly. Your <code>mdlProjection</code> method can compensate for the errors by perturbing the states so that they more closely approximate solution invariants at the current time step. As a result, the numerical solution adheres more closely to the ideal solution as the simulation progresses, producing a more accurate overall simulation of the system modeled by your S-function.</p> <p>Your <code>mdlProjection</code> method's perturbations of system states must fall within the solution error tolerances specified by the model in which the S-function is embedded. Otherwise, the perturbations may invalidate the solver's solution. It is up to your <code>mdlProjection</code> method to ensure that the perturbations meet the error tolerances specified by the model. See "Perturbing a System's States Using a Solution Invariant" on page</p>

8-31 for a simple method for perturbing a system's states. The following articles describe more sophisticated perturbation methods that your mdlProjection method can use.

- C.W. Gear, "Maintaining Solution Invariants in the Numerical Solution of ODEs," *Journal on Scientific and Statistical Computing*, Vol. 7, No. 3, July 1986.
- L.F. Shampine, "Conservation Laws and the Numerical Solution of ODEs I," *Computers and Mathematics with Applications*, Vol. 12B, pp. 1287–1296, 1986.
- L.F. Shampine, "Conservation Laws and the Numerical Solution of ODEs II," *Computers and Mathematics with Applications*, Vol. 38, pp. 61–72, 1999.

Perturbing a System's States Using a Solution Invariant

Here is a simple, Taylor-series-based approach to perturbing a system's states. Suppose your S-function models a dynamic system having a solution invariant, $g(X,t)$, i.e., g is a continuous, differentiable function of the system states, X , and time, t , whose value is constant with time. Then

$$X_n \cong X_n^* + J_n^T (J_n J_n^T)^{-1} R_n$$

where

- X_n is the system's ideal state vector at the solver's current time step
- X_n^* is the approximate state vector computed by the solver at the current time step
- J_n is the Jacobian of the invariant function evaluated at the point in state space specified by the approximate state vector at the current time step:

$$J_n = \frac{\partial g}{\partial X}(X_n^*, t_n)$$

- t_n is the time at the current time step
- R_n is the residual (difference) between the invariant function evaluated at X_n and X_n^* at the current time step:

$$R_n = g(X_n, t_n) - g(X_n^*, t_n)$$

Note The value of $g(X_n, t_n)$ is the same at each time step and is known by definition.

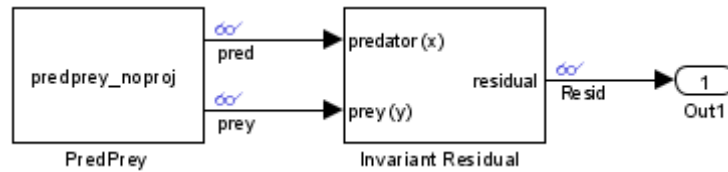
Given a continuous, differentiable invariant function for the system that your S-function models, this formula allows your S-function's mdlProjection method to compute a perturbation

$$J_n^T (J_n J_n^T)^{-1} R_n$$

of the solver's numerical solution, X_n , that more closely matches the ideal solution, X_n^* , keeping the S-function's solution from drifting from the ideal solution as the simulation progresses.

Example

This example illustrates how the perturbation method outlined in the previous section can keep a model's numerical solution from drifting from the ideal solution as a simulation progresses. Consider the following model (open):



The PredPrey block references an S-function, `predprey_noproj.m`, that uses the Lotka-Volterra equations

$$\begin{aligned}\dot{x} &= ax(1 - y) \\ \dot{y} &= -cy(1 - x)\end{aligned}$$

to model predator-prey population dynamics, where $x(t)$ is the population density of the predators and $y(t)$ is the population density of prey. The ideal solution to the predator-prey ODEs satisfies the time-invariant function

$$x^{-c} e^{cx} y^{-a} e^{ay} = d$$

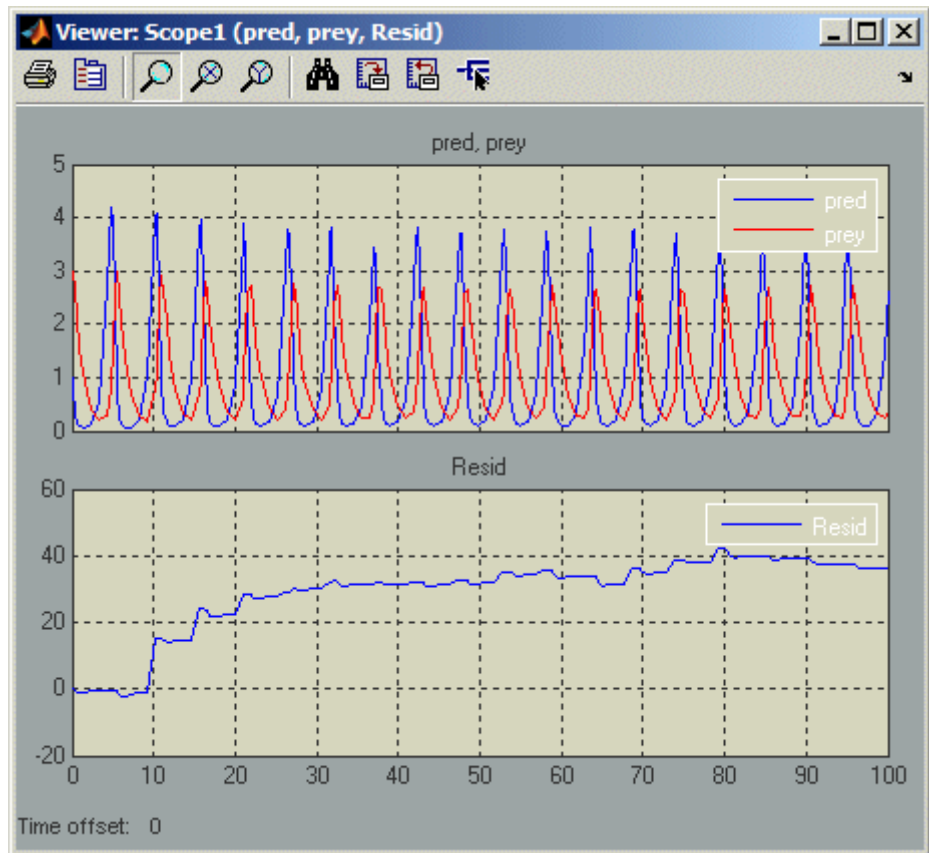
where a , c , and d are constants. The S-function assumes $a = 1$, $c = 2$, and $d = 121.85$.

The Invariant Residual block in this model computes the residual between the invariant function evaluated along the system's ideal trajectory through state space and its simulated trajectory:

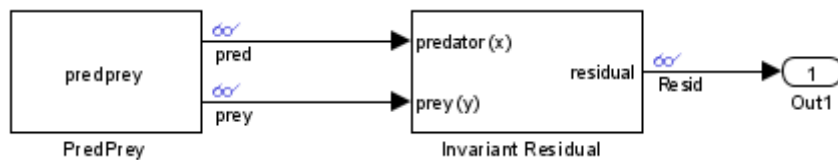
$$R_n = d - x_n^{-c} e^{cx_n} y_n^{-a} e^{ay_n}$$

where x_n and y_n are the values computed by the model's solver for the predator and prey population densities, respectively, at the current time step. Ideally, the residual should be zero throughout simulation of the model, but simulating the model reveals that the residual actually strays considerably from zero:

mdlProjection

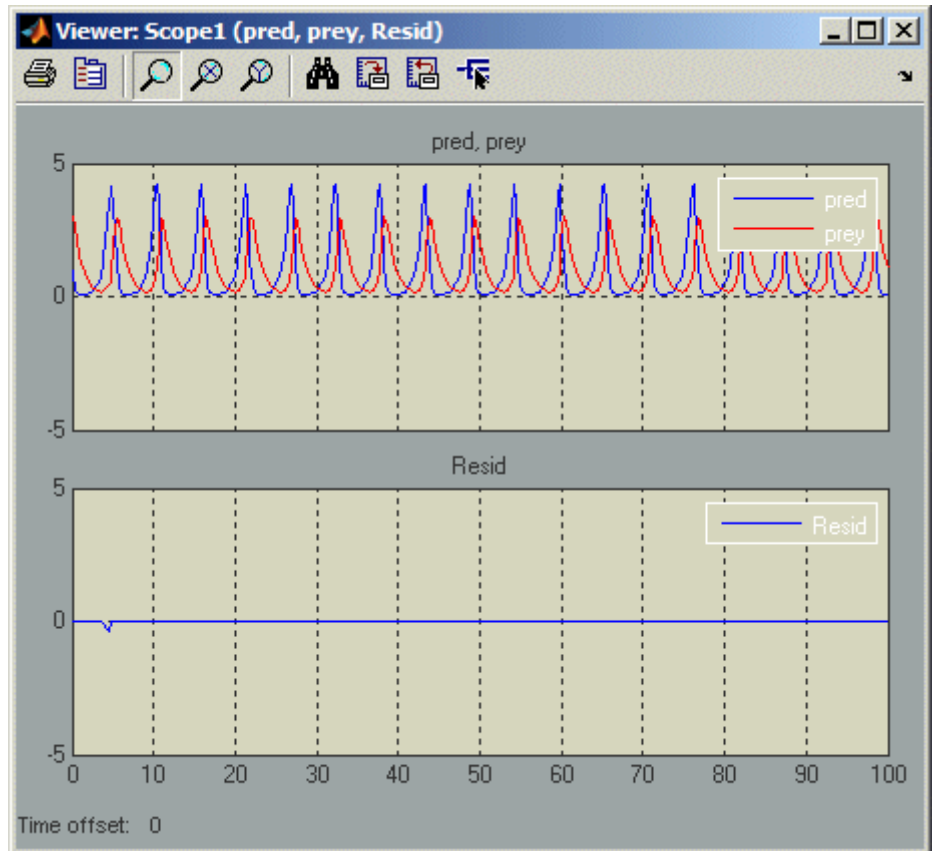


Now consider the following model (open):



This model is the same as the previous model, except that its S-function, `predprey.m`, includes a `mdlProjection` method that uses

the perturbation approach outlined in “Perturbing a System’s States Using a Solution Invariant” on page 8-31 to compensate for numerical drift. As a result, the numerical solution more closely tracks the ideal solution as the simulation progresses as demonstrated by the residual signal, which remains near or at zero throughout the simulation:



Languages

C, M

Purpose	Generate code generation data
Required	No
C Syntax	<code>void mdlRTW(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>WriteRTW(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	<p>This function is called when Real-Time Workshop is generating the <code>model.rtw</code> file. In this method, you can call the following functions that add fields to the <code>model.rtw</code> file:</p> <ul style="list-style-type: none">• <code>ssWriteRTWParameters</code>• <code>ssWriteRTWParamSettings</code>• <code>ssWriteRTWWorkVect</code>• <code>ssWriteRTWStr</code>• <code>ssWriteRTWStrParam</code>• <code>ssWriteRTWScalarParam</code>• <code>ssWriteRTWStrVectParam</code>• <code>ssWriteRTWVectParam</code>• <code>ssWriteRTW2dMatParam</code>• <code>ssWriteRTWMxVectParam</code>

- `ssWriteRTWMx2dMatParam`

This function must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

Languages

C, C++, M

See Also

`ssSetInputPortFrameData`, `ssSetOutputPortFrameData`,
`ssSetErrorStatus`

mdlSetDefaultPortComplexSignals

Purpose	Set the numeric types (real, complex, or inherited) of ports whose numeric types cannot be determined from block connectivity
Required	No
C Syntax	<pre>void mdlSetDefaultPortComplexSignals(SimStruct *S)</pre>
C Arguments	S SimStruct representing an S-Function block.
Description	<p>Simulink invokes this method if the block has ports whose numeric types cannot be determined from connectivity. (This usually happens when the block is unconnected or is part of a feedback loop.) This method must set the numeric types of all ports whose numeric types are not set. This method is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement.</p> <p>If the block does not implement this method and at least one port is known to be complex, Simulink sets the unknown ports to <code>COMPLEX_YES</code>; otherwise, it sets the unknown ports to <code>COMPLEX_NO</code>.</p>
Languages	C
See Also	<code>ssSetOutputPortComplexSignal</code> , <code>ssSetInputPortComplexSignal</code>

Purpose Set the data types of ports whose data types cannot be determined from block connectivity

Required No

C Syntax void mdlSetDefaultPortDataTypes(SimStruct *S)

C Arguments S
SimStruct representing an S-Function block.

Description Simulink invokes this method if the block has ports whose data types cannot be determined from block connectivity. (This usually happens when the block is unconnected or is part of a feedback loop.) This method must set the data types of all ports whose data types are not set. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

If the block does not implement this method and Simulink cannot determine the data types of any of its ports, Simulink sets the data types of all the ports to `double`. If the block does not implement this method and Simulink cannot determine the data types of some, but not all, of its ports, Simulink sets the unknown ports to the data type of the port whose data type has the largest size.

Simulink invokes an error if the `mdlSetDefaultPortDataType` method attempts to modify the data type of a port when the data type was previously specified by `mdlSetInputPortDataType` or `mdlSetOutputPortDataType`. If an S-function has multiple input or output ports, `mdlSetDefaultPortDataType` should check if the data type of a port is still dynamic before attempting to set the type. For example, the `mdlSetDefaultPortDataType` uses the following lines to check if the data type of the second input port is still unknown.

```
if (ssGetInputPortDataType(S, 1) == DYNAMICALLY_TYPED) {
    ssSetInputPortDataType(S, 1, SS_UINT8 );
}
```

mdlSetDefaultPortDataTypes

Languages C

See Also ssSetOutputPortDataType, ssSetInputPortDataType

Purpose	Set the default dimensions of the signals accepted or emitted by an S-function's ports
Required	No
C Syntax	<code>void mdlSetDefaultPortDimensionInfo(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
Description	<p>Simulink calls this method during signal dimension propagation when a model does not supply enough information to determine the dimensionality of signals that can enter or leave the block represented by S. This method should set the dimensions of any input and output ports that are dynamically sized to default values. This method is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement.</p> <p>If the S-function does not implement this method, Simulink tries to find a set of dimensions that will satisfy the dimension propagation rules implemented using <code>mdlSetInputPortDimensionInfo</code> and <code>mdlSetOutputPortDimensionInfo</code>. This process might not be able to produce a valid set of dimensions for S-functions with special dimension requirements.</p> <p>Simulink invokes an error if the <code>mdlSetDefaultPortDimensionInfo</code> method attempts to modify the dimensions of a port when the dimensions were previously specified by <code>mdlSetInputPortDimensionInfo</code> or <code>mdlSetOutputPortDimensionInfo</code>. If an S-function has multiple input or output ports, <code>mdlSetDefaultPortDimensionInfo</code> should check if the dimensions of the port are still dynamic before attempting to set the dimensions. For example, the <code>mdlSetDefaultPortDimensionInfo</code> uses the following lines to check if the dimensions of the first output port are still unknown.</p>

```
if (ssGetOutputPortWidth(S, 0) == DYNAMICALLY_SIZED) {
```

mdlSetDefaultPortDimensionInfo

```
        ssSetOutputPortMatrixDimensions(S, 0, 1, 1 );  
    }
```

Example See *matlabroot/simulink/src/sfun_matadd.c* for an example of how to use this function.

Languages C

See Also `ssSetErrorStatus`, `ssSetOutputPortMatrixDimensions`

Purpose	Set the numeric types (real, complex, or inherited) of the signals accepted by an input port
Required	No
C Syntax	<pre>void mdlSetInputPortComplexSignal(SimStruct *S, int_T port, CSignal_T csig)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>csig Numeric type of signal, either COMPLEX_NO (real) or COMPLEX_YES (complex).</p>
M Syntax	<pre>SetInputPortComplexSignal(s, port, typeId)</pre>
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>port Integer value specifying index of port to be set.</p> <p>typeId Integer value specifying whether the port accepts real (0) or complex (1) signals.</p>
Description	Simulink calls this routine to set the input port numeric type for inputs that have this attribute set to COMPLEX_INHERITED. The input csig is the proposed numeric type for this input port. This method is only valid for simulation, and must be enclosed in a #if defined(MATLAB_MEX_FILE) statement.

mdlSetInputPortComplexSignal

The S-function must check whether the proposed numeric type is a valid type for the specified port. If it is valid, the S-function must set the numeric type of the specified input port using `ssSetInputPortComplexSignal`. Otherwise, it must report an error using `ssSetErrorStatus`. The S-function can also set the numeric types of other input and output ports with inherited numeric types. Simulink reports an error if the S-function changes the numeric type of a port whose numeric type is known.

If the S-function does not implement this routine, Simulink assumes that the S-function accepts a real or complex signal and sets the input port numeric type to the specified value.

Simulink will call this method until all input ports with inherited numeric types have their numeric types specified.

Example

See `matlabroot/simulink/src/sdotproduct.c` for an example of how to use this function.

Languages

C, C++, M

See Also

`ssSetErrorStatus`, `ssSetInputPortComplexSignal`

Purpose	Set the data types of the signals accepted by an input port
Required	No
C Syntax	<code>void mdlSetInputPortDataType(SimStruct *S, int_T port, DTypeId id)</code>
C Arguments	<p><code>S</code> SimStruct representing an S-Function block.</p> <p><code>port</code> Index of a port.</p> <p><code>id</code> Data type ID.</p>
M Syntax	<code>SetInputPortDataType(s, port, typeId)</code>
M Arguments	<p><code>s</code> Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.</p> <p><code>port</code> Integer value specifying index of port to be set.</p> <p><code>typeId</code> Integer value specifying ID of port's data type. Use <code>s.getDatatypeName(typeId)</code> to get the data type's name.</p>
Description	Simulink calls this routine to set the data type of port when port has an inherited data type. The data type <code>id</code> is the proposed data type for this port. Data type IDs for the built-in data types can be found in <code>matlabroot/simulink/include/simstruc_types.h</code> . This method is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement.

mdlSetInputPortDataType

The S-function must check whether the specified data type is a valid data type for the specified port. If it is a valid data type, it must set the data type of the input port using `ssSetInputPortDataType`. Otherwise, it must report an error using `ssSetErrorStatus`.

The S-function can also set the data types of other input and output ports if they are unknown. Simulink reports an error if the S-function changes the data type of a port whose data type has been set.

If the block does not implement this routine, Simulink assumes that the block accepts any data type and sets the input port data type to the specified value.

Simulink will call this method until all input ports with inherited data types have their data types specified.

Languages C, M

See Also `ssSetErrorStatus`, `ssSetInputPortDataType`

Purpose	Set the dimensions of the signals accepted by an input port
Required	No
C Syntax	<pre>void mdlSetInputPortDimensionInfo(SimStruct *S, int_T port, const DimsInfo_T *dimsInfo)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>dimsInfo Structure that specifies the signal dimensions supported by the port.</p> <p>See <code>ssSetInputPortDimensionInfo</code> for a description of this structure.</p>
M Syntax	<pre>SetInputPortDimensions(s, port, dims)</pre>
M Arguments	<p>s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.</p> <p>port Integer value specifying index of port to be set.</p> <p>dims 1-D array that specifies the signal dimensions supported by the port, e.g., <code>[5]</code> for a 5-element vector signal or <code>[3 3]</code> for a 3-by-3 matrix signal.</p>
Description	Simulink calls this method during dimension propagation with candidate dimensions <code>dimsInfo</code> for <code>port</code> . If the proposed dimensions are acceptable, this method should go ahead and set the actual

mdlSetInputPortDimensionInfo

port dimensions, using `ssSetInputPortDimensionInfo`. If they are unacceptable, this method should generate an error via `ssSetErrorStatus`.

This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

Note This method can set the dimensions of any other input or output port whose dimensions derive from the dimensions of port.

By default, Simulink calls this method only if it can fully determine the dimensionality of port from the port to which it is connected. If it cannot completely determine the dimensionality from port connectivity, it invokes `mdlSetDefaultPortDimensionInfo`. If an S-function can fully determine the port dimensionality from partial information, the function should set the option `SS_OPTION_ALLOW_PARTIAL_DIMENSIONS_CALL` in `mdlInitializeSizes`, using `ssSetOptions`. If this option is set, Simulink invokes `mdlSetInputPortDimensionInfo` even if it can only partially determine the dimensionality of the input port from connectivity.

Simulink will call this method until all input ports with inherited dimensions have their dimensions specified.

Example

See `matlabroot/simulink/src/sfun_matadd.c` for an example of how to use this function.

Languages

C, C++, M

See Also

`ssSetErrorStatus`

Purpose	Specify whether an input port accepts frame data
Required	No
C Syntax	<pre>void mdlSetInputPortFrameData(SimStruct *S, int_T port, Frame_T frameData)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>frameData Frame data.</p>
M Syntax	<pre>SetInputPortSamplingMode(s, port, mode)</pre>
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>port Integer value specifying the index of port whose sampling mode is to be set.</p> <p>mode Integer value specifying the sampling mode of the port (0 = sample, 1 = frame).</p>
Description	<p>This method is called with the candidate frame setting (FRAME_YES or FRAME_NO) for an input port. If the proposed setting is acceptable, the method should set the actual frame data setting using <code>ssSetInputPortFrameData</code>. If the setting is unacceptable, an error should be generated via <code>ssSetErrorStatus</code>. Note that any other input or output ports whose frame data settings are implicitly defined by virtue</p>

mdlSetInputPortFrameData

of knowing the frame data setting of the given port can also have their frame data settings configured. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

Simulink will call this method until all input ports with inherited frame settings have their frame settings specified.

The use of frame-based signals (mode has a value of 1) requires a Signal Processing Blockset license.

Languages C, C++, M

See Also `ssSetInputPortFrameData`, `ssSetOutputPortFrameData`, `ssSetErrorStatus`

Purpose	Set the sample time of an input port that inherits its sample time from the port to which it is connected
Required	No
C Syntax	<pre>void mdlSetInputPortSampleTime(SimStruct *S, int_T port, real_T sampleTime, real_T offsetTime)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>sampleTime Inherited sample time for port.</p> <p>offsetTime Inherited offset time for port.</p>
M Syntax	<pre>SetInputPortSampleTime(s, port, time)</pre>
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>port Integer value specifying the index of port whose sampling mode is to be set.</p> <p>time Two-element array, [period offset], that specifies the period and offset of the times that this port samples its input.</p>
Description	Simulink invokes this method with the sample time that port inherits from the port to which it is connected. If the inherited sample time is acceptable, this method should set the sample time of

mdlSetInputPortSampleTime

port to the inherited time, using `ssSetInputPortSampleTime` and `ssSetInputPortOffsetTime`. If the sample time is unacceptable, this method should generate an error via `ssSetErrorStatus`. Note that any other input or output ports whose sample times are implicitly defined by virtue of knowing the sample time of the given port can also have their sample times set via calls to `ssSetInputPortSampleTime` or `ssSetOutputPortSampleTime`. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

Simulink invokes this method until all input ports with inherited sample times are specified.

When inherited port-based sample times are specified, the sample time is guaranteed to be one of the following where $0.0 < \text{period} < \text{inf}$ and $0.0 \leq \text{offset} < \text{period}$.

	Sample Time	Offset Time
Continuous	0.0	0.0
Discrete	period	offset

Constant, triggered, and variable-step sample times are not propagated to S-functions with port-based sample times.

Generally `mdlSetInputPortSampleTime` is called once per port with the input port sample time. However, there can be cases where this function is called more than once. This happens when the simulation engine is converting continuous sample times to continuous but fixed in minor steps sample times. When this occurs, the original values of the sample times specified in `mdlInitializeSizes` are restored before this method is called again.

The final sample time specified at the port can be different from (but equivalent to) the sample time specified by this method. This occurs when

- The model uses a fixed-step solver and the port has a continuous but fixed in minor step sample time. In this case, Simulink converts the sample time to the fundamental sample time for the model.

- Simulink adjusts the sample time to be as numerically sound as possible. For example, Simulink converts [0.249999999999999, 0] to [0.25, 0].

The S-function can examine the final sample times in `mdlInitializeSampleTimes`.

Languages

C, C++, M

See Also

`ssSetInputPortSampleTime`, `ssSetOutputPortSampleTime`,
`mdlInitializeSampleTimes`

mdlSetInputPortWidth

Purpose	Set the width of an input port that accepts 1-D (vector) signals
Required	No
C Syntax	<pre>void mdlSetInputPortWidth(SimStruct *S, int_T port, int_T width)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>width Width of signal.</p>
Description	<p>This method is called with the candidate width for a dynamically sized port. If the proposed width is acceptable, the method should set the actual port width using <code>ssSetInputPortWidth</code>. If the size is unacceptable, an error should be generated via <code>ssSetErrorStatus</code>. Note that any other dynamically sized input or output ports whose widths are implicitly defined by virtue of knowing the width of the given port can also have their widths set via calls to <code>ssSetInputPortWidth</code> or <code>ssSetOutputPortWidth</code>. This method is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement.</p> <p>Simulink invokes this method until all dynamically sized input ports are configured.</p>
Languages	C
See Also	<code>ssSetInputPortWidth</code> , <code>ssSetOutputPortWidth</code> , <code>ssSetErrorStatus</code>

Purpose	Set the numeric types (real, complex, or inherited) of the signals accepted by an output port
Required	No
C Syntax	<pre>void mdlSetOutputPortComplexSignal(SimStruct *S, int_T port, CSignal_T csig)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>csig Numeric type of signal, either COMPLEX_NO (real) or COMPLEX_YES (complex).</p>
M Syntax	<pre>SetOutputPortComplexSignal(s, port, typeId)</pre>
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>port Integer value specifying the index of port to be set.</p> <p>typeId Integer value specifying whether the port produces real (0) or complex (1) signals.</p>
Description	Simulink calls this routine to set the output port numeric type for outputs that have this attribute set to COMPLEX_INHERITED. The input argument csig is the proposed numeric type for this output port. The S-function must check whether the specified numeric type is a valid type for the specified port. If it is valid, the S-function

mdlSetOutputPortComplexSignal

must set the numeric type of the specified output port using `ssSetOutputPortComplexSignal`. Otherwise, it must report an error, using `ssSetErrorStatus`. The S-function can also set the numeric types of other input and output ports with unknown numeric types. Simulink reports an error if the S-function changes the numeric type of a port whose numeric type is known. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

If the S-function does not implement this routine, Simulink assumes that the S-function accepts a real or complex signal and sets the output port numeric type to the specified value.

Simulink will call this method until all output ports with inherited numeric types have their numeric types specified.

Example

See `matlabroot/simulink/src/sdotproduct.c` for an example of how to use this function.

Languages

C, C++, M

See Also

`ssSetOutputPortComplexSignal`, `ssSetErrorStatus`

Purpose	Set the data type of the signals emitted by an output port
Required	No
C Syntax	<pre>void mdlSetOutputPortDataType(SimStruct *S, int_T port, DTypeId id)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of an output port.</p> <p>id Data type ID.</p>
M Syntax	<pre>SetOutputPortDataType(s, port, typeId)</pre>
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>port Integer value specifying index of port to be set.</p> <p>typeId Integer value specifying ID of port's data type. Use <code>s.getDatatypeName(typeId)</code> to get the data type's name.</p>
Description	Simulink calls this routine to set the data type of port when port has an inherited data type. The data type ID <code>id</code> is the proposed data type for this port. Data type IDs for the built-in data types can be found in <code>matlabroot/simulink/include/simstruc_types.h</code> . The S-function must check whether the specified data type is a valid data type for the specified port. If it is a valid data type, it must set the data type of port using <code>ssSetOutputPortDataType</code> . Otherwise, it must report an error,

mdlSetOutputPortDataType

using `ssSetErrorStatus`. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

The S-function can also set the data types of other input and output ports if their data types have not been set. Simulink reports an error if the S-function changes the data type of a port whose data type has been set.

If the block does not implement this method, Simulink assumes that the block supports any data type and sets the output port data type to the specified value.

Simulink will call this method until all output ports with inherited data types have their data types specified.

Languages

C, C++, M

See Also

`ssSetOutputPortDataType`, `ssSetErrorStatus`

Purpose	Set the dimensions of the signals accepted by an output port
Required	No
C Syntax	<pre>void mdlSetOutputPortDimensionInfo(SimStruct *S, int_T port, const DimsInfo_T *dimsInfo)</pre>
C Arguments	<p>S SimStruct representing an S-Function block or a Simulink model.</p> <p>port Index of a port.</p> <p>dimsInfo Structure that specifies the signal dimensions supported by port.</p> <p>See <code>ssSetInputPortDimensionInfo</code> for a description of this structure.</p>
M Syntax	<pre>SetOutputPortDimensions(s, port, dims)</pre>
M Arguments	<p>s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.</p> <p>port Integer value specifying the index of the port to be set.</p> <p>dims 1-D array that specifies the signal dimensions supported by the port, e.g., <code>[5]</code> for a 5-element vector signal or <code>[3 3]</code> for a 3-by-3 matrix signal.</p>
Description	Simulink calls this method with candidate dimensions <code>dimsInfo</code> for port. If the proposed dimensions are acceptable, this method should go ahead and set the actual port dimensions, using <code>ssSetOutputPortDimensionInfo</code> . If they are unacceptable, this

mdlSetOutputPortDimensionInfo

method should generate an error via `ssSetErrorStatus`. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

Note This method can set the dimensions of any other input or output port whose dimensions derive from the dimensions of port.

By default, Simulink calls this method only if it can fully determine the dimensionality of port from the port to which it is connected. If it cannot completely determine the dimensionality from port connectivity, it invokes `mdlSetDefaultPortDimensionInfo`. If an S-function can fully determine the port dimensionality from partial information, the function should set the option `SS_OPTION_ALLOW_PARTIAL_DIMENSIONS_CALL` in `mdlInitializeSizes`, using `ssSetOptions`. If this option is set, Simulink invokes `mdlSetOutputPortDimensionInfo` even if it can only partially determine the dimensionality of the output port from connectivity. Simulink will call this method until all output ports with inherited dimensions have their dimensions specified.

Example

See `matlabroot/simulink/src/sfun_matadd.c` for an example of how to use this function.

Languages

C, C++, M

See Also

`ssSetErrorStatus`, `ssSetOutputPortDimensionInfo`

Purpose	Set the sample time of an output port that inherits its sample time from the port to which it is connected
Required	No
C Syntax	<pre>void mdlSetOutputPortSampleTime(SimStruct *S, int_T port, real_T sampleTime, real_T offsetTime)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>sampleTime Inherited sample time for port.</p> <p>offsetTime Inherited offset time for port.</p>
M Syntax	<pre>SetOutputPortSampleTime(s, port, time)</pre>
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>port Integer value specifying the index of port whose sampling mode is to be set.</p> <p>time Two-element array, [period offset], that specifies the period and offset of the times that this port produces output.</p>
Description	Simulink calls this method with the sample time that port inherits from the port to which it is connected. If the inherited sample time is acceptable, this method should set the sample time of port to the

mdlSetOutputPortSampleTime

inherited sample time and offset time, using `ssSetOutputPortSampleTime` and `ssSetOutputPortOffsetTime`, or

```
pd = s.OutputPort(port);  
pd.SampleTime = time;
```

in the case of a Level-2 M-file S-function.

If the inherited sample time is unacceptable, this method should generate an error via `ssSetErrorStatus`. Note that this method can set the sample time of any other input or output port whose sample time derives from the sample time of `port`, using `ssSetInputPortSampleTime` or `ssSetOutputPortSampleTime` or the `SampleTime` property of the `Simulink.BlockPortData` object associated with the port in the case of Level-2 M-file S-functions. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement when used in a C-MEX S-function.

Normally, sample times are propagated forward; however, if sources feeding this block have inherited sample times, Simulink might choose to back-propagate known sample times to this block. When back-propagating sample times, this method is called in succession for all inherited output port signals.

See `mdlSetInputPortSampleTime` for more information about when this method is called.

Languages

C, M

See Also

`ssSetOutputPortSampleTime`, `ssSetErrorStatus`,
`ssSetInputPortSampleTime`, `ssSetOutputPortSampleTime`,
`mdlSetInputPortSampleTime`, `Simulink.MSFcnRuntimeBlock`,
`Simulink.BlockPortData`

Purpose	Set the width of an output port that outputs 1-D (vector) signals
Required	No
C Syntax	<pre>void mdlSetOutputPortWidth(SimStruct *S, int_T port, int_T width)</pre>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>port Index of a port.</p> <p>width Width of signal.</p>
Description	<p>This method is called with the candidate width for a dynamically sized port. If the proposed width is acceptable, the method should go ahead and set the actual port width, using <code>ssSetOutputPortWidth</code>. If the size is unacceptable, an error should be generated via <code>ssSetErrorStatus</code>. Note that any other dynamically sized input or output ports whose widths are implicitly defined by virtue of knowing the width of the given port can also have their widths set via calls to <code>ssSetInputPortWidth</code> or <code>ssSetOutputPortWidth</code>. This method is only valid for simulation, and must be enclosed in a <code>#if defined(MATLAB_MEX_FILE)</code> statement.</p>
Languages	C
See Also	<code>ssSetInputPortWidth</code> , <code>ssSetOutputPortWidth</code> , <code>ssSetErrorStatus</code>

mdlSetWorkWidths

Purpose	Specify the sizes of the work vectors and create the run-time parameters required by this S-function
Required	No
C Syntax	<code>void mdlSetWorkWidths(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	<code>PostPropagationSetup(s)</code>
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	<p>Simulink calls this optional method to enable this S-function to set the sizes of state and work vectors that it needs to store global data and to create run-time parameters (see “Run-Time Parameters” on page 7-7). Simulink invokes this method after it has determined the input port width, output port width, and sample times of the S-function. This allows the S-function to size the state and work vectors based on the number and sizes of inputs and outputs and/or the number of sample times. This method specifies the state and work vector sizes via the macros <code>ssGetNumContStates</code>, <code>ssSetNumDiscStates</code>, <code>ssSetNumRWork</code>, <code>ssSetNumIWork</code>, <code>ssSetNumPWork</code>, <code>ssSetNumModes</code>, and <code>ssSetNumNonsampledZCs</code>.</p> <p>A C-MEX S-function needs to implement this method only if it does not know the sizes of all the work vectors it requires when Simulink invokes the function’s <code>mdlInitializeSizes</code> method. If this S-function implements <code>mdlSetWorkWidths</code>, it should initialize the sizes of any work vectors that it needs to <code>DYNAMICALLY_SIZED</code> in <code>mdlInitializeSizes</code>, even for those whose exact size it knows at that point. The S-function</p>

should then specify the actual size in `mdlSetWorkWidths`. This method is only valid for simulation, and must be enclosed in a `#if defined(MATLAB_MEX_FILE)` statement.

A Level-2 M-file S-function must implement this method if any Dwork vectors are used in the S-function. In the case of M-file S-functions, this method sets the number of Dwork vectors and initializes their attributes. For example, the following code in the `PostPropagationSetup` method specifies the usage type for the Dwork vector:

```
block.DWork(1).UsageType = type;
```

where `block` is an instance of the `Simulink.MSFcnRunTimeBlock` class representing the S-Function block and `type` is one of the following:

- DWork
- DState
- Scratch
- Mode

For a full example of a Level-2 M-file S-function using Dwork vectors, see the file `matlabroot/toolbox/simulink/simdemos/adapt_lms.m` used in the Simulink model `sldemo_msfcn_lms.mdl`.

Languages

Ada, C, M

See Also

`mdlInitializeSizes`

mdlSimStatusChange

Purpose	Respond to a pause or resumption of the simulation of the model that contains this S-function
Required	No
C Syntax	<pre>void mdlSimStatusChange(SimStruct *S, ssSimStatusChangeType simStatus)</pre>
C Arguments	<p>S</p> <p>SimStruct representing an S-Function block.</p> <p>simStatus</p> <p>Status of the simulation, either SIM_PAUSE or SIM_CONTINUE.</p>
M Syntax	<pre>SimStatusChange(s, status)</pre>
M Arguments	<p>s</p> <p>Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p> <p>status</p> <p>Status of the simulation, either 0 when paused or 1 when continued.</p>
Description	Simulink calls this routine when a simulation of the model containing S pauses or resumes. This method is only valid for simulation, and must be enclosed in a #if defined(MATLAB_MEX_FILE) statement.
Example	<pre>#if defined(MATLAB_MEX_FILE) #define MDL_SIM_STATUS_CHANGE static void mdlSimStatusChange(SimStruct *S, ssSimStatusChangeType simStatus) { if (simStatus == SIM_PAUSE) { slPrintf("Pause has been called! \n"); } else if (simStatus == SIM_CONTINUE) {</pre>

```
        slPrintf("Continue has been called! \n");  
    }  
}  
#endif
```

Languages C

mdlStart

Purpose	Initialize the state vectors of this S-function
Required	No
C Syntax	<code>void mdlStart(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	Start(s)
M Arguments	s Instance of <code>Simulink.MSFcnRunTimeBlock</code> class representing the S-Function block.
Description	Simulink invokes this optional method at the beginning of a simulation. It should initialize the continuous and discrete states, if any, of this S-Function block. Use <code>ssGetContStates</code> and/or <code>ssGetDiscStates</code> to get the states. This method can also perform any other initialization activities that this S-function requires, such as allocating memory or setting up user data.
Languages	Ada, C, M
Example	See <code>matlabroot/simulink/src/sfun_directlook.c</code> for an example of how to use this function.
See Also	<code>mdlInitializeConditions</code> , <code>ssGetContStates</code> , <code>ssGetDiscStates</code>

Purpose	Perform any actions required at termination of the simulation
Required	Yes
C Syntax	<code>void mdlTerminate(SimStruct *S)</code>
C Arguments	S SimStruct representing an S-Function block.
M Syntax	Terminate(s)
M Arguments	s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.
Description	<p>This method should perform any actions, such as freeing memory, that must be performed at the end of simulation or when an S-Function block is destroyed (e.g., when it is deleted from a model). The option <code>SS_OPTION_CALL_TERMINATE_ON_EXIT</code> determines whether Simulink invokes this method. If this option is not set, Simulink invokes <code>mdlTerminate</code> at the end of the simulation only if the <code>mdlStart</code> method of at least one block in the model has executed without error during the simulation. If this option is set, Simulink always invokes the <code>mdlTerminate</code> method at the end of a simulation run and whenever it destroys a block.</p> <p>Use the <code>UNUSED_ARG</code> macro if the <code>mdlTerminate</code> function does not perform any actions that require the <code>SimStruct S</code> to indicate that the <code>S</code> input argument is required but not used in the body of the callback. To do this, insert the line</p> <pre>UNUSED_ARG(S)</pre> <p>after any declarations in <code>mdlTerminate</code>.</p>

mdlTerminate

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#if defined(MATLAB_MEX_FILE)
static void mdlTerminate(SimStruct *S)
{
    /* Add mdlTerminate code here */
}
#endif
```

The define statement makes the `mdlTerminate` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Example

Suppose your S-function allocates blocks of memory in `mdlStart` and saves pointers to the blocks in a `PWork` vector. The following code fragment would free this memory.

```
{
    int i;
    for (i = 0; i<ssGetNumPWork(S); i++) {
        if (ssGetPWorkValue(S,i) != NULL) {
            free(ssGetPWorkValue(S,i));
        }
    }
}
```

Languages Ada, C, M

See Also `ssSetOptions`

Purpose	Update a block's states
Required	No
C Syntax	<code>void mdlUpdate(SimStruct *S, int_T tid)</code>
C Arguments	<p>S SimStruct representing an S-Function block.</p> <p>tid Task ID.</p>
M Syntax	Update(s)
M Arguments	<p>s Instance of Simulink.MSFcnRunTimeBlock class representing the S-Function block.</p>
Description	<p>Simulink invokes this optional method at each major simulation time step. The method should compute the S-function's states at the current time step and store the states in the S-function's state vector. The method can also perform any other tasks that the S-function needs to perform at each major time step.</p> <p>Use this code if your S-function has one or more discrete states or does <i>not</i> have direct feedthrough.</p> <p>The reason for this is that most S-functions that do not have discrete states but do have direct feedthrough do not have update functions. Therefore, Simulink is able to eliminate the need for the extra call in these circumstances.</p> <p>If your S-function needs to have its mdlUpdate routine called and it does not satisfy either of the above two conditions, specify that it has a discrete state, using the <code>ssSetNumDiscStates</code> macro in the <code>mdlInitializeSizes</code> function.</p>

mdlUpdate

The `tid` (task ID) argument specifies the task running when the `mdlOutputs` routine is invoked. You can use this argument in the `mdlUpdate` routine of a multirate S-Function block to encapsulate task-specific blocks of code (see “Multirate S-Function Blocks” on page 7-37).

Use the `UNUSED_ARG` macro if the S-function does not contain task-specific blocks of code to indicate that the `tid` input argument is required but not used in the body of the callback. To do this, insert the line

```
UNUSED_ARG(tid)
```

after the declarations in `mdlUpdate`.

Note When generating code for a noninlined S-function that contains this method, make sure the method is not wrapped in a `#if defined(MATLAB_MEX_FILE)` statement. For example:

```
#define MDL_UPDATE
#if defined(MDL_UPDATE) && defined(MATLAB_MEX_FILE)
static void mdlUpdate(SimStruct *S)
{
    /* Add mdlUpdate code here */
}
#endif
```

The `define` statement makes the `mdlUpdate` method available only to a MATLAB MEX-file. If the S-function is not inlined, Real-Time Workshop cannot use this method, resulting in link or run-time errors.

Example

For an example that uses this function to update discrete states, see `matlabroot/simulink/src/dsfunc.c`. For an example that uses this function to update the transfer function coefficients of a time-varying continuous transfer function, see `matlabroot/simulink/src/stvctf.c`.

Languages Ada, C, C++, M

See Also mdlDerivatives, ssGetContStates, ssGetDiscStates

mdlZeroCrossings

Purpose Update zero-crossing vector

Required No

C Syntax `void mdlZeroCrossings(SimStruct *S)`

C Arguments S
SimStruct representing an S-Function block.

M Syntax `ZeroCrossings(s)`

M Arguments s
Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description An S-function needs to provide this optional method only if it does zero-crossing detection. Implementing zero-crossing detection typically requires using the zero-crossing and mode work vectors to determine when a zero crossing occurs and how the S-function's outputs should respond to this event. The `mdlZeroCrossings` method should update the S-function's zero-crossing vector, using `ssGetNonsampledZCs`.

You can use the optional `mdlZeroCrossings` routine when your S-function has registered the `CONTINUOUS_SAMPLE_TIME` and has nonsampled zero crossings (`ssGetNumNonsampledZCs(S) > 0`). The `mdlZeroCrossings` routine is used to provide Simulink with signals that are to be tracked for zero crossings. These are typically

- Continuous signals entering the S-function
- Internally generated signals that cross zero when a discontinuity would normally occur in `mdlOutputs`

Thus, the zero-crossing signals are used to locate the discontinuities and end the current time step at the point of the zero crossing. To provide

Simulink with zero-crossing signals, `mdlZeroCrossings` updates the `ssGetNonsampleZCs(S)` vector.

Example

For an example, see `matlabroot/simulink/src/sfun_zc_sat.c`. A detailed description of this example can be found in “Work Vectors and Zero Crossings” on page 7-44 in the Simulink documentation.

Languages

C, C++, M

See Also

`mdlInitializeSizes`, `ssGetNonsampledZCs`

mdlZeroCrossings

SimStruct Functions — By Category

Introduction (p. 9-2)

SimStruct Macros and Functions
Listed by Usage (p. 9-3)

Overview of SimStruct macros and
functions.

SimStruct functions listed by usage.

Introduction

In this section...
“About SimStruct Functions” on page 9-2
“Language Support” on page 9-2
“The SimStruct” on page 9-2

About SimStruct Functions

Simulink provides a set of functions for accessing the fields of an S-function’s simulation data structure (SimStruct). S-function callback methods use these functions to store and retrieve information about an S-function.

Language Support

Some SimStruct functions are available only in some of the languages supported by Simulink. The reference page for each SimStruct macro or function lists the languages in which it is available. If the SimStruct function is available in C, the reference page gives its C syntax. Otherwise, it gives its syntax in the language in which it is available.

Note Most SimStruct functions available in C are implemented as C macros.

The SimStruct

The file `matlabroot/simulink/include/simstruc.h` is a C language header file that defines the Simulink data structure and the SimStruct access macros. It encapsulates all the data relating to the model or S-function, including block parameters and outputs.

There is one SimStruct data structure allocated for the Simulink model. Each S-function in the model has its own SimStruct associated with it. The organization of these SimStructs is much like a directory tree. The SimStruct associated with the model is the *root* SimStruct. The SimStructs associated with the S-functions are the *child* SimStructs.

SimStruct Macros and Functions Listed by Usage

SimStruct Macros and Functions Listed by Usage

Data Type

Dialog Box Parameters

Error Handling and Status

Function Call

I/O Port — Signal Specification

I/O Port — Signal Dimensions

I/O Port — Signal Access on page 9-10

Run-Time Parameters on page 9-12

Sample Time on page 9-13

Simulation Information on page 9-15

State and Work Vector on page 9-17

Miscellaneous

Real-Time Workshop

Data Type

Macro	Description
ssGetDataTypeId	Get the ID for a data type.
ssGetDataTypeIdAliasedThruTo	Get the ID for the built-in data type associated with a data type alias.
ssGetDataTypeName	Get a data type's name.
ssGetDataTypeSize	Get a data type's size.
ssGetDataTypeZero	Get the zero representation of a data type.
ssGetInputPortDataType	Get the data type of an input port.

Data Type (Continued)

Macro	Description
ssGetNumDataTypes	Get the number of data types defined by an S-function or the model.
ssGetOutputPortDataType	Get the data type of an output port.
ssGetOutputPortSignal	Get an output signal of any type except double.
ssRegisterDataType	Register a data type.
ssSetDataTypeSize	Specify the size of a data type.
ssSetDataTypeZero	Specify the zero representation of a data type.
ssSetInputPortDataType	Specify the data type of signals accepted by an input port.
ssSetOutputPortDataType	Specify the data type of an output port.

Dialog Box Parameters

Macro	Description
ssGetDTypeIdFromMxArray	Get the Simulink data type of a dialog parameter.
ssGetNumParameters	Get the number of parameters that this block has (Ada only).
ssGetNumSFcnParams	Get the number of parameters that an S-function expects.
ssGetSFcnParam	Get a parameter entered by a user in the S-Function block dialog box.
ssGetSFcnParamsCount	Get the actual number of parameters specified by the user.
ssSetNumSFcnParams	Set the number of parameters that an S-function expects.
ssSetParameterName	Set the name of a parameter (Ada only).

Dialog Box Parameters (Continued)

Macro	Description
ssSetParameterTunable	Set the tunability of a parameter (Ada only).
ssSetSFcnParamNotTunable	Obsolete.
ssSetSFcnParamTunable	Specify the tunability of a dialog box parameter.

Error Handling and Status

Macro	Description
ssGetErrorStatus	Get a string that identifies the last error.
ssPrintf	Print a variable-content msg.
ssSetErrorStatus	Report errors.
ssWarning	Display a warning message.

Function Call

Macro	Description
ssCallSystemWithTid	Execute a function-call subsystem connected to an S-function.
ssDisableSystemWithTid	Disable a function-call subsystem connected to this S-function block.
ssEnableSystemWithTid	Enable a function-call subsystem connected to this S-function.
ssGetExplicitFCSSCtrl	Determine whether this S-function explicitly enables and disables the function-call subsystem that it invokes.

Function Call (Continued)

Macro	Description
ssSetCallSystemOutput	Specify that an output port element issues a function call.
ssSetExplicitFCSSCtrl	Specify whether an S-function explicitly enables and disables the function-call subsystem that it calls.

Input and Output Ports**I/O Port — Signal Specification**

Macro	Description
ssGetInputPortComplexSignal	Get the numeric type (complex or real) of an input port.
ssGetInputPortDataType	Get the data type of an input port.
ssGetInputPortDirectFeedThrough	Determine whether an input port has direct feedthrough.
ssGetInputPortFrameData	Determine whether a port accepts signal frames.
ssGetInputPortOffsetTime	Determine the offset time of an input port.
ssGetInputPortRequiredContiguous	Determine whether the signal elements entering a port must be contiguous.
ssGetInputPortSampleTime	Determine the sample time of an input port.
ssGetInputPortSampleTimeIndex	Get the sample time index of an input port.
ssGetOutputPortComplexSignal	Get the numeric type (complex or real) of an output port.

I/O Port – Signal Specification (Continued)

Macro	Description
ssGetOutputPortDataType	Get the data type of an output port.
ssGetOutputPortFrameData	Determine whether a port outputs signal frames.
ssGetOutputPortOffsetTime	Determine the offset time of an output port.
ssGetOutputPortSampleTime	Determine the sample time of an output port.
ssSetInputPortComplexSignal	Set the numeric type (real or complex) of an input port.
ssSetInputPortDataType	Set the data type of an input port.
ssSetInputPortDirectFeedThrough	Specify that an input port is a direct-feedthrough port.
ssSetInputPortFrameData	Specify whether a port accepts signal frames.
ssSetInputPortOffsetTime	Specify the sample time offset for an input port.
ssSetInputPortRequiredContiguous	Specify that the signal elements entering a port must be contiguous.
ssSetInputPortSampleTime	Set the sample time of an input port.
ssSetNumInputPorts	Set the number of input ports on an S-Function block.
ssSetNumOutputPorts	Specify the number of output ports on an S-Function block.
ssSetOneBasedIndexInputPort	Specify that an input port expects one-based indices.

I/O Port — Signal Specification (Continued)

Macro	Description
ssSetOneBasedIndexOutputPort	Specify that an output port emits one-based indices.
ssSetOutputPortComplexSignal	Specify the numeric type (real or complex) of this port.
ssSetOutputPortDataType	Specify the data type of an output port.
ssSetOutputPortFrameData	Specify whether a port outputs framed data.
ssSetOutputPortOffsetTime	Specify the sample time offset value of an output port.
ssSetOutputPortSampleTime	Specify the sample time of an output port.
ssSetZeroBasedIndexInputPort	Specify that an input port expects zero-based indices.
ssSetZeroBasedIndexOutputPort	Specify that an output port emits zero-based indices.

I/O Port — Signal Dimensions

Macro	Description
ssAllowSignalsWithMoreThan2D	Enable S-function to work with multidimensional signals.
ssGetInputPortDimensions	Get the dimensions of the signal accepted by an input port.
ssGetInputPortNumDimensions	Get the dimensionality of the signals accepted by an input port.
ssGetInputPortWidth	Determine the width of an input port.

I/O Port – Signal Dimensions (Continued)

Macro	Description
ssGetOutputPortDimensions	Get the dimensions of the signal leaving an output port.
ssGetOutputPortNumDimensions	Get the number of dimensions of an output port.
ssGetOutputPortWidth	Determine the width of an output port.
ssSetInputPortDimensionInfo	Set the dimensionality of an input port.
ssSetInputPortMatrixDimensions	Specify dimension information for an input port that accepts matrix signals.
ssSetInputPortVectorDimension	Specify dimension information for an input port that accepts vector signals.
ssSetInputPortWidth	Set the width of a 1-D (vector) input port.
ssSetOutputPortDimensionInfo	Specify the dimensionality of an output port.
ssSetOutputPortMatrixDimensions	Specify dimension information for an output port that emits matrix signals.
ssSetOutputPortVectorDimension	Specify dimension information for an output port that emits vector signals.
ssSetOutputPortWidth	Specify the width of a 1-D (vector) output port.

I/O Port — Signal Dimensions (Continued)

Macro	Description
ssSetOutputPortMatrixDimensions	Specify the dimensions of a 2-D (matrix) signal.
ssSetVectorMode	Specify the vector mode that an S-function supports.

I/O Port — Signal Access

Macro	Description
ssGetInputPortBufferDstPort	Determine the output port that is overwriting an input port's memory buffer.
ssGetInputPortConnected	Determine whether an S-Function block port is connected to a nonvirtual block.
ssGetInputPortOptimOpts	Determine the reusability setting of the memory allocated to the input port of an S-function.
ssGetInputPortOverWritable	Determine whether an input port can be overwritten.
ssGetInputPortRealSignal	Get the address of a real, contiguous signal entering an input port.
ssGetInputPortRealSignalPtrs	Access the signal elements connected to an input port.
ssGetInputPortSignal	Get the address of a contiguous signal entering an input port.
ssGetInputPortSignalAddress	Get the address of an input port's signal (Ada only).
ssGetInputPortSignalPtrs	Get pointers to input signal elements of type other than double.

I/O Port – Signal Access (Continued)

Macro	Description
ssGetNumInputPorts	Can be used in any routine (except mdlInitializeSizes) to determine how many input ports a block has.
ssGetNumOutputPorts	Can be used in any routine (except mdlInitializeSizes) to determine how many output ports a block has.
ssGetOutputPortConnected	Determine whether an output port is connected to a nonvirtual block.
ssGetOutputPortBeingMerged	Determine whether the output of this block is connected to a Merge block.
ssGetOutputPortOptimOpts	Determine the reusability of the memory allocated to the output port of an S-function.
ssGetOutputPortRealSignal	Access the elements of a signal connected to an output port.
ssGetOutputPortSignal	Get the vector of signal elements emitted by an output port.
ssGetOutputPortSignalAddress	Get the address of an output port's signal (Ada only).
ssSetInputPortOptimOpts	Specify the reusability of the memory allocated to the input port of an S-function.
ssSetInputPortOverWritable	Specify whether an input port is overwritable by an output port.

I/O Port — Signal Access (Continued)

Macro	Description
ssSetOutputPortOptimOpts	Specify the reusability of the memory allocated to the output port of an S-function.
ssSetOutputPortOverwritesInputPort	Specify whether an output port can share its memory buffer with an input port.

Run-Time Parameters

These macros allow you to create, update, and access run-time parameters corresponding to a block's dialog parameters.

Run-Time Parameters

Macro	Description
ssGetNumRunTimeParams	Get the number of run-time parameters created by this S-function.
ssGetRunTimeParamInfo	Get the attributes of a specified run-time parameter.
ssRegAllTunableParamsAsRunTimeParams	Register all tunable dialog parameters as run-time parameters.
ssRegDlgParamAsRunTimeParam	Register a run-time parameter.
ssSetNumRunTimeParams	Specify the number of run-time parameters to be created by this S-function.

Run-Time Parameters (Continued)

Macro	Description
ssSetRunTimeParamInfo	Specify the attributes of a specified run-time parameter.
ssUpdateAllTunableParamsAsRunTimeParams	Update all run-time parameters corresponding to tunable dialog parameters.
ssUpdateDlgParamAsRunTimeParam	Update a run-time parameter.
ssUpdateRunTimeParamData	Update the value of a specified run-time parameter.
ssUpdateRunTimeParamInfo	Update the attributes of a specified run-time parameter from the attributes of the corresponding dialog parameters.

Sample Time

Macro	Description
ssGetInputPortSampleTime	Determine the sample time of an input port.
ssGetInputPortSampleTimeIndex	Get the sample time index of an input port.
ssGetNumSampleTimes	Get the number of sample times an S-function has.
ssGetOffsetTime	Determine one of an S-function's sample time offsets.

Sample Time (Continued)

Macro	Description
<code>ssGetOutputPortSampleTime</code>	Determine the sample time of an output port.
<code>ssGetPortBasedSampleTimeBlockIsTriggered</code>	Determine whether a block that uses port-based sample times resides in a triggered subsystem.
<code>ssGetSampleTime</code>	Determine one of an S-function's sample times.
<code>ssGetSampleTimeOffset</code>	Get the offset of the current sample time (Ada only).
<code>ssGetSampleTimePeriod</code>	Get the period of the current sample time (Ada only).
<code>ssGetTNext</code>	Get the time of the next sample hit in a discrete S-function with a variable sample time.
<code>ssIsContinuousTask</code>	Determine whether a specified rate is the continuous rate.
<code>ssIsSampleHit</code>	Determine the sample rate at which an S-function is operating.
<code>ssIsSpecialSampleHit</code>	Determine whether the current sample time hits two specified rates.
<code>ssSampleAndOffsetAreTriggered</code>	Determine whether a sample time and offset value pair indicate a triggered sample time.
<code>ssSetInputPortSampleTime</code>	Set the sample time of an input port.
<code>ssSetModelReferenceSampleTime-InheritanceRule</code>	Specify whether use of an S-function in a submodel prevents the submodel from inheriting its sample time from the parent model.

Sample Time (Continued)

Macro	Description
ssSetNumSampleTimes	Set the number of sample times an S-function has.
ssSetOffsetTime	Specify the offset of a sample time.
ssSetSampleTime	Specify a sample time for an S-function.
ssSetTNext	Specify the time of the next sample hit in an S-function.

Simulation Information

Macro	Description
ssGetAbsTol	Get the absolute tolerances used by a model's variable-step solver.
ssGetBlockReduction	Determine whether a block has requested block reduction before the simulation has begun and whether it has actually been reduced after the simulation loop has begun.
ssGetErrorStatus	Get a string that identifies the last error.
ssGetInlineParameters	Determine whether the user has set the inline parameters option for the model containing this S-function.
ssGetSimMode	Determine the context in which an S-function is being invoked: normal simulation, external-mode simulation, model editor, etc.
ssGetSolverMode	Get the solver mode being used to solve the S-function.
ssGetSolverName	Get the name of the solver being used for the simulation.

Simulation Information (Continued)

Macro	Description
ssGetStateAbsTol	Get the absolute tolerance used by the model's variable-step solver for a specified state.
ssGetStopRequested	Get the value of the simulation stop requested flag.
ssGetT	Get the current base simulation time.
ssGetTaskTime	Get the current time for a task.
ssGetTFinal	Get the end time of the current simulation.
ssGetTNext	Get the time of the next sample hit.
ssGetTStart	Get the start time of the current simulation.
ssIsFirstInitCond	Determine whether this is the first call to mdlInitializeConditions.
ssIsMajorTimeStep	Determine whether the current time step is a major time step.
ssIsMinorTimeStep	Determine whether the current time step is a minor time step.
ssIsVariableStepSolver	Determine whether the current solver is a variable-step solver.
ssSetBlockReduction	Request that Simulink attempt to reduce a block.
ssSetSolverNeedsReset	Ask Simulink to reset the solver.
ssSetStopRequested	Ask Simulink to terminate the simulation at the end of the current time step.

State and Work Vector

These macros enable an S-function to access and set the S-function's work vectors.

State and Work Vector

Macro	Description
ssGetContStateAddress	Get the address of a block's continuous state vector.
ssGetContStates	Get an S-function's continuous states.
ssGetDiscStates	Get an S-function's discrete states.
ssGetDWork	Get a DWork vector.
ssGetDWorkComplexSignal	Determine whether the elements of a data type work vector are real or complex numbers.
ssGetDWorkDataType	Get the data type of a data type work vector.
ssGetDWorkName	Get the name of a data type work vector.
ssGetDWorkUsedAsDState	Determine whether a data type work vector is used as a discrete state vector.
ssGetDWorkWidth	Get the size of a data type work vector.
ssGetdX	Get the derivatives of the continuous states of an S-function.
ssGetIWork	Get an S-function's integer-valued (<code>int_T</code>) work vector.
ssGetIWorkValue	Get a value from a block's integer work vector.
ssGetModeVector	Get an S-function's mode work vector.
ssGetModeVectorValue	Get an element of a block's mode vector.
ssGetNonsampledZCs	Get an S-function's zero-crossing signals vector.
ssGetNumContStates	Determine the number of continuous states that an S-function has.

State and Work Vector (Continued)

Macro	Description
ssGetNumDiscStates	Determine the number of discrete states that an S-function has.
ssGetNumDWork	Get the number of data type work vectors used by a block.
ssGetNumIWork	Get the size of an S-function's integer work vector.
ssGetNumModes	Determine the size of an S-function's mode vector.
ssGetNumNonsampledZCs	Determine the number of nonsampled zero crossings that an S-function detects.
ssGetNumPWork	Determine the size of an S-function's pointer work vector.
ssGetNumRWork	Determine the size of an S-function's real-valued (real_T) work vector.
ssGetPWork	Get an S-function's pointer (void *) work vector.
ssGetPWorkValue	Get a pointer from a pointer work vector.
ssGetRealDiscStates	Get the real (real_T) values of an S-function's discrete state vector.
ssGetRWork	Get an S-function's real-valued (real_T) work vector.
ssGetRWorkValue	Get an element of an S-function's real-valued work vector.
ssSetDWorkComplexSignal	Specify whether the elements of a data type work vector are real or complex.
ssSetDWorkDataType	Specify the data type of a data type work vector.
ssSetDWorkName	Specify the name of a data type work vector.

State and Work Vector (Continued)

Macro	Description
ssSetDWorkUsedAsDState	Specify that a data type work vector is used as a discrete state vector.
ssSetDWorkWidth	Specify the width of a data type work vector.
ssSetIWorkValue	Set an element of a block's integer work vector.
ssSetModeVectorValue	Set an element of a block's mode vector.
ssSetNumContStates	Specify the number of continuous states that an S-function has.
ssSetNumDiscStates	Specify the number of discrete states that an S-function has.
ssSetNumDWork	Specify the number of data type work vectors used by a block.
ssSetNumIWork	Specify the size of an S-function's integer (<code>int_T</code>) work vector.
ssSetNumModes	Specify the number of operating modes that an S-function has.
ssSetNumNonsampledZCs	Specify the number of zero crossings that an S-function detects.
ssSetNumPWork	Specify the size of an S-function's pointer (<code>void *</code>) work vector.
ssSetNumRWork	Specify the size of an S-function's real (<code>real_T</code>) work vector.

State and Work Vector (Continued)

Macro	Description
ssSetPWorkValue	Set an element of a block's pointer work vector.
ssSetRWorkValue	Set an element of a block's floating-point work vector.

Miscellaneous

Macro	Description
ssCallExternalModeFcn	Invoke the external mode function for an S-function.
ssGetModelName	Get the name of an S-Function block or model containing the S-function.
ssGetParentSS	Get the parent of an S-function.
ssGetPath	Get the path of an S-function or the model containing the S-function.
ssGetRootSS	Return the root (model) SimStruct.
ssGetUserData	Access user data.
ssSetExternalModeFcn	Specify the external mode function for an S-function.
ssSetOptions	Set various simulation options.

Miscellaneous (Continued)

Macro	Description
ssSetPlacementGroup	Specify the execution order of a sink or source S-function.
ssSetUserData	Specify user data.

Real-Time Workshop

Macro	Description
ssGetDWorkRTWIdentifier	Get the identifier used to declare a DWork vector in code generated from the associated S-function.
ssGetDWorkRTWStorageClass	Get the storage class of a DWork vector in code generated from the associated S-function.
ssGetDWorkRTWTypeQualifier	Get the C type qualifier (e.g., const) used to declare a DWork vector in code generated from the associated S-function.
ssGetPlacementGroup	Get the name of the placement group of a block.
ssSetDWorkRTWIdentifier	Set the identifier used to declare a DWork vector in code generated from the associated S-function.
ssSetDWorkRTWStorageClass	Set the storage class of a DWork vector in code generated from the associated S-function.
ssSetDWorkRTWTypeQualifier	Set the C type qualifier (e.g., const) used to declare a DWork vector in code generated from the associated S-function.
ssSetPlacementGroup	Specify the name of the placement group of a block.

Real-Time Workshop (Continued)

Macro	Description
ssWriteRTW2dMatParam	Write a Simulink matrix parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWMx2dMatParam	Write a MATLAB matrix parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWMxVectParam	Write a MATLAB vector parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWParameters	Write tunable parameters to the S-function's <i>model.rtw</i> file.
ssWriteRTWParamSettings	Write settings for the S-function's parameters to the <i>model.rtw</i> file.
ssWriteRTWScalarParam	Write a scalar parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWStr	Write a string to the S-function's <i>model.rtw</i> file.
ssWriteRTWStrParam	Write a string parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWStrVectParam	Write a string vector parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWVectParam	Write a Simulink vector parameter to the S-function's <i>model.rtw</i> file.
ssWriteRTWorkVect	Write the S-function's work vectors to the <i>model.rtw</i> file.

S-Function Options — Alphabetical List

This section describes the S-function options available through `ssSetOptions`. Each S-function sets its applicable options at the end of its `mdlInitializeSizes` method. Use the OR operator (`|`) to set multiple options. For example:

```
ssSetOptions(S, SS_OPTION_EXCEPTION_FREE_CODE |  
              SS_OPTION_DISCRETE_VALUED_OUTPUT);
```

SS_OPTION_ALLOW_CONSTANT_PORT_SAMPLE_TIME

Purpose	Allow constant sample time for a port
Description	Allows an S-function with port-based sample times to specify or inherit constant sample times. Setting this option tells Simulink that all input and output ports support constant sample times. See “Specifying Constant Sample Time for a Port” on page 7-33 for more information.
Example	See <code>sfun_port_constant.c</code> , the source file for the <code>sfcndemo_port_constant.mdl</code> demo, for an example.
See Also	<code>SS_OPTION_DISALLOW_CONSTANT_SAMPLE_TIME</code>

SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION

- Purpose** Allow scalar expansion of input ports
- Description** Specifies that the input to your S-function input ports can be have a width of either 1 or the size specified by the port, usually referred to as the block width. The S-function expands scalar inputs to the same dimensions as the block width. See “Scalar Expansion of Inputs” on page 7-21 for more information.
- Example** See `sfun_multiport.c`, the source file for the `sfcndemo_sfun_multiport.mdl` demo, for an example.

SS_OPTION_ALLOW_PARTIAL_DIMENSIONS_CALL

Purpose Allow calls to `mdlSetInputPortDimensionInfo` and `mdlSetOutputPortDimensionInfo` with partial dimension information

Description Indicates the S-function can handle dynamically dimensioned signals. By default, Simulink calls the `mdlSetInputPortDimensionInfo` or `mdlSetOutputPortDimensionInfo` methods if the number of dimensions and size of each dimension for the candidate port are fully known. If `SS_OPTION_ALLOW_PARTIAL_DIMENSIONS_CALLS` is set, Simulink may also call these methods with partial dimension information. For example, the methods may be called when the port width is known, but the actual 2-D dimensions are unknown. See `mdlSetDefaultPortDimensionInfo` for more information.

See Also `mdlSetDefaultPortDimensionInfo`

SS_OPTION_ALLOW_PORT_SAMPLE_TIME_IN_TRIGSS

- Purpose** Allow an S-function with port-based sample times to operate in a triggered subsystem
- Description** Allows an S-function that uses port-based sample times to operate in a triggered subsystem. During sample time propagation, use the macro `ssSampleAndOffsetAreTriggered` to determine if the sample and offset times correspond to the block being in a triggered subsystem. If the block is triggered, all port sample times must be either triggered or constant. See “Configuring Port-Based Sample Times for Use in Triggered Subsystems” on page 7-34 for more information.
- Example** See `sfun_port_triggered.c`, the source file for the `sfcndemo_port_triggered.mdl` demo, for an example.
- See Also** `ssSampleAndOffsetAreTriggered`

SS_OPTION_ASYNC_RATE_TRANSITION

Purpose

Create a read-write pair of blocks that ensure correct data transfer

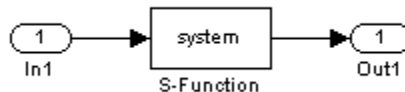
Description

Creates a read-write pair of blocks intended to guarantee correct data transfers between a synchronously (periodic) and an asynchronously executing subsystem or between two asynchronously executing subsystems. Both the read S-function and write S-function should set this option.

An asynchronously executed function-call subsystem is a function-call subsystem driven by an S-function with the `SS_OPTION_ASYNCHRONOUS` specified.

Simulink defines two classes of asynchronous rate transitions.

- Read-write pairs. In this class, two blocks, using a technique such as double buffering, ensure data integrity in a multitasking environment. When creating the read-write pair of blocks, the S-functions for these blocks should set the `SS_OPTION_ASYNC_RATE_TRANSITION` option. Furthermore, the `MaskType` property of the read block, must include the string `read` and the `MaskType` property of write block must include the string `write`.
- A single protected or unprotected block. To create a single Protected Rate Transition block, create a subsystem that contains the following



and set the `Tag` value of the Output block to `AsyncRateTransition`. The S-function then provides the code for the protected transition. Note, this S-function does not set the `SS_OPTION_ASYNC_RATE_TRANSITION` option.

See Also

`SS_OPTION_ASYNCHRONOUS`

Purpose

Specify this S-function drives a function-call subsystem attached to interrupt service routines

Description

Specifies that the S-function is driving function-call subsystems attached to interrupt service routines. This option applies only to S-functions that have no input ports during code generation and 1 output port. During simulation, the S-function may have an input port to provide a condition on which to execute. The output port must be configured to perform function calls on every element. If any of these requirements is not met, the `SS_OPTION_ASYNCHRONOUS` option is ignored. Specifying this option

- Informs Simulink that there is no implied data dependency involving the data sources or destinations of the function-call subsystem called by the S-function.
- Causes the function-call subsystem attached to the S-function to be colored cyan, indicating that it does not execute at a periodic rate.
- Enables additional checks to verify that the model is constructed correctly.
 - Simulink validates that the appropriate asynchronous rate transition blocks reside between the cyan function-call subsystem. Simulink also checks that period tasks exists. You can directly read and write from the function-call subsystem by using a block that has no computational overhead. To ensure safe task transitions between period and asynchronous tasks, use the `SS_OPTION_ASYNC_RATE_TRANSITION` option.
 - For data transfers between two asynchronously executed (cyan) function-call subsystem, Simulink validates that the appropriate asynchronous task transition blocks exists.

See Also

`SS_OPTION_ASYNC_RATE_TRANSITION`

SS_OPTION_CALL_TERMINATE_ON_EXIT

Purpose Force call to `mdlTerminate`

Description Guarantees Simulink will call the S-function's `mdlTerminate` method before destroying a block that references the S-function. Calling `mdlTerminate` allows your S-function to clean up after itself, for example, by freeing memory it allocated during a simulation. Simulink destroys an S-function block under the following circumstances.

- 1** A simulation ends either normally or as a result of invoking `ssSetErrorStatus`.
- 2** A user deletes the block.
- 3** Simulink eliminates the block as part of a block reduction optimization (see “Block reduction”).

If this option is not set, Simulink calls your S-function's `mdlTerminate` method only if the `mdlStart` method of at least one block in the model containing the S-function executed without error.

See Also `mdlTerminate`

SS_OPTION_CAN_BE_CALLED_CONDITIONALLY

Purpose

Specify this S-function can be called conditionally

Description

Specifies that the S-function can be called conditionally by other blocks. Simulink uses this option to determine if the S-Function block can be moved into the execution context of the conditionally executed subsystem in which the S-function resides. See “Conditional Execution Behavior” in Using Simulink for more information.

SS_OPTION_DISALLOW_CONSTANT_SAMPLE_TIME

Purpose Disallow constant sample time inheritance

Description Prohibits the S-Function block that references this S-function from inheriting a constant sample time. The `SS_OPTION_DISALLOW_CONSTANT_SAMPLE_TIME` option applies only to S-functions that use block-based sample times.

Note If the S-function declares the number of sample times as `PORT_BASED_SAMPLE_TIMES` it will not inherit a constant sample time unless it specifies the `SS_OPTION_ALLOW_CONSTANT_PORT_SAMPLE_TIME` option.

If the S-function specifies this option and inherits a constant sample time, i.e., a sample time of `inf`, Real-Time Workshop may not generate code for the corresponding S-function block. Real-Time Workshop determines how to generate code for the block based on if the block is invariant.

A block is invariant if all of its port signals are invariant. A signal is invariant if it has a constant value during the entire simulation. However, a constant block sample time does not guarantee all the block's signals are invariant. See “Inlining Invariant Signals” in the Real-Time Workshop User's Guide for more information.

If the block is not invariant, Real-Time Workshop generates code only in the `model_initialize` function. If the block is invariant, Real-Time Workshop eliminates the block's code altogether.

Example See `matlabroot/simulink/src/sfblk_manswitch.c` for an example.

See Also `SS_OPTION_ALLOW_CONSTANT_PORT_SAMPLE_TIME`

SS_OPTION_DISCRETE_VALUED_OUTPUT

Purpose

Specify this S-function has discrete valued output

Description

Specifies this S-function has discrete valued outputs. With this option set, Simulink does not assign algebraic variables to this S-function when it appears in an algebraic loop.

SS_OPTION_EXCEPTION_FREE_CODE

- Purpose** Improve performance of exception-free S-functions
- Description** Improves performance of S-functions that do not use `mexErrMsgTxt`, `mxCalloc`, or any other routines that can throw an exception. An S-function is not exception free if it contains any routine that, when called, has the potential of long-jumping out of a block of code and into another scope. See “Exception Free Code” on page 7-60 for more information.
- See Also** `SS_OPTION_RUNTIME_EXCEPTION_FREE_CODE`

SS_OPTION_FORCE_NONINLINED_FCNCALL

Purpose

Specify generated code format for function-call subsystems called by this S-function

Description

Indicates that Real-Time Workshop should generate procedures for all function-call subsystems called by this S-function, instead of possibly inlining the subsystem's code. If an S-function sets this option, Real-Time Workshop ignores the `Inline` setting for the **Real-Time Workshop system code** option on the subsystem's Block Parameters dialog box. See "Nonvirtual Subsystem Code Generation" in the Real-Time Workshop User's Guide for more information.

SS_OPTION_NONVOLATILE

Purpose Enable Simulink to remove unnecessary S-Function blocks

Description Specifies this S-function has no side effects. Setting this option enables Simulink to remove the S-Function block referencing this S-function during dead branch elimination, if it is not needed.

Purpose

Specify this S-function should be placed as soon as possible

Description

Specifies that this S-function should be placed as soon as possible. This option is typically used by devices connecting to hardware.

SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED

Purpose

Specify this S-function uses port-based sample times

Description

Indicates the S-function registers multiple sample times (`ssSetNumSampleTimes > 1`) to specify the rate at which each input and output port is running. The simulation engine needs this information when checking for illegal rate transitions. If an S-function uses this option, it cannot inherit its sample times. See “Hybrid Block-Based and Port-Based Sample Times” on page 7-36 for more information.

Example

See `matlabroot/simulink/src/mixedm.c` for an example.

SS_OPTION_REQ_INPUT_SAMPLE_TIME_MATCH

Purpose Specify sample times of input signal and port must match

Description Specifies that the input signal sample times must match the sample time assigned to the block input port. For example:



generates an error if this option is set. Simulink does not generate an error if the block or input port sample time is inherited.

SS_OPTION_RUNTIME_EXCEPTION_FREE_CODE

- Purpose** Improve performance of run-time exception-free S-functions
- Description** Improves performance of S-functions that do not use mexErrMsgTxt, mxMalloc, or any other routines that can throw an exception inside of a run-time routines. Applicable run-time routines include mdlGetTimeOfNextVarHit, mdlOutputs, mdlUpdate, and mdlDerivatives.
- See Also** SS_OPTION_EXCEPTION_FREE_CODE

Purpose

Indicate S-Function block is a `SimViewingDevice`

Description

Indicates the S-Function block referencing this S-function is a `SimViewingDevice`. As long as the block meets the other requirements for a `SimViewingDevice`, i.e., no states, no outputs, etc., Simulink considers the block to be an external mode block. As an external model block, the block appears in the external mode GUI and Simulink does not generate code for it. During an external mode simulation, Simulink runs the block only on the host. See “Sim Viewing Devices in External Mode” on page 7-55 in *Writing S-Functions* for more information.

SS_OPTION_SFUNCTION_INLINED_FOR_RTW

Purpose Specify use of TLC-file during code generation

Description Indicates the S-function has an associated TLC-file and does not contain an mdlRTW method. Setting this option has no effect if the S-function contains an mdlRTW method. During code generation, if SS_OPTION_SFUNCTION_INLINED_FOR_RTW is set and Real-Time Workshop cannot locate the S-function's TLC-file, Real-Time Workshop generates an error. If SS_OPTION_SFUNCTION_INLINED_FOR_RTW is not set but Real-Time Workshop does locate a TLC-file for the S-function, it uses the TLC-file.

Purpose

Support data type aliases

Description

Specifies how the S-function handles signals whose data types are aliases (see `Simulink.Aliastype` for more information about data type aliases). If this option is set and the S-function's inputs and outputs use data type aliases, `SimStruct` macros such as `ssGetInputPortDataType` and `ssGetOutputPortDataType` return the data type IDs of those aliases. However, if this option is not set, the `SimStruct` macros return the data type IDs associated with the equivalent built-in data types instead. For a list of built-in values for the data type ID, see `ssGetInputPortDataType`.

Note If this option is not set and the S-function's inputs use data type aliases, Simulink attempts to propagate the aliases to the S-function's outputs. However, this process can fail, in which case Simulink propagates the equivalent built-in data types instead. To explicitly control the propagation of data type aliases through an S-function, enable the `SS_OPTION_SUPPORTS_ALIAS_DATA_TYPES` option.

SS_OPTION_USE_TLC_WITH_ACCELERATOR

Purpose

Use TLC-file when simulating in accelerated mode

Description

Forces the Accelerator mode in Simulink to use the TLC inlining code for the S-function, which speeds up execution of the S-function. If this option is not set, the Accelerator mode uses the MEX version of the S-function even if a TLC-file for the S-function exists. This option should not be set for device driver blocks (A/D) or when there is an incompatibility between running the MEX `mdlStart` or `mdlInitializeConditions` functions together with the TLC `Outputs`, `Update`, or `Derivatives` functions. Also, this option indicates that the TLC inlining code should be used when generating a simulation target for a reference submodel that contains this S-function.

Note The Accelerator mode in Simulink does not require the Real-Time Workshop to run an inlined S-function. However, to ensure that the inlined S-function can run in accelerated mode in current and future Simulink releases, the TLC-file for the S-function must use documented TLC functions to access the `CompiledModel` structure.

SS_OPTION_WORKS_WITH_CODE_REUSE

Purpose

Specify this S-function supports code reuse

Description

Signifies that this S-function is compatible with the subsystem code reuse feature of Real-Time Workshop. See “Writing S-Functions That Support Code Reuse” in the "Real-Time Workshop User’s Guide" for more information. If this option is not set, Real-Time Workshop will not reuse any subsystem containing this S-Function.

SS_OPTION_WORKS_WITH_CODE_REUSE

Examples

Use this list to find examples in the documentation.

S-Function Features

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- “Multirate S-Function Blocks” on page 7-37
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