Simulink®

Simulation and Model-Based Design

- Modeling
- Simulation
- Implementation

Writing S-Functions

Version 6

The MathWorks

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508-647-7000 (Phone)

508-647-7001 (Fax)

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

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

Writing S-Functions

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Overview of S-Functions

S-functions (system-functions) provide a powerful mechanism for extending the capabilities of Simulink®. The following sections explain what an S-function is and when and why you might use one and how to write your own 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. 1-10)	How to write S-functions.
S-Function Concepts (p. 1-13)	Key concepts needed to write certain types of S-functions.
S-Function Examples (p. 1-19)	Examples that illustrate the creation of various types of S-functions and S-function features.

What Is an S-Function?

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.

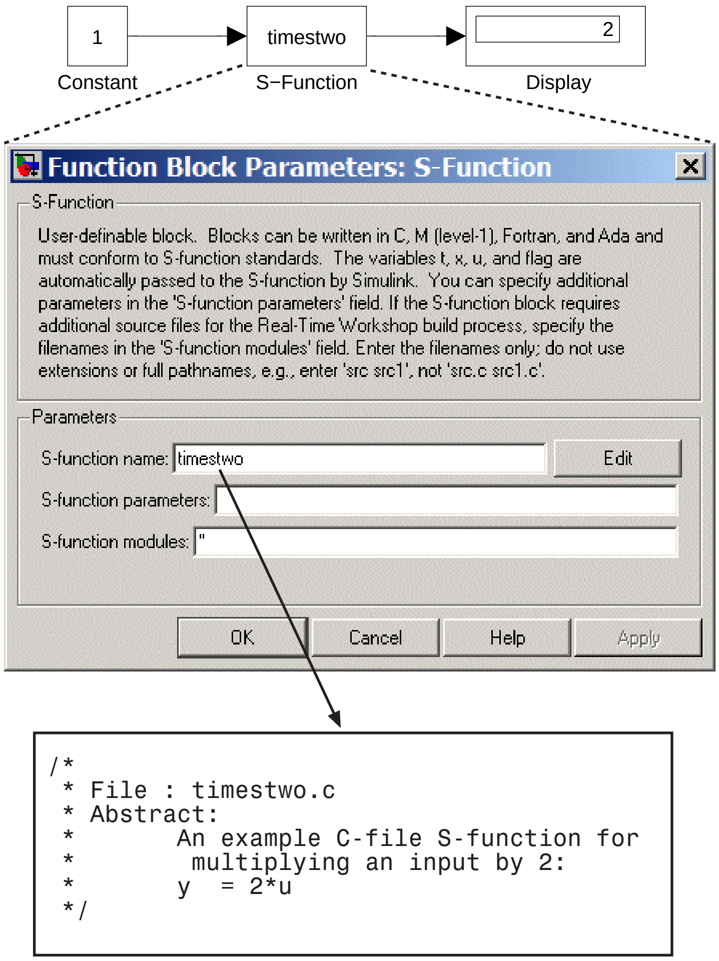
S-functions use a special calling syntax that enables you to interact with Simulink equation solvers. This interaction is very similar to the interaction that takes place between the solvers and built-in Simulink blocks. The form of an S-function is very general and can accommodate continuous, discrete,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

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.



User-definable block. Blocks can be written in C, M (level-1), Fortran, and Ada and must conform to S-function standards. The variables t, x, u, and flag are automatically passed to the S-function by Simulink. You can specify additional parameters in the 'S-function parameters' field. If the S-function block requires additional source files for the Real-Time Workshop build process, specify the filenames in the 'S-function modules' field. Enter the filenames only; do not use extensions or full pathnames, e.g., enter 'src src1', not 'src.c src1.c'.

S-function name: timestwo

S-function parameters:

S-function modules: ''

```
/*
 * File : timestwo.c
 * Abstract:
 *       An example C-file S-function for
 *        multiplying an input by 2:
 *       y  = 2*u
 */
```

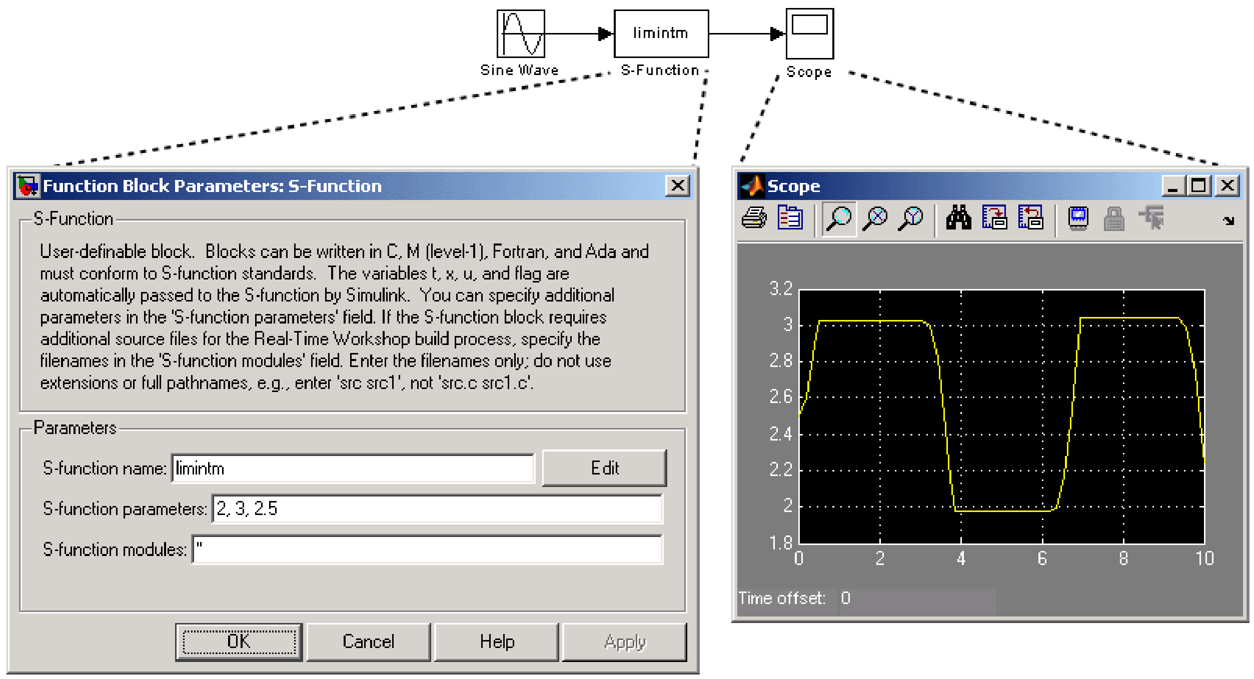
In this example, the model contains an instance of an S-Function block that references a C MEX-file having the root name `timestwo`.

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.



Function Block Parameters: S-Function

S-Function

User-definable block. Blocks can be written in C, M (level-1), Fortran, and Ada and must conform to S-function standards. The variables t, x, u, and flag are automatically passed to the S-function by Simulink. You can specify additional parameters in the 'S-function parameters' field. If the S-function block requires additional source files for the Real-Time Workshop build process, specify the filenames in the 'S-function modules' field. Enter the filenames only; do not use extensions or full pathnames, e.g., enter 'src src1', not 'src.c src1.c'.

Parameters

S-function name: limintm

S-function parameters: 2, 3, 2.5

S-function modules: ''

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 2-11 and "Handling Errors" on page 7-52 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 Masked Subsystems” 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`)

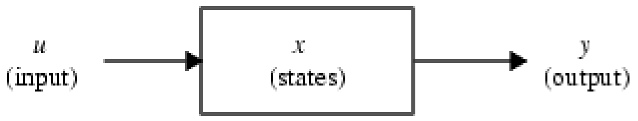
An advantage of using S-functions is that you can build a general-purpose block that you can use many times in a model, varying parameters with each instance of the block.

How S-Functions Work

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 therefore 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 sample time, the inputs, and the block's states.



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

$$y = f_0(t, x, u) \qquad \text{(Output)}$$

$$\dot{x}_c = f_d(t, x, u) \qquad \text{(Derivative)}$$

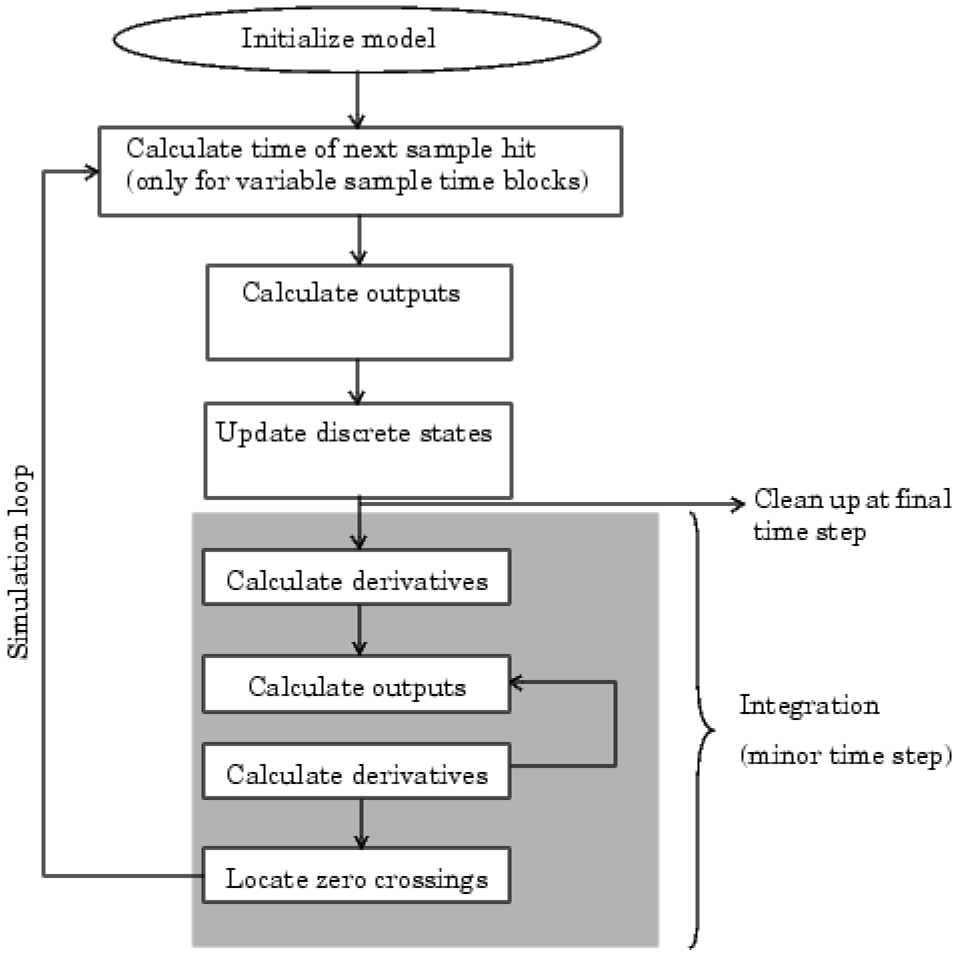
$$x_{d_{k+1}} = f_u(t, x, u) \qquad \text{(Update)}$$

$$\text{where} \quad x = x_c + x_d$$

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

You can implement an S-function as either an M-file or a MEX-file. The following sections describe these alternative implementations and discuss the advantages of each.

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	`mdlInitializeSizes`	`flag = 0`
Calculation of next sample hit (variable sample time block only)	`mdlGetTimeOfNextVarHit`	`flag = 4`
Calculation of outputs	`mdlOutputs`	`flag = 3`
Update of discrete states	`mdlUpdate`	`flag = 2`

Simulation Stage	S-Function Routine	Flag
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

Understanding these key concepts should enable you to build S-functions correctly:

- Direct feedthrough
- Dynamically sized inputs
- Setting sample times and offsets

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.

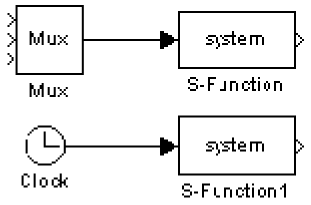
Dynamically Sized Arrays

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 7-12.

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

  ```
  TimeHit = (n * period) + 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 ≤ offset < 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.

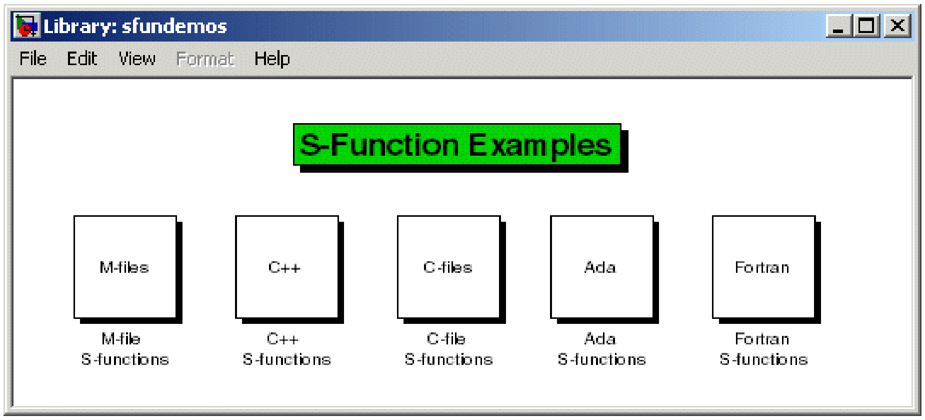
S-Function Examples

Simulink comes with a library of S-function examples.

To run an example:

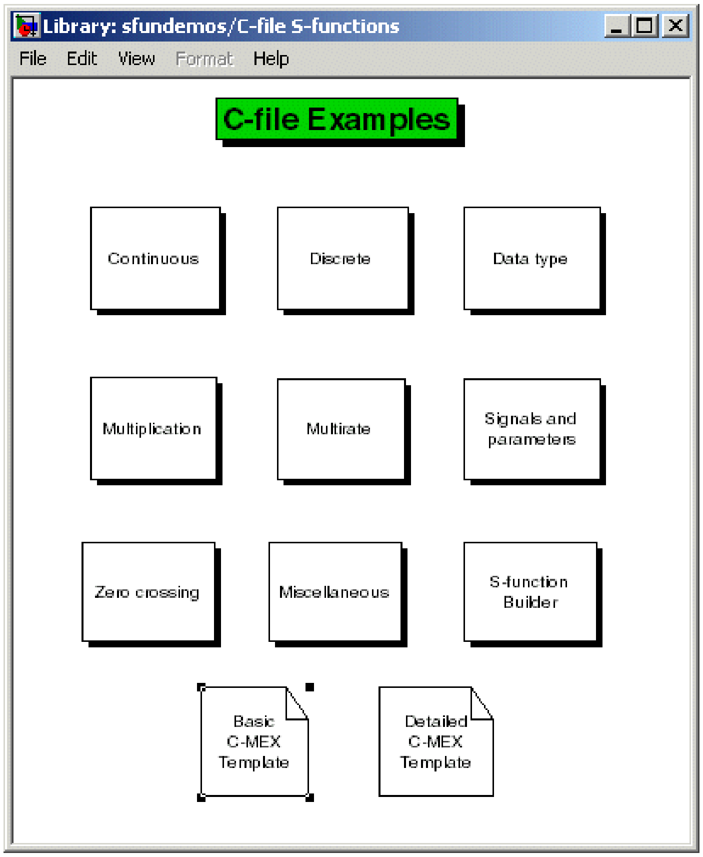
1 Enter `sfundemos` at the MATLAB command line.

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`

M-File S-Function Examples

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

Filename	Description
`csfunc.m`	Define a continuous system in state-space format.
`dsfunc.m`	Define a discrete system in state-space format.
`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`	Example state-space M-file S-function with internal `A`, `B`, `C`, and `D` matrices. This S-function implements
	`dx/dt = Ax + By`
	`y = Cx + Du`
	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.

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

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

Filename	Description
`sfun_psbbreaker.c`	Implement the logic for the breaker block in the Power System 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 `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`	Implements a single-input, two-output state-space dynamic system described by these state-space equations
	
	`dx/dt = Ax + Bu`
	`y = Cx + Du`
	
	where `x` is the state vector, `u` is vector of inputs, and `y` is the vector of outputs.

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.
vsfunc.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 `vdpmex` S-function.

C++ S-Function Examples

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

Filename	Description
`sfun_counter_cpp.cpp`	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
`matrix_gain`	Implement a Matrix Gain block.
`multi_port`	Multiport block.
`simple_lookup`	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.
`times_two`	Output twice its input.

Writing S-Functions in M

The following sections explain how to use the MATLAB M programming language to create S-functions.

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. 2-8)	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 2-8). You should not use the Level-1 API to develop new M-file S-functions. Instead, you should use the Level-2 API.

Writing 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.

About Level-2 M-File S-Functions

First, a word about Level-2 M-File S-functions themselves. 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 2-4) 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 2-6 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 Simulink Accelerator runs Level-2 M-file S-functions in interpreted mode.

Callback Methods

The Level-2 M-file S-function API specifies a set of callback methods that an M-file S-function must implement 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`
`Outputs`	`mdlOutputs`
`PostPropagationSetup`	`mdlSetWorkWidths`
`ProcessParameters`	`mdlProcessParameters`
`SetInputPortComplexSignal`	`mdlSetInputPortComplexSignal`
`SetInputPortDataType`	`mdlSetInputPortDataType`
`SetInputPortDimensions`	`mdlSetInputPortDimensionInfo`
`SetInputPortSampleTime`	`mdlSetInputPortSampleTime`
`SetInputPortSamplingMode`	`mdlSetInputPortFrameData`
`SetOutputPortComplexSignal`	`mdlSetOutputPortComplexSignal`
`SetOutputPortDataType`	`mdlSetOutputPortDataType`
`SetOutputPortDimensions`	`mdlSetOutputPortDimensionInfo`
`SetOutputPortSampleTime`	`mdlSetOutputPortSampleTime`
`Start`	`mdlStart`
`Update`	`mdlUpdate`

Level-2 M-File Method	C MEX-File Method
`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.

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

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).

A Level-1 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 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	`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.
4	`mdlGetTimeOfNextVarHit`	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 `mdlInitializeSizes`.
9	`mdlTerminate`	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
`sizes.NumContStates`	Number of continuous states
`sizes.NumDiscStates`	Number of discrete states
`sizes.NumOutputs`	Number of outputs
`sizes.NumInputs`	Number of inputs
`sizes.DirFeedthrough`	Flag for direct feedthrough
`sizes.NumSampleTimes`	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 1-4). 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.

Writing S-Functions in C

The following sections explain how to use the C programming language to create S-functions.

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. 3-35)	Illustrates the code needed to create a C S-function.
Templates for C S-Functions (p. 3-41)	Describes code templates that you can use as starting points for writing your own C S-functions.
Legacy Code Tool (p. 3-45)	How to use the Legacy Code Tool to generate S-functions automatically from existing C code.
How Simulink Interacts with C S-Functions (p. 3-59)	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. 3-67)	How to write methods that Simulink calls as it executes your S-function.
Converting Level 1 C MEX S-Functions to Level 2 (p. 3-68)	How to convert S-functions written for earlier releases of Simulink to work with the current version.

Introduction

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
```

`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 3-35 provides a step-by-step example of how to write a simple S-function from scratch. See "Templates for C S-Functions" on page 3-41 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 “Legacy Code Tool” on page 3-45 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

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 1-19 for more information).

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

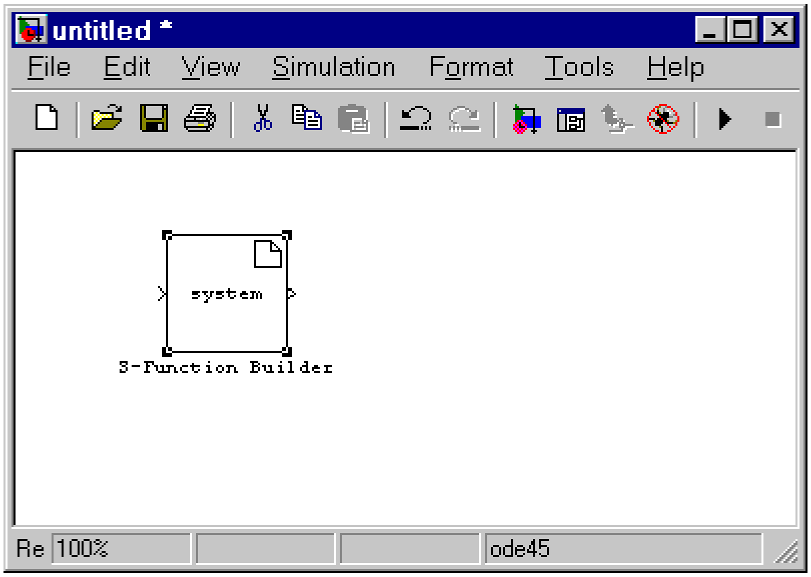
1 Set the MATLAB current directory to the directory in which you want to create the S-function.

   Note This directory must be on the MATLAB path.

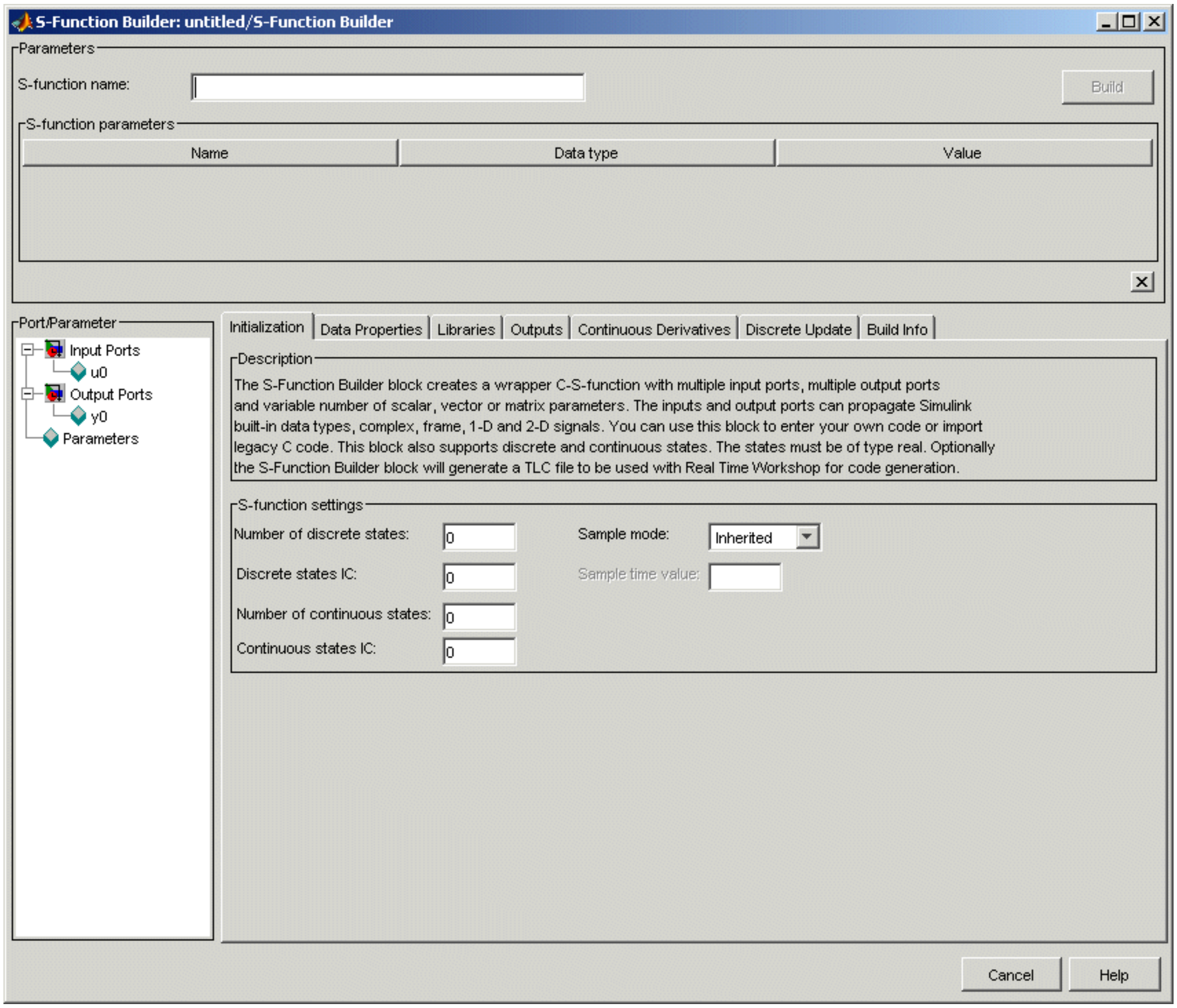
   ---

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).



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:	0	Sample mode:	Inherited
Discrete states IC:	0	Sample time value:	
Number of continuous states:	0		
Continuous states IC:	0		

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 3-9).

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.

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.

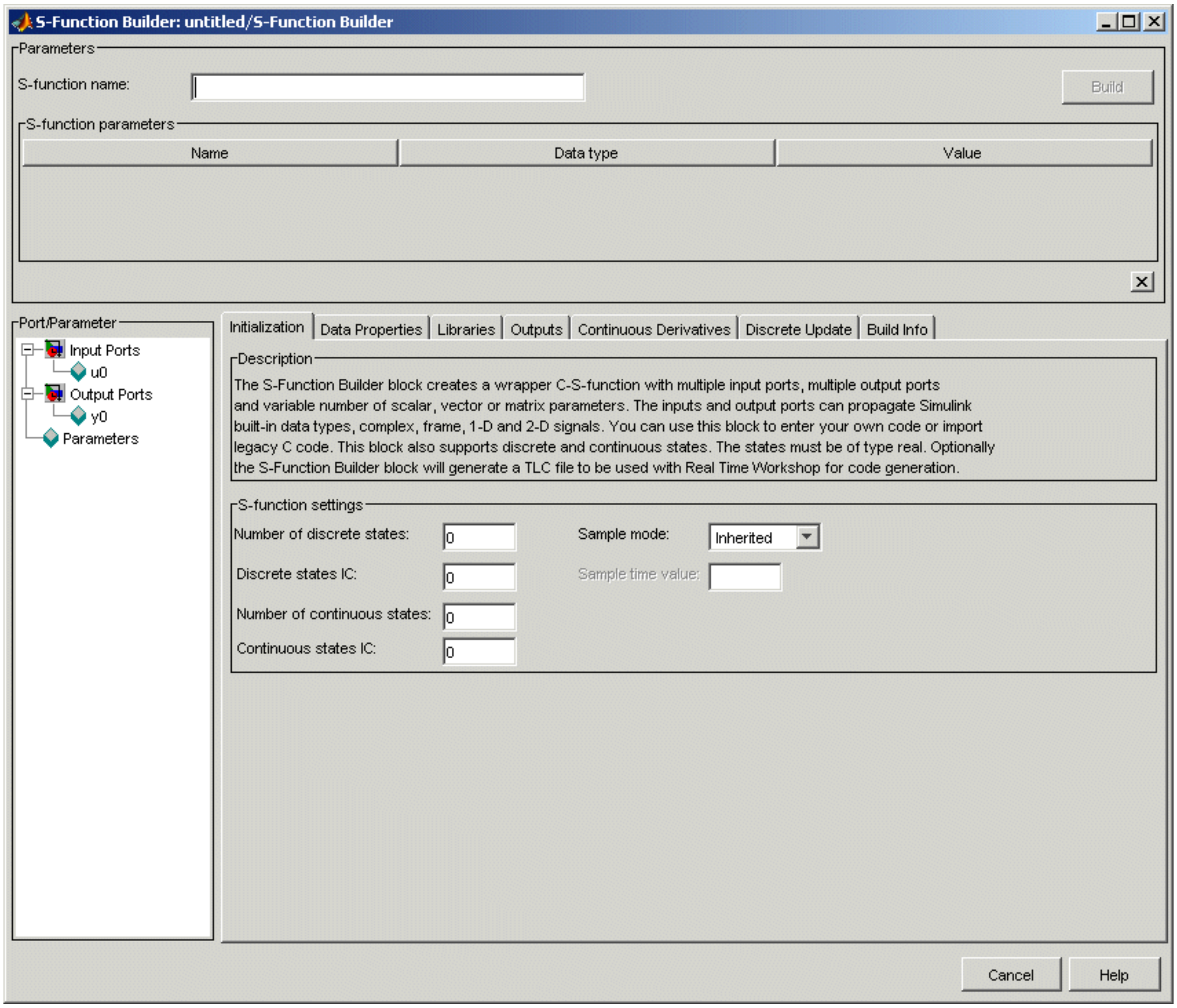
- `sfun.tlc`

  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

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 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.

Number of discrete states: 0
Discrete states IC: 0
Number of continuous states: 0
Continuous states IC: 0
Sample mode: Inherited
Sample time value:

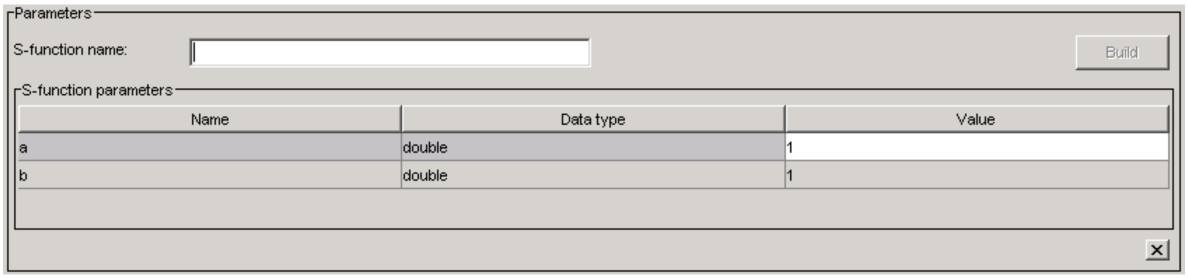
The dialog box contains controls that let you enter information needed for the S-Function Builder block to build an S-function to your specifications. The controls are grouped into panes. See the following sections for information on the panes and the controls that they contain.

- “Parameters/S-Function Name Pane” on page 3-12
- “Port/Parameter Pane” on page 3-13
- “Initialization Pane” on page 3-14
- “Data Properties Pane” on page 3-16
- “Libraries Pane” on page 3-22
- “Outputs Pane” on page 3-24
- “Continuous Derivatives Pane” on page 3-28
- “Discrete Update Pane” on page 3-30
- “Build Info Pane” on page 3-32

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

Parameters/S-Function Name Pane

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



Name	Data type	Value
a	double	1
b	double	1

The pane contains the following controls.

S-function name

Specifies the name of the target S-function.

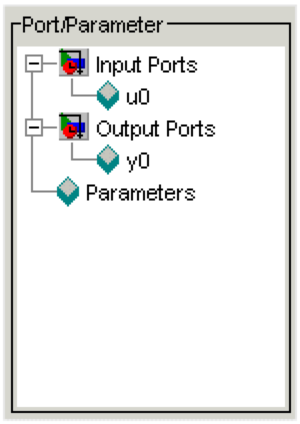
S-function parameters

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 3-20.
- **Data type** — Lists the data type of the parameter. Define and modify this property from the “Parameters Pane” on page 3-20.
- **Value** — Specifies the value of the parameter. Enter a valid MATLAB expression in this field.

Port/Parameter Pane

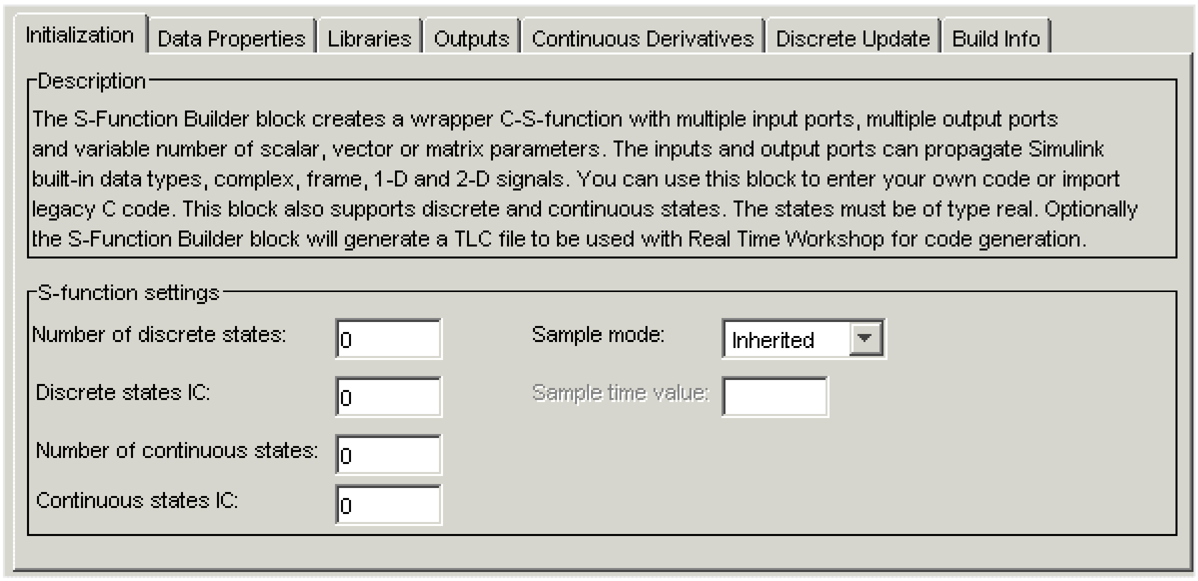
This pane displays the ports and parameters that the dialog box specifies for the target S-function.



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.



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:	0	Sample mode:	Inherited
Discrete states IC:	0	Sample time value:	
Number of continuous states:	0		
Continuous states IC:	0		

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 3-59 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`

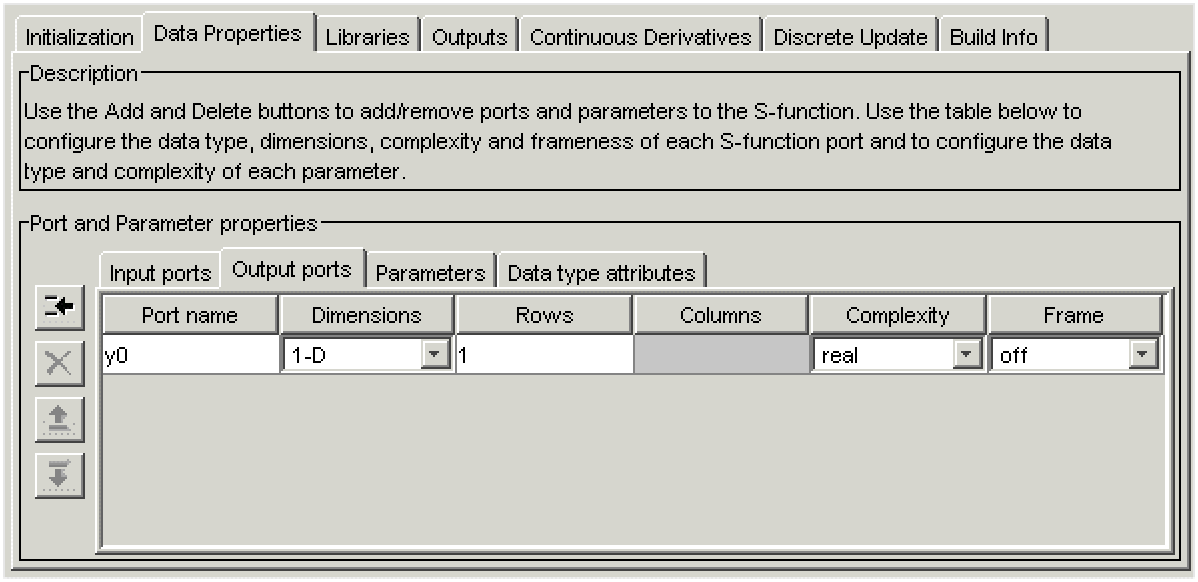
  The S-function updates its outputs at the rate specified in the **Sample time value** field of the S-Function Builder dialog box.

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.



Description

Use the Add and Delete buttons to add/remove ports and parameters to the S-function. Use the table below to configure the data type, dimensions, complexity and frameness of each S-function port and to configure the data type and complexity of each parameter.

Port and Parameter properties

Port name	Dimensions	Rows	Columns	Complexity	Frame
y0	1-D	1		real	off

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.

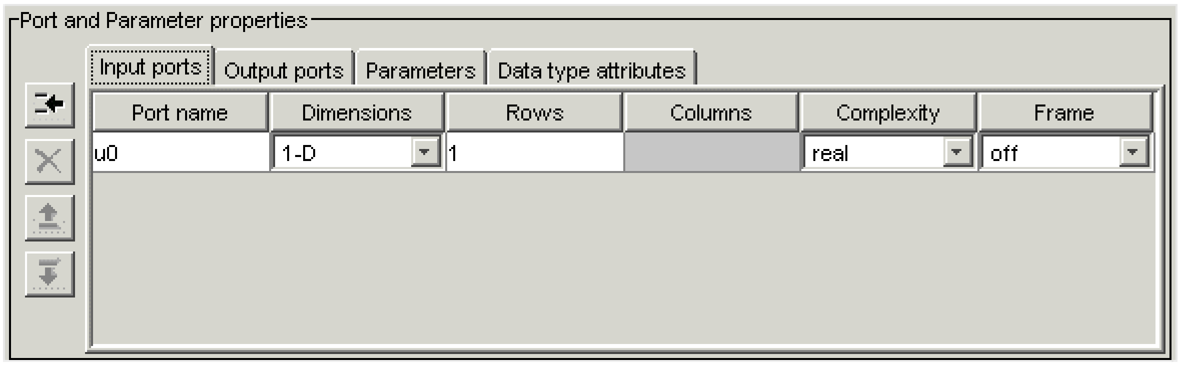
- To add a port or parameter, click the **Add** button (the top button in the column of buttons).
- To delete the currently selected port/parameter, click the **Delete** button (located beneath the **Add** button).
- To move the currently selected port/parameter up one position in the corresponding S-Function 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 3-17
- "Output Ports Pane" on page 3-18
- "Parameters Pane" on page 3-20
- "Data Type Attributes Pane" on page 3-21

Input Ports Pane

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



Port name	Dimensions	Rows	Columns	Complexity	Frame
u0	1-D	1		real	off

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.

Note Simulink signals can have at most two dimensions.

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 dimensions 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

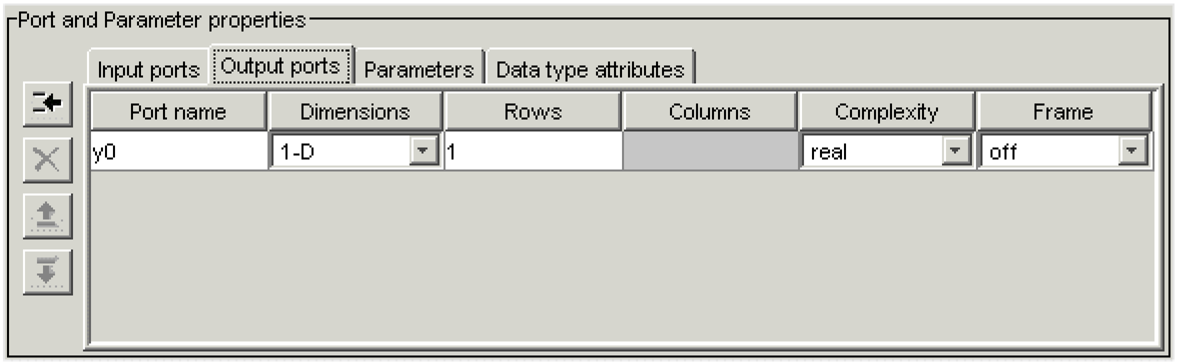
Specifies whether the input port accepts real or complex-valued signals.

Frame

Specifies whether this port accepts frame-based signals generated by the 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.



Port name	Dimensions	Rows	Columns	Complexity	Frame
y0	1-D	1		real	off

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.

Note Simulink signals can have at most two dimensions.

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

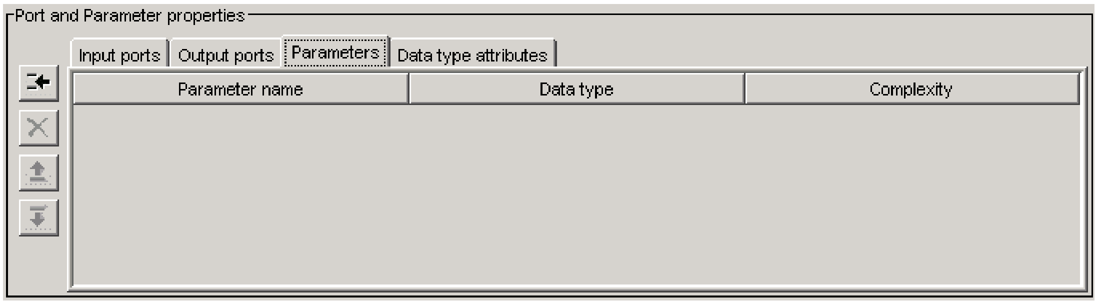
Specifies whether the port outputs real or complex-valued signals.

Frame

Specifies whether this port outputs frame-based signals generated by the 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

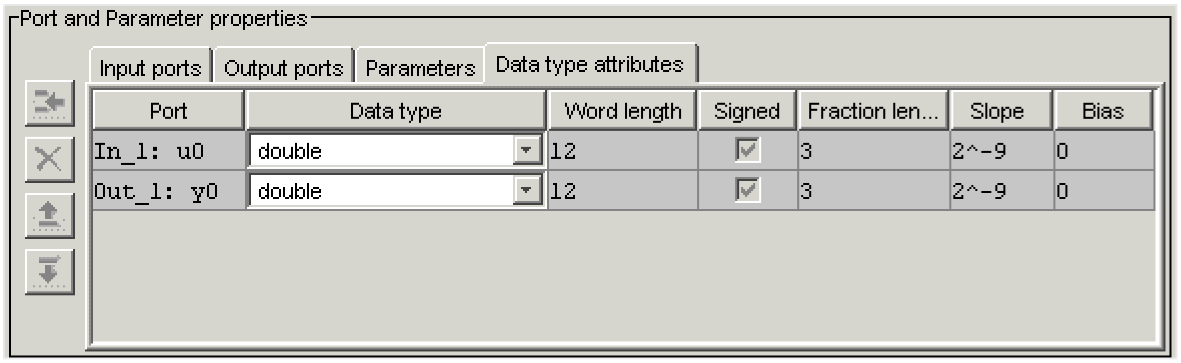
Lists the data type of the parameter. Click the adjacent button to display a list of supported data types. To change the parameter's data type, select a new type from the list.

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.



Port	Data type	Word length	Signed	Fraction len...	Slope	Bias
In_1: u0	double	12	✓	3	2^-9	0
Out_1: y0	double	12	✓	3	2^-9	0

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.

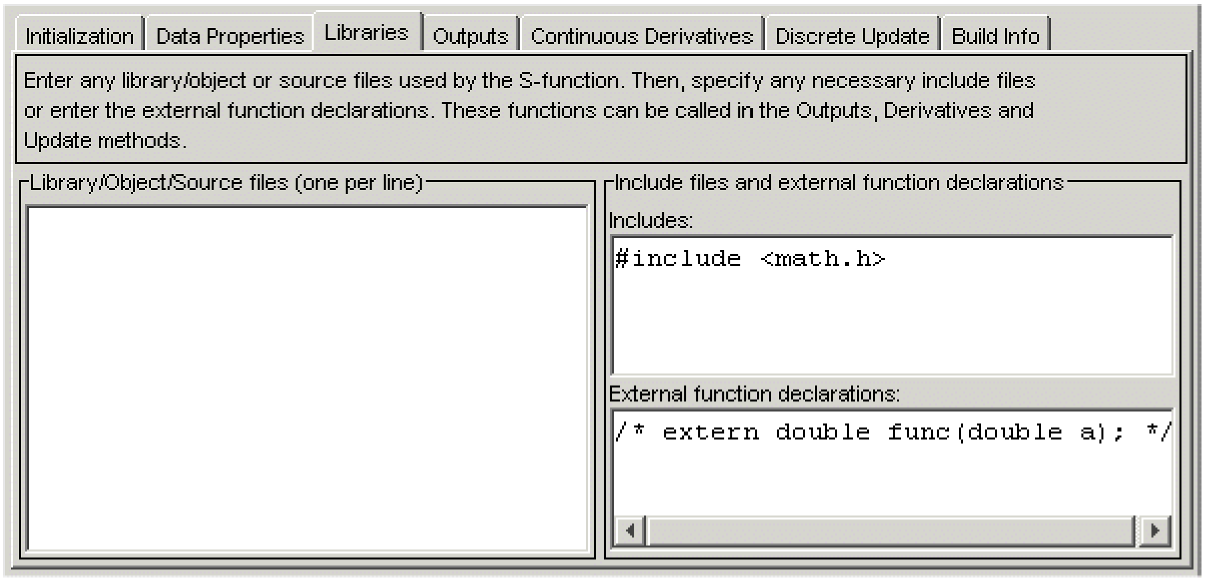
Data Type

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.



Enter any library/object or source files used by the S-function. Then, specify any necessary include files or enter the external function declarations. These functions can be called in the Outputs, Derivatives and Update methods.

Library/Object/Source files (one per line)
Include files and external function declarations

Includes:

```
#include <math.h>
```

External function declarations:

```
/* extern double func(double a); */
```

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.

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:

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

As this example illustrates, you can use `LIB_PATH` to specify both object and library file paths and the tag `$MATLABROOT` to indicate paths relative to the MATLAB installation. You can also 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

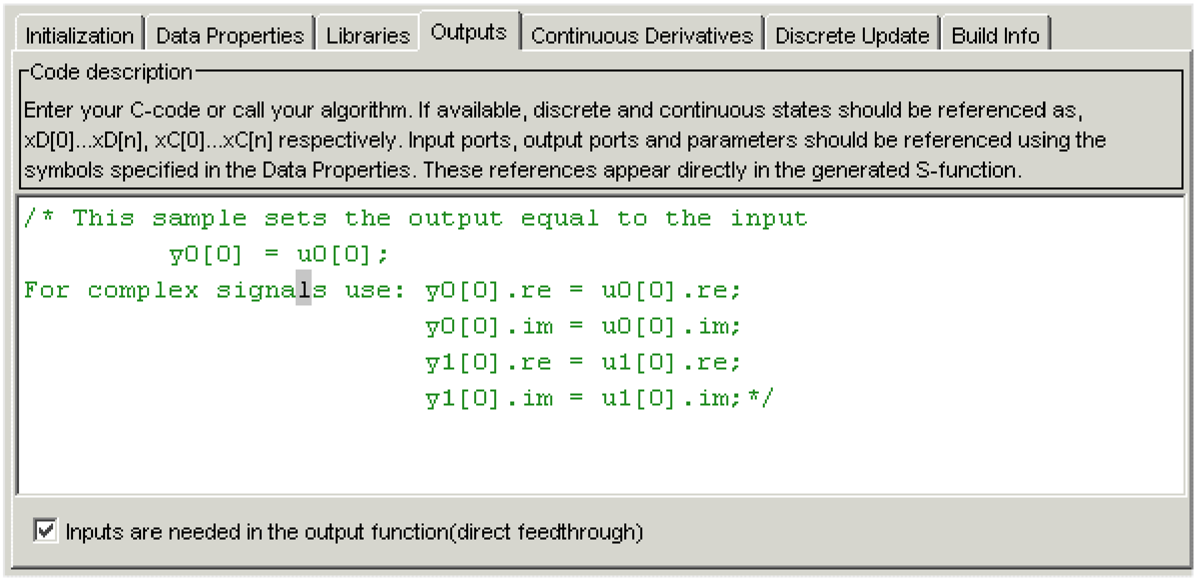
Header files containing declarations of functions, variables, and macros referenced by custom code that you enter elsewhere on the S-Function Builder dialog box. Specify each file on a separate line as `#include` statements. Use brackets to enclose the names of standard C header files (e.g., `#include <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 3-23).

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.



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

```
/* This sample sets the output equal to the input
         y0[0] = u0[0];
For complex signals use: y0[0].re = u0[0].re;
                         y0[0].im = u0[0].im;
                         y1[0].re = u1[0].re;
                         y1[0].im = u1[0].im;*/
```

☑ Inputs are needed in the output function(direct feedthrough)

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 `u_width` argument (see below).

Argument	Description
`y0, y1, ...  yN`	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 `y_width` argument (see below). Use this array to pass the outputs that your code computes back to Simulink.
`xD`	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 3-30 for more information).
`xC`	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 3-28 for more information).

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.

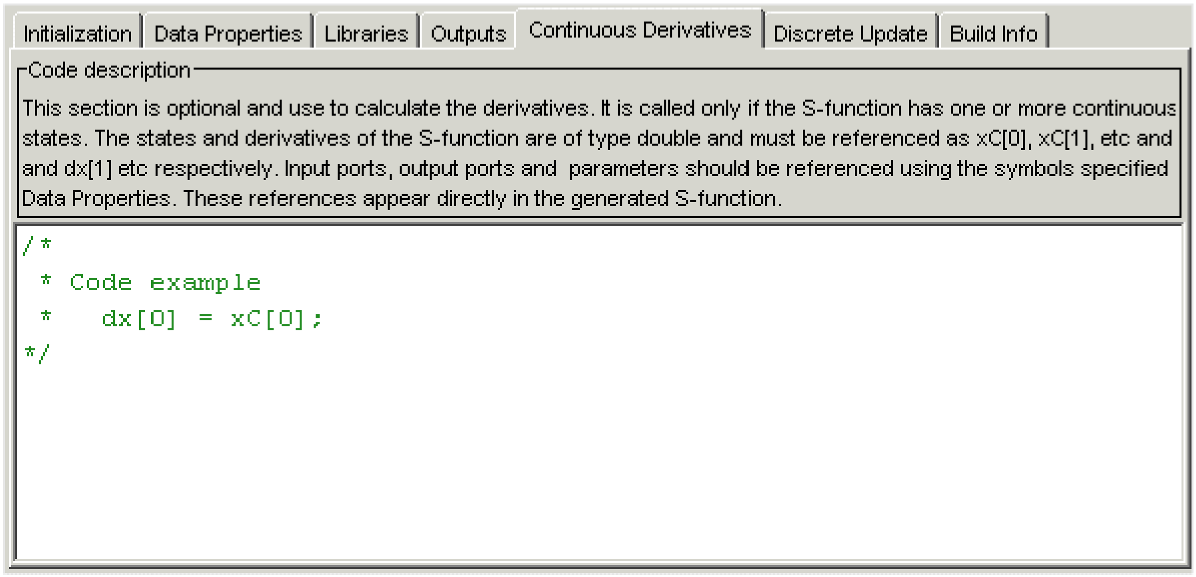
These arguments permit you to compute the output of the block as a function of its inputs and, optionally, its states and parameters. The code that you enter in this field can invoke external functions declared in the header files or external declarations on the **Libraries** pane. This allows you to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



Code description

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

```
/*
 * Code example
 *   dx[0] = xC[0];
*/
```

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 3-59). 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 3-24).

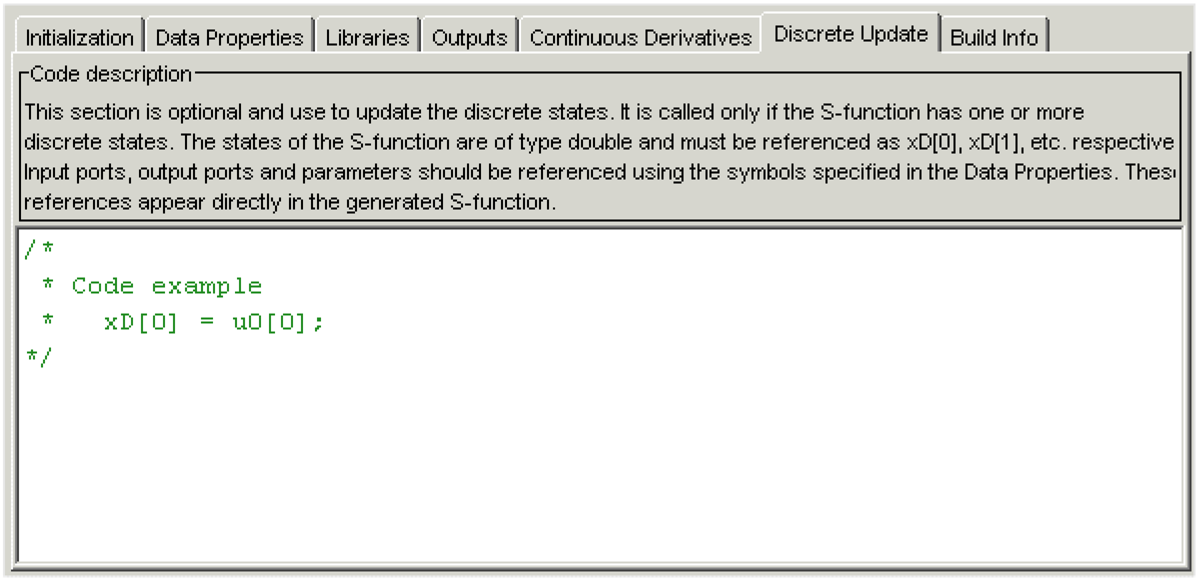
The generated S-function's `mdlDerivatives` callback method passes the following arguments to the derivatives wrapper function:

- `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 3-24 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.



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. respective Input ports, output ports and parameters should be referenced using the symbols specified in the Data Properties. Thes references appear directly in the generated S-function.

```
/*
 * Code example
 *   xD[0] = u0[0];
*/
```

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 3-59). At the next time step, Simulink passes the updated states back to the S-function's `mdlOutputs` method (see "Outputs Pane" on page 3-24).

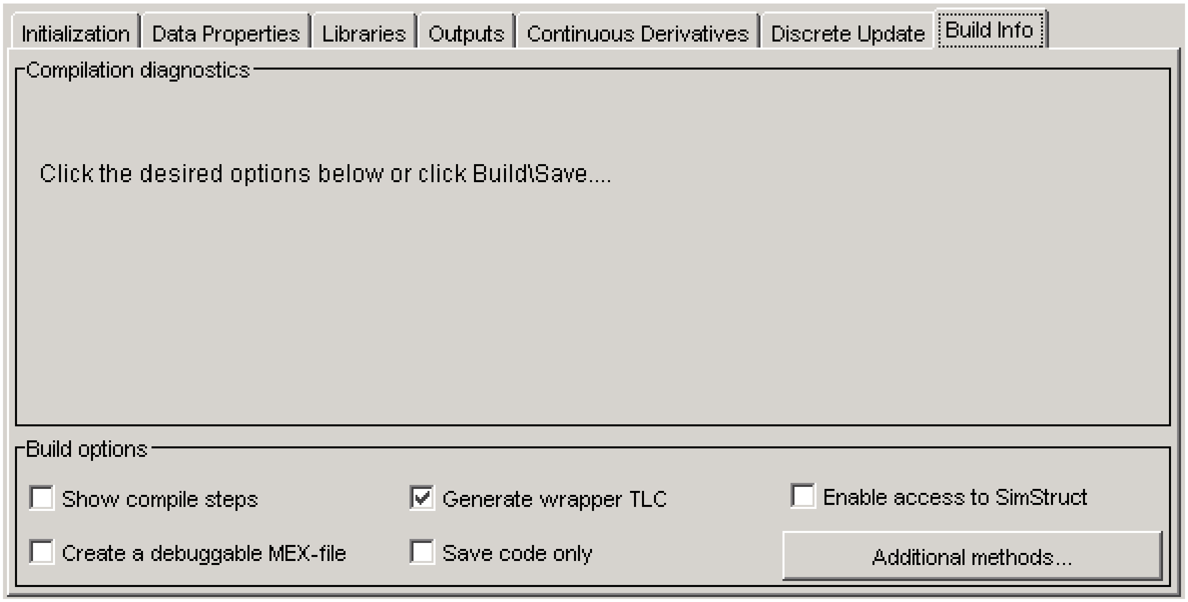
The generated S-function's `mdlUpdates` callback method passes the following arguments to the updates wrapper function:

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

See "Outputs Pane" on page 3-24 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.



Compilation diagnostics

Click the desired options below or click Build\Save....

Build options

- [ ] Show compile steps
- [✓] Generate wrapper TLC
- [ ] Enable access to SimStruct
- [ ] Create a debuggable MEX-file
- [ ] Save code only

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

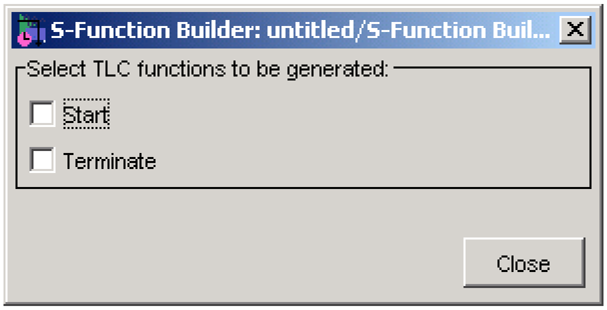
Makes the `SimStruct` (`S`) accessible to the wrapper functions that S-Function Builder generates. This enables you to use the `SimStruct` macros and functions with your code in the **Outputs**, **Continuous Derivatives**, and **Discrete Updates** panes. For example, with this option enabled, you can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

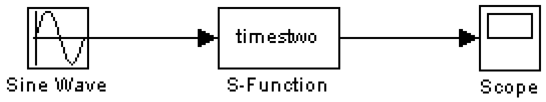

S-Function Builder: untitled/S-Function Buil...
Select TLC functions to be generated:
Start
Terminate
Close

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 of a Basic C MEX S-Function

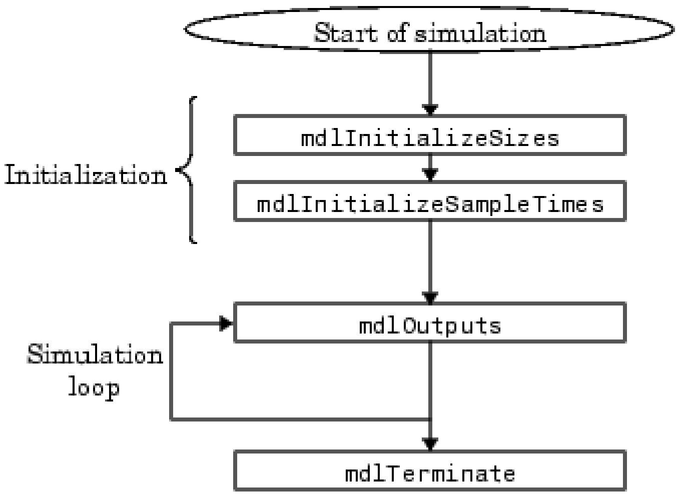
This section presents an example of a C MEX S-function that you can use as a model for creating simple C S-functions. The example is the `timestwo` S-function example that comes with Simulink (see *`matlabroot`*`/simulink/src/timestwo.c`). This S-function outputs twice its input.

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

The following sections explain each of these parts.

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 3-68).

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 3-59.

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 3-63.

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, in Microsoft Windows, the MEX-file extension is `.mexw32`.

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 3-68. 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
matlabroot/extern/include/tmwtypes.h	General data types, e.g., `real_T`
matlabroot/extern/include/mex.h	MATLAB MEX-file API routines to interface MEX-files with MATLAB
matlabroot/extern/include/matrix.h	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
matlabroot/extern/include/tmwtypes.h	General types, e.g., `real_T`
matlabroot/rtw/c/libsrc/rt_matrx.h	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 3-67):

- `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 `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`.

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.

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.

Legacy Code Tool

The Legacy Code Tool is a utility that generates an S-function automatically from existing C code and specifications that you supply using M-code. It enables you to transform your C functions into C MEX S-functions for inclusion in a Simulink model. If you use Real-Time Workshop to generate code from that model, the Legacy Code Tool can insert an appropriate call to your C function in the generated code. The following sections outline aspects of using the Legacy Code Tool:

- “Overview of Legacy Code Tool” on page 3-45
- “Using Legacy Code Tool” on page 3-47
- “Legacy Code Tool Data Structure” on page 3-50
- “Legacy Code Tool Function Specifications” on page 3-53
- “Legacy Code Tool Demos” on page 3-58

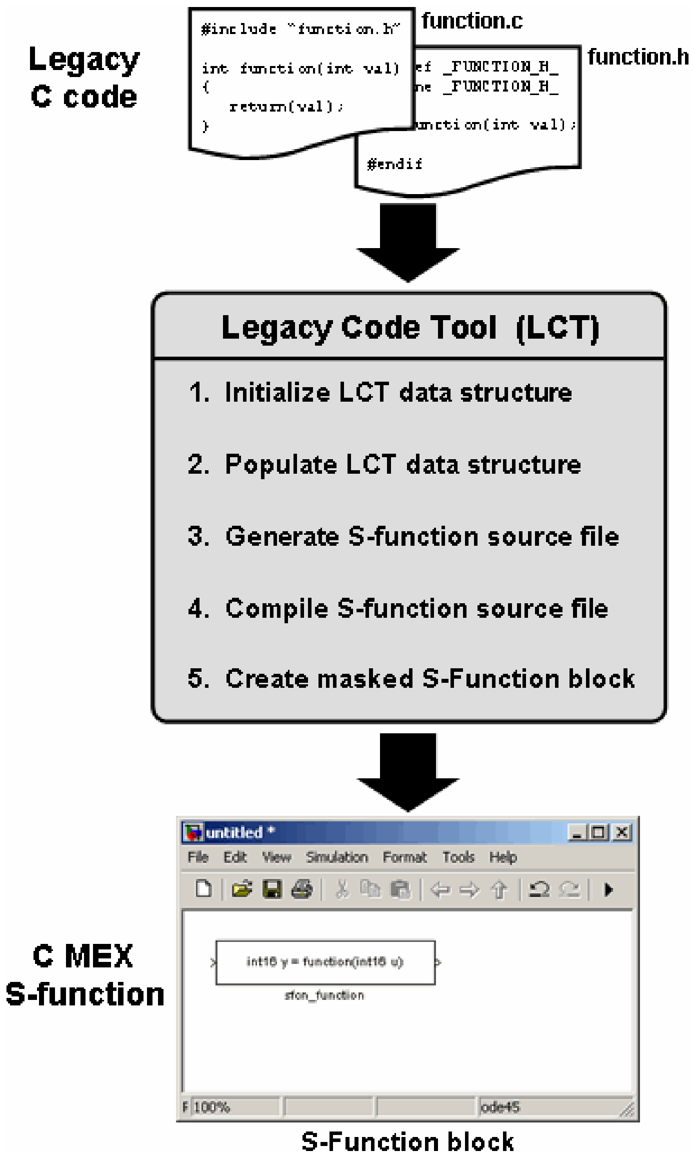
Overview of Legacy Code Tool

The Legacy Code Tool provides a means for incorporating your existing C code in a Simulink simulation. The tool transforms your C functions into C MEX S-functions for inclusion in a Simulink model. Toward that end, the tool can be easier to use than its alternatives, namely, using the S-Function Builder block or writing S-functions from scratch.

To interact with the Legacy Code Tool, use the

- `legacy_code` function to perform the requisite steps for transforming your C code into a C MEX S-function.
- Legacy Code Tool data structure to specify properties of both your C code and the S-function that the tool will produce.

The following diagram illustrates a general procedure for using the Legacy Code Tool. The next section provides an example that demonstrates how to use the Legacy Code Tool to transform an existing C function into a C MEX S-function in Simulink.

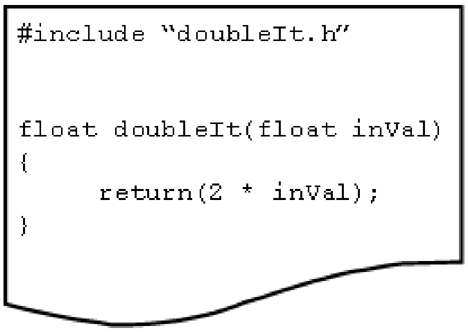

Legacy
C code
function.c
function.h
Legacy Code Tool (LCT)
1. Initialize LCT data structure
2. Populate LCT data structure
3. Generate S-function source file
4. Compile S-function source file
5. Create masked S-Function block
C MEX
S-function
untitled *
File Edit View Simulation Format Tools Help
int16 y = function(int16 u)
sfcn_function
100%
ode45
S-Function block

```
#include "function.h"

int function(int val)
{
   return(val);
}
```

```
ef _FUNCTION_H_
ne _FUNCTION_H_

nction(int val);

#endif
```

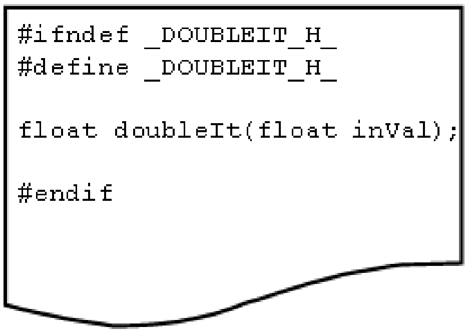
Using Legacy Code Tool

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"


float doubleIt(float inVal)
{
     return(2 * inVal);
}
```

doubleIt.c



```
#ifndef _DOUBLEIT_H_
#define _DOUBLEIT_H_

float doubleIt(float inVal);

#endif
```

doubleIt.h

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

1 Use the `legacy_code` function to initialize a MATLAB structure whose fields represent Legacy Code Tool properties. For example, create a Legacy Code Tool data structure named `def` by issuing 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: ''
       OutputFcnSpec: ''
        StartFcnSpec: ''
    TerminateFcnSpec: ''
         HeaderFiles: {}
         SourceFiles: {}
        HostLibFiles: {}
```

```
         TargetLibFiles: {}
               IncPaths: {}
               SrcPaths: {}
               LibPaths: {}
                Options: [1x1 struct]
```

2 Specify appropriate values for fields in the Legacy Code Tool data structure to identify characteristics of the existing C function. For example, specify the C function source and header filenames by issuing 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 typing the commands:

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

See “Legacy Code Tool Data Structure” on page 3-50 for information about its various 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 Use the `legacy_code` function to compile the S-function source file into a C MEX S-function that Simulink can use. At the MATLAB prompt, type:

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

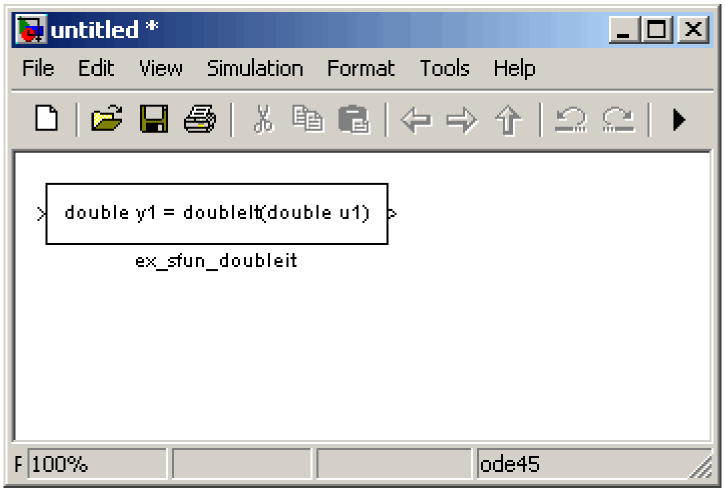
The Legacy Code Tool uses the information specified in `def` to create a dynamically loadable executable file in the current MATLAB directory.

On Microsoft Windows, the resulting C MEX S-function is named `ex_sfun_doubleit.mexw32`.

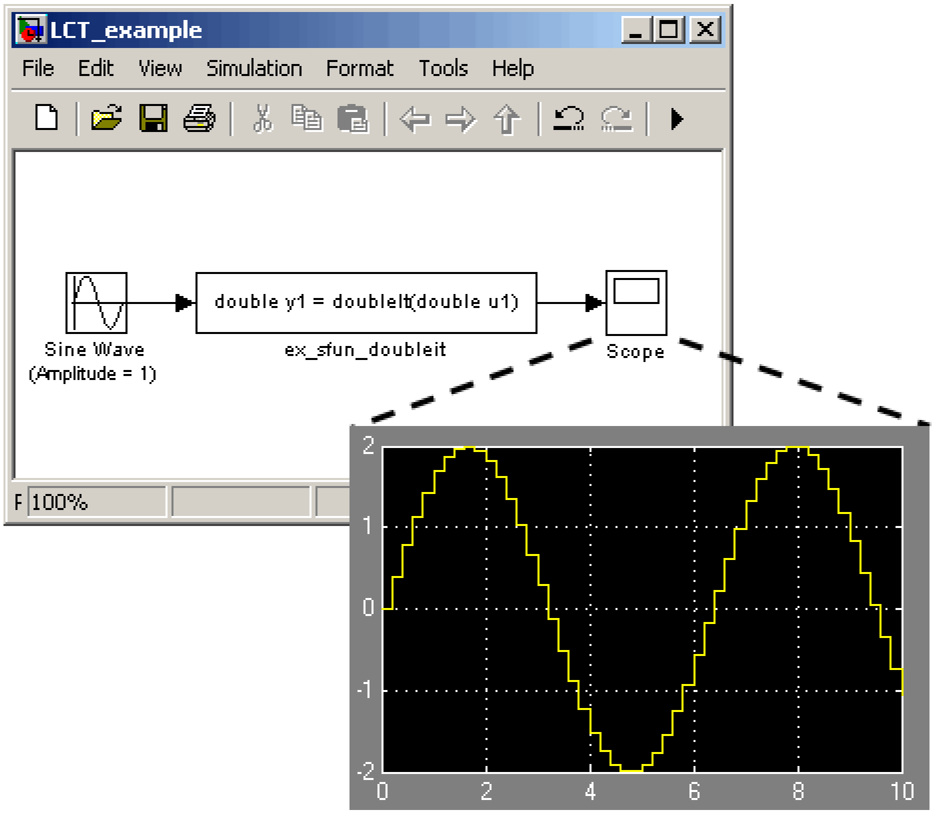
5 Use the `legacy_code` function to insert a masked S-Function block into a Simulink model. The Legacy Code Tool configures the block to use the C MEX S-function created in the previous step. Also, the tool masks the block such that it displays the value of its `OutputFcnSpec` property (see "Legacy Code Tool Data Structure" on page 3-50). 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_sfun_doubleit` returns the value of its floating-point input multiplied by two.


LCT_example
File Edit View Simulation Format Tools Help
double y1 = doubleIt(double u1)
Sine Wave
(Amplitude = 1)
ex_sfun_doubleit
Scope
100%
2
1
0
-1
-2
0
2
4
6
8
10

Legacy Code Tool Data Structure

The Legacy Code Tool uses a data structure to define properties of the existing C code. The structure also includes properties that determine characteristics of the S-function the tool will produce. The following table describes each field contained in the Legacy Code Tool data structure.

Field	Description
`SFunctionName`	A string specifying a name for the S-function to be produced by the Legacy Code Tool. (Required)

Field	Description
`OutputFcnSpec`	A nonempty string specifying the function that the S-function calls at each time step. You must define this function using tokens that Simulink can interpret (see "Legacy Code Tool Function Specifications" on page 3-53).
`StartFcnSpec`	A string specifying the function that the S-function calls when it begins execution. This function can access only the S-function parameters. You must define this function using tokens that Simulink can interpret (see "Legacy Code Tool Function Specifications" on page 3-53).
`TerminateFcnSpec`	A string specifying the function that the S-function calls when it terminates execution. This function can access only the S-function parameters. You must define this function using tokens that Simulink can interpret (see "Legacy Code Tool Function Specifications" on page 3-53).
`HeaderFiles`	A cell array of strings specifying header files required for compilation. You can specify the header files using absolute or relative pathnames.
`SourceFiles`	A cell array of strings specifying source files required for compilation. You can specify the source files using absolute or relative pathnames.
`HostLibFiles`	A cell array of strings specifying library files required for host compilation. You can specify the library files using absolute or relative pathnames.
`TargetLibFiles`	A cell array of strings specifying library files required for target (i.e., standalone) compilation. You can specify the library files using absolute or relative pathnames.
`IncPaths`	A cell array of strings specifying include directories containing header files. You can specify the include directories using absolute or relative pathnames.

Field	Description
`SrcPaths`	A cell array of strings specifying include directories containing source files. You can specify the include directories using absolute or relative pathnames.
`LibPaths`	A cell array of strings specifying include directories containing host and target library files. You can specify the include directories using absolute or relative pathnames.
`Options`	A structure that controls S-function options. Its fields include: `isMacro` — A logical value specifying whether the legacy code is a C macro. By default, its value is false (i.e., `0`). `isVolatile` — A logical value specifying the setting of the S-function `SS_OPTION_NONVOLATILE` option (see `ssSetOptions`). By default, its value is true (i.e., `1`). `canBeCalledConditionally` — A logical value specifying the setting of the S-function `SS_OPTION_CAN_BE_CALLED_CONDITIONALLY` option (see `ssSetOptions`). By default, its value is true (i.e., `1`). `useTlcWithAccel` — A logical value specifying the setting of the S-function `SS_OPTION_USE_TLC_WITH_ACCELERATOR` option (see `ssSetOptions`). By default, its value is true (i.e., `1`). `language` — A string specifying either `'C'` or `'C++'` as the target language of the S-function that Legacy Code Tool will produce. By default, its value is `'C'`.

Legacy Code Tool Function Specifications

The `OutputFcnSpec`, `StartFcnSpec`, and `TerminateFcnSpec` fields defined in the Legacy Code Tool data structure (see "Legacy Code Tool Data Structure" on page 3-50) require string values that adhere to a particular convention. This enables Legacy Code Tool to map the arguments of your C function to the inputs, outputs, and parameters of the S-function that the tool produces. The general syntax for these function specifications is:

```
output_arguments = function_name(input_arguments, parameter_arguments)
```

The following sections explain the different components of the function specification:

- "Function Name" on page 3-53
- "Input Arguments" on page 3-53
- "Output Arguments" on page 3-55
- "Parameter Arguments" on page 3-56

Function Name

The function name that you specify must be the same as your existing C function name. For example, if your C function prototype is

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

the function name in the Legacy Code Tool function specification must be `doubleIt`.

Input Arguments

You must define input arguments in the function specification using tokens that Simulink can interpret. This enables Legacy Code Tool to map the input arguments of your C function to the inputs of the S-function that the tool produces. Specify each input argument in the function specification by designating a

- Data type that Simulink supports (see "Data Types Supported by Simulink" in the Simulink documentation)

- Token of the form `u1`, `u2`, `...`, `u`*n*, where *n* is the total number of input arguments

For example, if your C function prototype is

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

the `OutputFcnSpec` string should define the token `u1` whose data type is `double` as follows:

```
'double y1 = doubleIt(double u1)'
```

Using this function specification, Simulink maps the input argument `inVal` to the token `u1`, and its `float` C data type to the `double` data type supported by Simulink.

Also, the input argument type and its declaration in a C function prototype determine the syntax of the Legacy Code Tool function specification. The following table presents the allowable function specification syntax for an integer input argument. Use the table to identify the appropriate syntax for input arguments in the Legacy Code Tool function specification, given your input argument type and its declaration in your C function prototype.

Argument Type	C Function Prototype	Legacy Code Tool Function Specification
No arguments	`function(void)`	`function(void)`
Scalar pass by value	`function(int in1)`	`function(int16 u1)`
Scalar pass by pointer	`function(int *in1)`	`function(int16 u1[1])`
Fixed vector	`function(int in1[10])` or `function(int *in1)`	`function(int16 u1[10])`
Variable vector	`function(int in1[])` or `function(int *in1)`	`function(int16 u1[])`

Argument Type	C Function Prototype	Legacy Code Tool Function Specification
Fixed matrix	`function(int in1[15])` or `function(int in1[])` or `function(int *in1)`	`function(int16 u1[3][5])`
Variable matrix	`function(int in1[])` or `function(int *in1)`	`function(int16 u1[][])`

Note At the MATLAB prompt, enter `legacy_code('help')` for more information about creating function specifications in Legacy Code Tool.

Output Arguments

You must define output arguments in the function specification using tokens that Simulink can interpret. This enables Legacy Code Tool to map the output arguments of your C function to the outputs of the S-function that the tool produces. Specify each output argument in the function specification by designating a

- Data type that Simulink supports (see "Data Types Supported by Simulink" in the Simulink documentation)
- Token of the form `y1`, `y2`, `...`, `y`*n*, where *n* is the total number of output arguments

For example, if your C function prototype is

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

the `OutputFcnSpec` string should define the token `y1` whose data type is `double` as follows:

```
'double y1 = doubleIt(double u1)'
```

Using this function specification, Simulink maps the output argument to the token `y1`, and its `float` C data type to the `double` data type supported by Simulink.

Also, the output argument type and its declaration in a C function prototype determine the syntax of the Legacy Code Tool function specification. The following table presents the allowable function specification syntax for an integer output argument. Use the table to identify the appropriate syntax for output arguments in the Legacy Code Tool function specification, given your output argument type and its declaration in your C function prototype.

Argument Type	C Function Prototype	Legacy Code Tool Function Specification
No arguments	`void function(...)`	`void function(...)`
Scalar value	`int y1 = function(...)`	`int16 y1 = function(...)`
Scalar pointer	`function(int *y1)`	`function(int16 y1[1])`
Fixed vector	`function(int y1[10])` or `function(int *y1)`	`function(int16 y1[10])`
Fixed matrix	`function(int y1[15])` or `function(int y1[])` or `function(int *y1)`	`function(int16 y1[3][5])`

Note At the MATLAB prompt, enter `legacy_code('help')` for more information about creating function specifications in Legacy Code Tool.

Parameter Arguments

You must define parameter arguments in the function specification using tokens that Simulink can interpret. This enables Legacy Code Tool to map certain arguments from your C function to the parameters of the S-function that the tool produces. Specify each parameter argument in the function specification by designating a

- Data type that Simulink supports (see “Data Types Supported by Simulink” in the Simulink documentation)
- Token of the form `p1`, `p2`, . . ., `p`*n*, where *n* is the total number of parameter arguments

For example, if you intend to parameterize the exponent argument in the following C function prototype:

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

the OutputFcnSpec string should define the token p1 whose data type is double as follows:

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

Using this function specification, Simulink maps the parameter argument exponent to the token p1, and its int C data type to the int16 data type supported by Simulink.

Also, the parameter argument type and its declaration in a C function prototype determine the syntax of the Legacy Code Tool function specification. The following table presents the allowable function specification syntax for an integer parameter argument. Use the table to identify the appropriate syntax for parameter arguments in the Legacy Code Tool function specification, given your parameter argument type and its declaration in your C function prototype.

Argument Type	C Function Prototype	Legacy Code Tool Function Specification
Scalar pass by value	`function(int p1)`	`function(int16 p1)`
Scalar pass by pointer	`function(int *p1)`	`function(int16 p1[1])`
Fixed vector	`function(int p1[10])` or `function(int *p1)`	`function(int16 p1[10])`
Variable vector	`function(int p1[])` or `function(int *p1)`	`function(int16 p1[])`
Fixed matrix	`function(int p1[15])` or `function(int p1[])` or `function(int *p1)`	`function(int16 p1[3][5])`
Variable matrix	`function(int p1[])` or `function(int *p1)`	`function(int16 p1[][])`

Note At the MATLAB prompt, enter `legacy_code('help')` for more information about creating function specifications in Legacy Code Tool.

Legacy Code Tool Demos

Simulink provides a set of demos that illustrate usage of the Legacy Code Tool. At the MATLAB prompt, enter

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

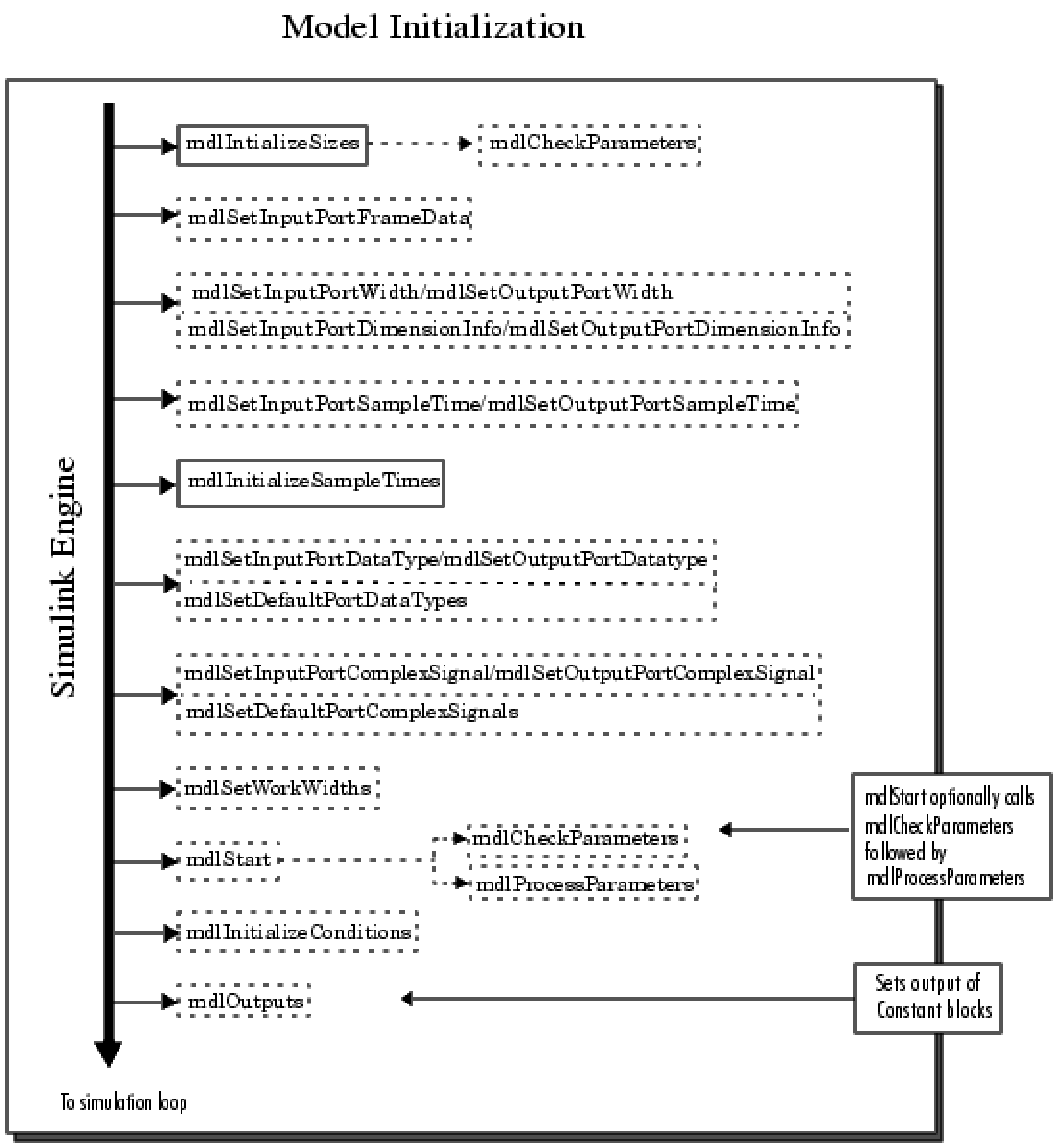
to view the Legacy Code Tool demos listed under the heading “Calling Legacy C and C++ Functions.”

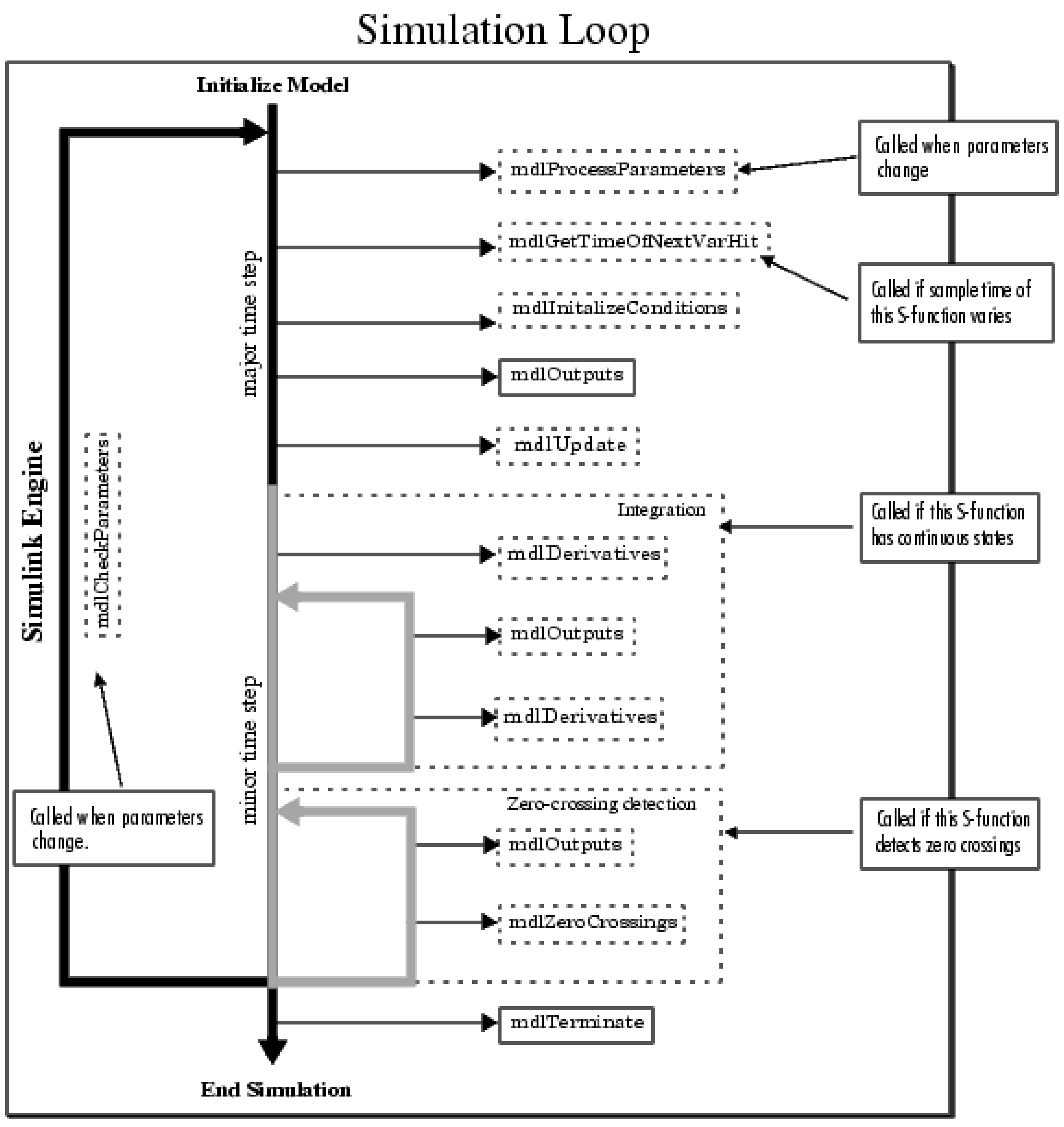
How Simulink Interacts with C S-Functions

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.


Model Initialization
Simulink Engine
mdlIntializeSizes
mdlCheckParameters
mdlSetInputPortFrameData
mdlSetInputPortWidth/mdlSetOutputPortWidth
mdlSetInputPortDimensionInfo/mdlSetOutputPortDimensionInfo
mdlSetInputPortSampleTime/mdlSetOutputPortSampleTime
mdlInitializeSampleTimes
mdlSetInputPortDataType/mdlSetOutputPortDatatype
mdlSetDefaultPortDataTypes
mdlSetInputPortComplexSignal/mdlSetOutputPortComplexSignal
mdlSetDefaultPortComplexSignals
mdlSetWorkWidths
mdlStart
mdlCheckParameters
mdlProcessParameters
mdlStart optionally calls mdlCheckParameters followed by mdlProcessParameters
mdlInitializeConditions
mdlOutputs
Sets output of Constant blocks
To simulation loop


Simulation Loop
Initialize Model
Simulink Engine
mdlCheckParameters
Called when parameters change.
major time step
mdlProcessParameters
Called when parameters change
mdlGetTimeOfNextVarHit
Called if sample time of this S-function varies
mdlInitalizeConditions
mdlOutputs
mdlUpdate
minor time step
Integration
Called if this S-function has continuous states
mdlDerivatives
mdlOutputs
mdlDerivatives
Zero-crossing detection
Called if this S-function detects zero crossings
mdlOutputs
mdlZeroCrossings
mdlTerminate
End Simulation

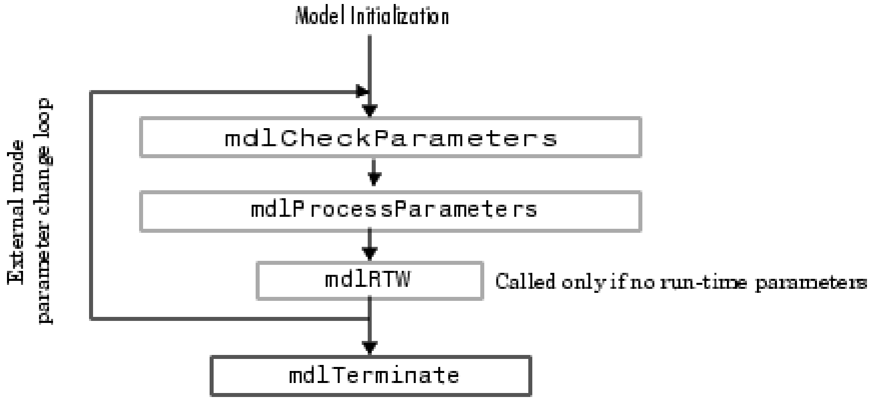
Calling Structure for Real-Time Workshop

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

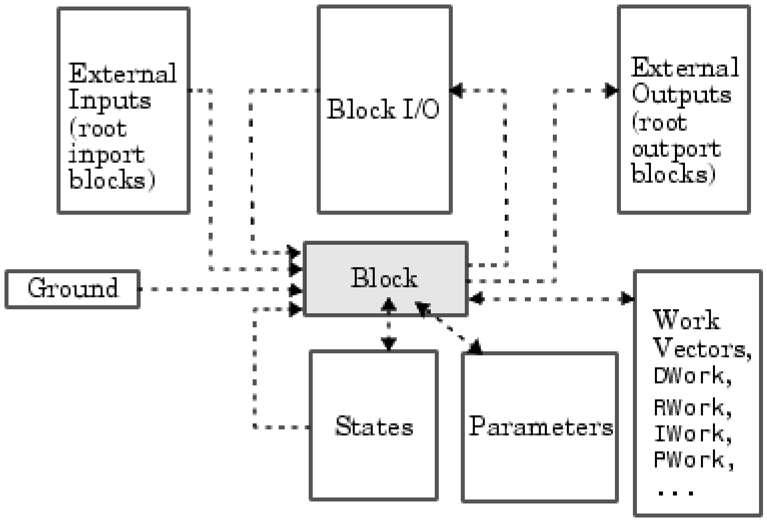
- External inputs via the root inport blocks
- Ground if the input signal is unconnected or grounded

Block outputs can also go to the external outputs via the root outport 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.


External Inputs (root inport blocks)
Block I/O
External Outputs (root outport blocks)
Ground
Block
Work Vectors, DWork, RWork, IWork, PWork, ...
States
Parameters

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

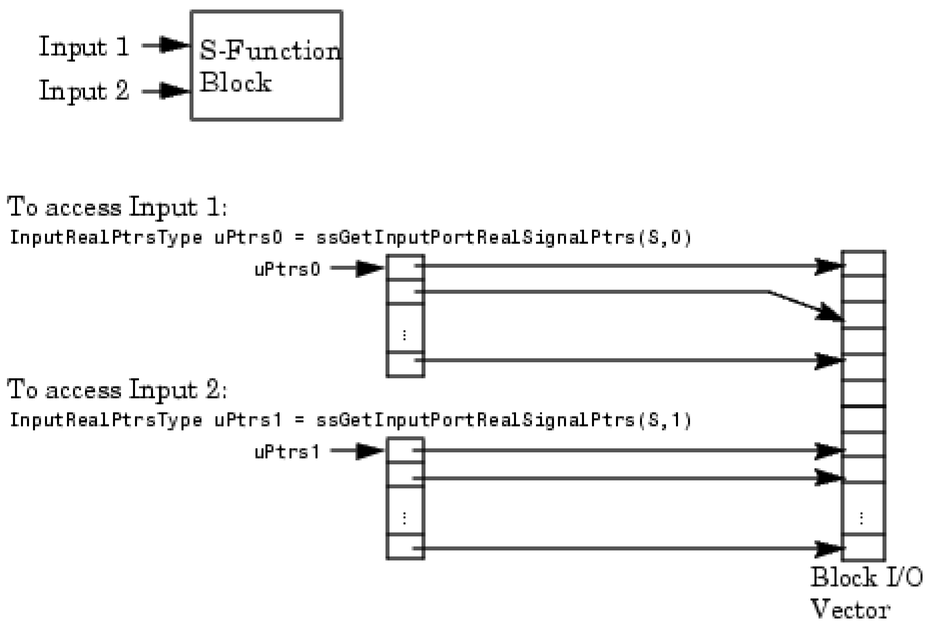
During the simulation loop, accessing the input signals is performed using

```
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.


Input 1
Input 2
S-Function Block
To access Input 1:
InputRealPtrsType uPtrs0 = ssGetInputPortRealSignalPtrs(S,0)
uPtrs0
To access Input 2:
InputRealPtrsType uPtrs1 = ssGetInputPortRealSignalPtrs(S,1)
uPtrs1
Block I/O Vector

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

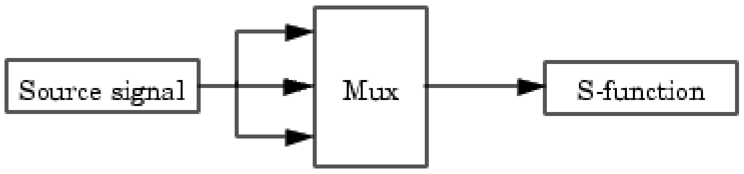
```
real_T *u = *uPtrs; /* Incorrect */
```

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”.

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, int_T tid)
  {
  }
  ```

  Otherwise, delete the function.

- Replace all obsolete SimStruct macros. See "Obsolete Macros" on page 3-71 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)`
`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`*`)`
`ssGetNumInputs`	`ssGetNumInputPorts(S)` and `ssGetInputPortWidth(S,`*`port`*`)`
`ssSetNumInputs`	`ssSetNumInputPorts(S,`*`nInputPorts`*`)` and `ssSetInputPortWidth(S,`*`port`*`,`*`val`*`)`

Obsolete Macro	Replace with
`ssGetNumOutputs`	`ssGetNumOutputPorts(S)` and `ssGetOutputPortWidth(S,`*`port`*`)`
`ssSetNumOutputs`	`ssSetNumOutputPorts(S,`*`nOutputPorts`*`)` and `ssSetOutputPortWidth(S,`*`port`*`,`*`val`*`)`

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

The following sections explain how to use the Ada programming language to create S-functions.

Introduction (p. 5-2)	Overview of creating Ada S-functions.
Ada S-Function Source File Format (p. 5-3)	Source code structure of an Ada S-function.
Writing Callback Methods in Ada (p. 5-7)	How to use Ada to implement S-function callback methods.
Building an Ada S-Function (p. 5-10)	Compiling and linking an Ada S-function.
Example of an Ada S-Function (p. 5-11)	An Ada version of the times_two S-function example.

Introduction

Simulink allows you to use the Ada programming language to create S-functions. 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.

Ada S-Function Source File Format

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.

Ada S-Function Specification

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.

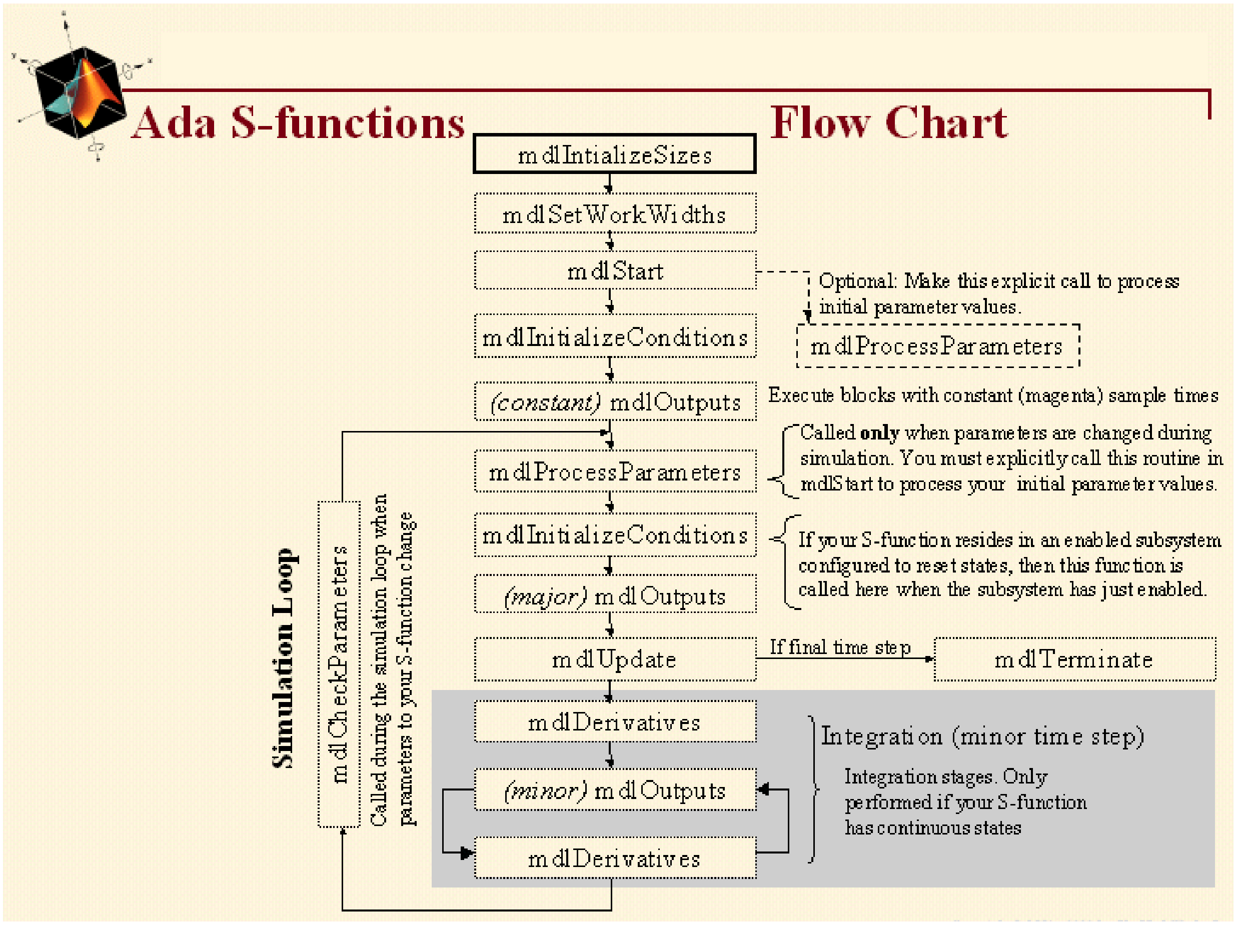
```
with Simulink; use Simulink;
with Ada.Exceptions; use Ada.Exceptions;

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 occured 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 occured 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

Simulink interacts with an Ada S-function by invoking callback methods that the S-function implements. This section specifies the callback methods that an Ada S-function can implement and provides guidelines for implementing them.

Callbacks Invoked by Simulink

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.


Ada S-functions
Flow Chart
mdlIntializeSizes
mdlSetWorkWidths
mdlStart
Optional: Make this explicit call to process initial parameter values.
mdlProcessParameters
mdlInitializeConditions
(constant) mdlOutputs
Execute blocks with constant (magenta) sample times
Simulation Loop
mdlCheckParameters
Called during the simulation loop when parameters to your S-function change
mdlProcessParameters
Called **only** when parameters are changed during simulation. You must explicitly call this routine in mdlStart to process your initial parameter values.
mdlInitializeConditions
If your S-function resides in an enabled subsystem configured to reset states, then this function is called here when the subsystem has just enabled.
(major) mdlOutputs
mdlUpdate
If final time step
mdlTerminate
mdlDerivatives
Integration (minor time step)
Integration stages. Only performed if your S-function has continuous states
(minor) mdlOutputs
mdlDerivatives

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 1-23 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 5-10) 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.

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

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

Ada Compiler Requirements

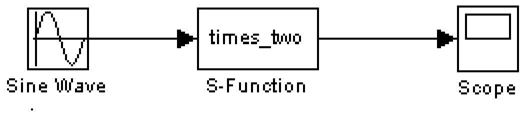
To build a MEX-file from Ada source code, using the `mex` tool, you must have previously installed a copy of Version 3.12 (or higher) of the GNAT Ada95 compiler on your system. You can obtain the latest Solaris, Windows, and GNU-Linux versions of the compiler at the GNAT ftp site (`ftp://cs.nyu.edu/pub/gnat`). 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.

Example of an Ada S-Function

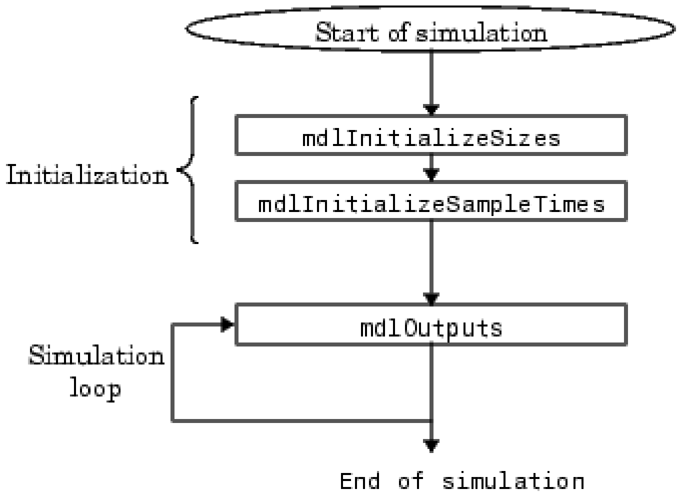
This section presents an example of a basic Ada S-function that you can use as a model when creating your own Ada S-functions. The example is the `times_two` S-function example that comes with Simulink (see *`matlabroot`*`/simulink/ada/examples/times_two/times_two.ads` and *`matlabroot`*`/simulink/ada/examples/times_two/times_two.adb`).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

The following sections explain each of these parts.

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 attrubouts 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 occured 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 occured in mdlOutputs. " &
                          "Name: " & Exception_Name(E) & ", " &
                          "Message: " & Exception_Message(E) & " and " &
                          "Information: " & Exception_Information(E));
      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

The following sections explain how to use the Fortran programming language to create S-functions.

Introduction (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. 6-18)	How to wrap an S-function around existing Fortran code.

Introduction

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.

Level 1 Versus Level 2 S-Functions

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

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
      SUBROUTINE SIZES(SIZE)
C     .. Array arguments ..
      INTEGER*4        SIZE(*)
C     .. Parameters ..
      INTEGER*4       NSIZES
      PARAMETER       (NSIZES=6)

      SIZE(1) = 0
      SIZE(2) = 0
      SIZE(3) = 1
      SIZE(4) = 1
      SIZE(5) = 0
      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

The capabilities of Fortran MEX S-functions can be fully inlined using a Target Language Compiler block target file. The block target file is a self-contained definition of how to inline the block's functionality directly into the various portions of the generated code for a Simulink model. 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 the example in

"Inlining S-Functions" in the Real-Time Workshop Target Language Compiler documentation.

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 6-18).

Template File

The file 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 only work with one of these compilers at a time. If you install or change compilers, you must run `mex -setup` in 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`.

The example C source code file `yprime.c` is included in the *`matlabroot`*`/extern/examples/mex` directory. If using a C compiler on Windows, test the `mex` setup using the following commands.

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

The Fortran counterparts to this example, `yprimef.F` and `yprimefg.F` are also found in *`matlabroot`*`/extern/examples/mex`. To test the installation of a Fortran compiler, select a Fortran compiler using the `mex -setup` command then type the following at the MATLAB prompt.

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

For more information, see Building MEX-Files in the MATLAB External Interfaces Reference Guide.

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` 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 subroutine Atmos is in file *matlabroot*/simulink/src/sfun_atmos_sub.F. This subroutine calculates the standard atmosphere up to 86 kilometers. The subroutine has four arguments, as shown by the file's subroutine line.

```
SUBROUTINE Atmos(alt, sigma, delta, theta)
```

The gateway C MEX S-function is *matlabroot*/simulink/src/sfun_atmos.c, The Fortran subroutine is declared at the beginning of the C gateway file.

```
/*
 * 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 Fortran subroutine can then be called in the mdlOutputs callback using pass-by-reference for the arguments.

```
   /* call the Fortran routine using pass-by-reference */
    atmos_(&falt, &fsigma, &fdelta, &ftheta);
```

The gateway is built on UNIX using the command

```
mex -L/usr/local/lib -lf2c sfun_atmos.c sfun_atmos_sub.o
```

On a 32-bit Windows machine using Microsoft Visual C/C++ and Compaq Visual Fortran 6.6, there are separate commands to compile the Fortran file and then link it to the C gateway file. 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 executed 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
```

Note 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`.

On some UNIX systems where the C and Fortran compilers were installed separately (or aren't aware of each other), you might need to reference the library `libf2c.a`. To do this, use the `-lf2c` flag.

UNIX only: if the `libf2c.a` library isn't 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
```

This sample is prebuilt and is on the MATLAB search path already, so you can see it working by opening the sample model `sfcndemo_atmos.mdl`. Enter

```
sfcndemo_atmos
```

at the command prompt, or to get all the S-function demos for Simulink, type `sfcndemos` at the MATLAB prompt. Note, the S-function has three dialog parameters as specified by the C gateway function. These parameters include a reference temperature, pressure, an density. Default values are already entered into the example MDL-file.

Porting Legacy Code

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

The following sections explain how to use S-function callback methods to implement various 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. 7-12)	How to create input and output ports on a block.
Custom Data Types (p. 7-18)	How to create custom data types for the values of a block's signals and parameters.
Sample Times (p. 7-20)	How to specify the rate or rates at which your block operates.
Work Vectors (p. 7-36)	How to create and use work vectors.
Function-Call Subsystems (p. 7-44)	How to create a function-call subsystem.
Processing Frame-Based Signals (p. 7-49)	How to create an S-function that process frame-based signals.
Handling Errors (p. 7-52)	How to handle errors in an S-function.
S-Function Examples (p. 7-56)	Examples of S-functions.

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 `mxArray` containing the parameter. You can use `ssGetDTypeIdFromMxArray` 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 */
#if defined(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*/

#if defined(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-functions' `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

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 weight of the object. In this case, the weight 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.

- 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/sfcndemo_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.

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. The S-function *matlabroot*`/simulink/src/sfun_runtime1.c` shows how to create run-time parameters all at once.

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);
}
#endif /* 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;
    }
```

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 can use `ssUpdateRunTimeParamData` to update the run-time parameter, as is 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`.

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

Simulink allows S-functions to create and use any number of block I/O ports. This section shows how to create and initialize I/O ports and how to change the characteristics of an S-function block's ports, such as dimensionality and data type, based on its connections to other blocks.

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 7-13)

  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 7-13).

- Whether the input port allows scalar expansion of inputs (see "Scalar Expansion of Inputs" on page 7-15)

- Whether the input port has direct feedthrough, using `ssSetInputPortDirectFeedThrough`

  A port has direct feedthrough if the input is used in either the `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 `ssSetInputComplexSignal` 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 data type as `inherited`. In this case, you must provide implementations of the `mdlSetInputPortComplexSignal` and `mdlSetDefaultPortComplexSignal` methods to enable the numeric type to be set correctly during signal propagation.

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 Simulink crashes.

Initializing Input Port Dimensions

The following options exist for setting the input port dimensions:

- If the input signal is one-dimensional and the input port width is `w`, use

  ```
  ssSetInputPortVectorDimension(S, inputPortIdx, w)
  ```

- If the input signal is a matrix of dimension `m-by-n`, use

  ```
  ssSetInputPortMatrixDimensions(S, inputPortIdx, m, n)
  ```

- Otherwise 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.

  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.

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`
  - `ssSetOutputPortVectorDimensions`
  - `ssSetOutputWidth`

  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 `ssSetDefaultPortDimensionInfo` methods to ensure that output port dimensions are set to the correct values in code generation.

- 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 input port, if the port outputs complex-valued signals

  Use `ssSetOutputComplexSignal` 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 data type as `inherited`. In this case, you must provide implementations of the `mdlSetOutputPortComplexSignal` and `mdlSetDefaultPortComplexSignal` methods to enable the numeric type to be set correctly during signal propagation.

Scalar Expansion of Inputs

Scalar expansion of inputs refers conceptually to the process of expanding scalar input signals to have the same dimensions as the ports to which they are connected. 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 for its input ports by setting the `SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION` option, using `ssSetOptions`.

The best way to understand the scalar expansion rules is to consider a Sum block with two input ports, where the first input signal is scalar, the second input signal is a 1-D vector with `w > 1` elements, and the output signal is a 1-D vector with `w` elements. In this case, the scalar input is expanded to a 1-D vector with `w` elements in the output method, and each element of the expanded signal is set to the value of the scalar input.

```
Outputs
 <snip>
 u1inc = (u1width > 1);
 u2inc = (u2width > 1);
 for (i=0;i<w;i++) {
  y[i] = *u1 + *u2;
  u1 += u1inc;
  u2 += u2inc;
 }
```

If the block has more than two inputs, each input signal must be scalar, or the wide signals must have the same number of elements. In addition, 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.

The way scalar expansion actually works depends on whether the S-function manages the dimensions of its input and output ports using `mdlSetInputPortWidth` and `mdlSetOutputPortWidth` or `mdlSetInputPortDimensionInfo`, `mdlSetOutputPortDimensionInfo`, and `mdlSetDefaultPortDimensionInfo`.

If the S-function does not specify/control the dimensions of its input and output ports using the preceding methods, Simulink uses a default method to set the input and output ports.

In the `mdlInitializeSizes` method, the S-function can enable scalar expansion for its input ports by setting the `SS_OPTION_ALLOW_INPUT_SCALAR_EXPANSION` option, using `ssSetOptions`. The Simulink default method uses the preceding option to allow or disallow scalar expansion for a block's input ports. If the preceding option is not set by an S-function, 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.

If the S-function specifies/controls the dimensions of its input and output ports, Simulink ignores the `SCALAR_EXPANSION` option.

See *`matlabroot`*`/simulink/src/sfun_multiport.c` for an example.

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('block','MaskSelfModifiable','on')
```

at the MATLAB prompt before saving the library. 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);
```

Note If a signal with an aliased data type is passed to the S-function and the S-function creates a data type ID for it using `ssRegisterDataType`, the S-function should not set the size or zero representation for that data type. See Simulink.AliasType for a discussion on aliased data types.

Sample Times

This section explains 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 2Hz and outputs at 4Hz.

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` is used to specify 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 7-44 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 7-33 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 7-26)
- Constant sample time, i.e., the port's input or output never changes (see "Specifying Constant Sample Time for a Port" on page 7-26)

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 7-28).

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.

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 7-33 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_BASED_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 (ssISampleHit(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 inheritence rule as follows:

```
ssSetModelReferenceSampleTimeInheritanceRule
(S, DISALLOW_SAMPLE_TIME_INHERITANCE);
```

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
`ssSetNumContStates`	Width of the continuous-state vector
`ssSetNumDiscStates`	Width of the discrete-state vector
`ssSetNumDWork`	Width of the data type work vector
`ssSetNumRWork`	Width of the real-work vector
`ssSetNumIWork`	Width of the integer-work vector
`ssSetNumPWork`	Width of the pointer-work vector
`ssSetNumModes`	Width of the mode-work vector
`ssSetNumNonsampledZCs`	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 7-37, 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. */
#if defined(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 `mxCalloc` 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);
```

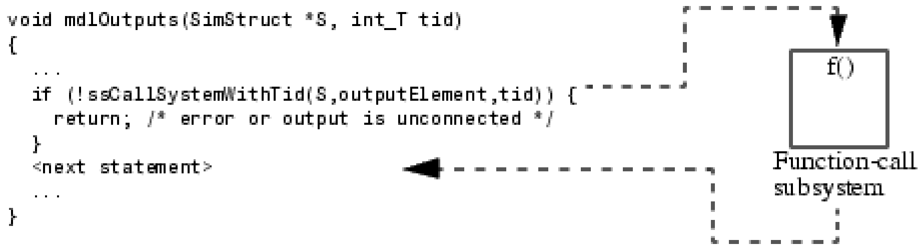
Function-Call Subsystems

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.



```
void mdlOutputs(SimStruct *S, int_T tid)
{
  ...
  if (!ssCallSystemWithTid(S,outputElement,tid)) {
    return; /* error or output is unconnected */
  }
  <next statement>
  ...
}
```

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);
  ```

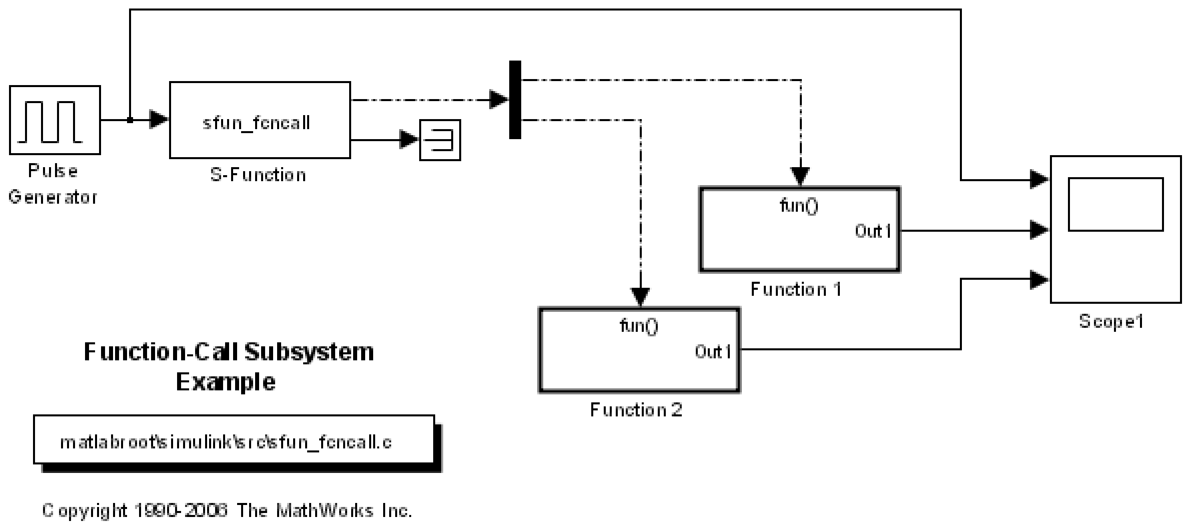
  in `mdlInitializeSampleTimes` specifies that the S-function can enable and disable the function-call subsystem. In this case, the S-function must invoke `ssEnableSystemWithTid` before executing the subsystem using `ssCallSystemWithTid`.

- Execute the subsystem in the appropriate `mdlOutputs` or `mdlUpdate` S-function routine. For example:

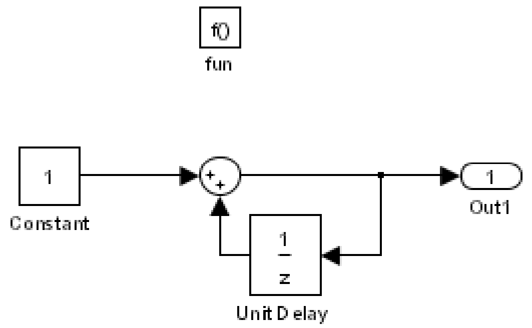
```
static void mdlOutputs(...)
{
    if (((int)*uPtrs[0]) % 2 == 1) {
      if (!ssCallSystemWithTid(S,0,tid)) {
        /* Error occurred, which will be reported by */
    /*Simulink*/
        return;
      }
    } else {
      if (!ssCallSystemWithTid(S,1,tid)) {
        /* Error occurred, which will 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.

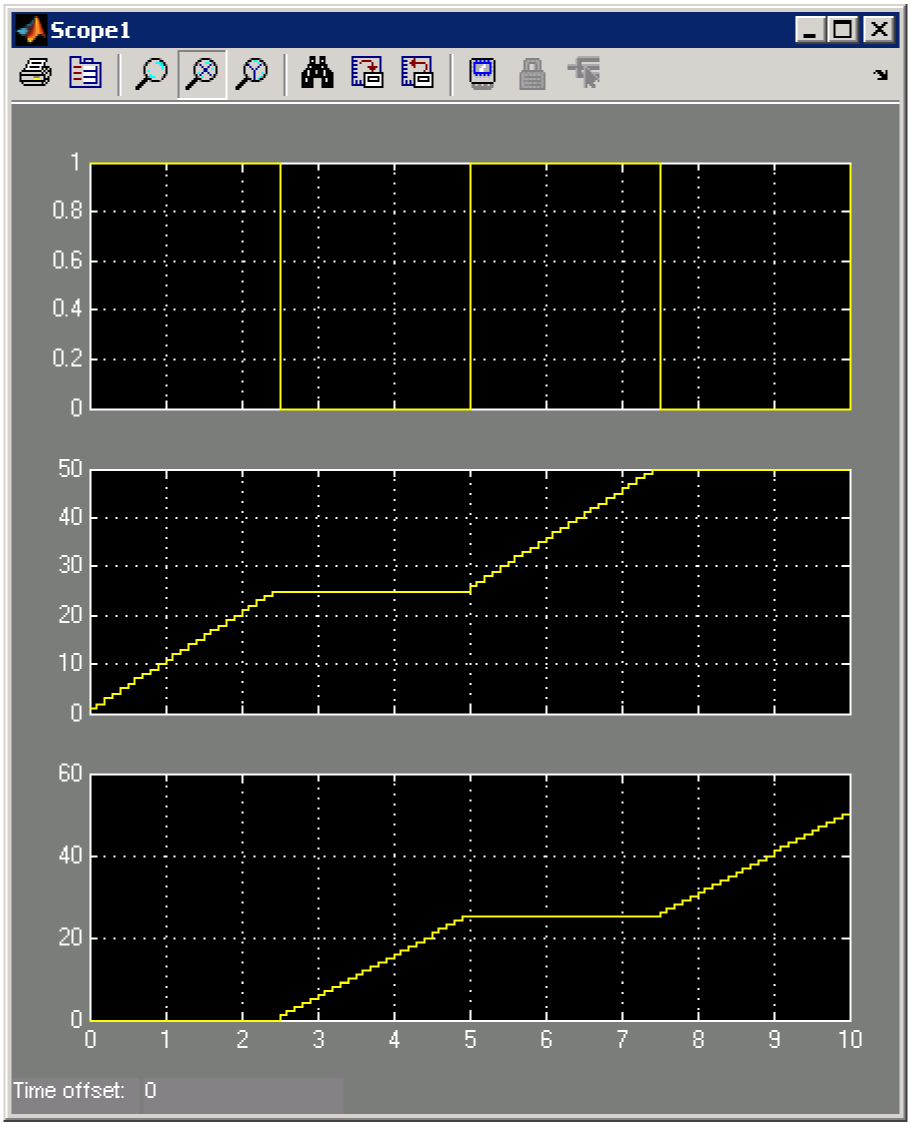
See *`matlabroot`*`/simulink/src/sfun_fcncall.c` for an example that executes a function-call subsystem on the first and second elements of the S-function's first output. The following Simulink model implements this S-function.


Pulse Generator
sfun_fcncall
S-Function
fun()
Out1
Function 1
fun()
Out1
Function 2
Scope1
Function-Call Subsystem Example
matlabroot\simulink\src\sfun_fcncall.c
Copyright 1990-2006 The MathWorks Inc.

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.

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 sfcndemo_frame.mdl.

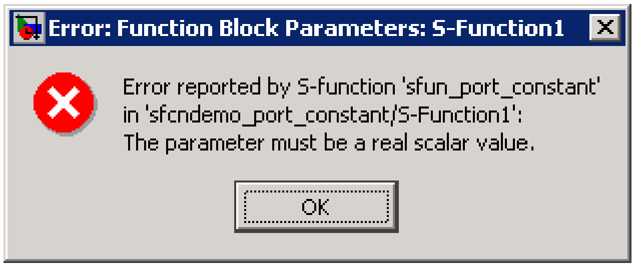
Handling Errors

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 Diagnsostics 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.


Error: Function Block Parameters: S-Function1

Error reported by S-function 'sfun_port_constant'
in 'sfcndemo_port_constant/S-Function1':
The parameter must be a real scalar value.

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 mx* 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 3-59). 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

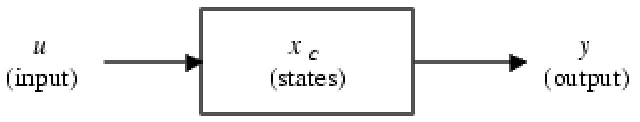
Most S-Function blocks require the handling of states, continuous or discrete. The following sections discuss common types of systems that you can model in Simulink with S-functions:

- Continuous state
- Discrete state
- Hybrid
- Variable step sample time
- Zero crossings
- Time-varying continuous transfer function

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.

Example of a Continuous State S-Function

The *`matlabroot`*`/simulink/src/csfunc.c` example shows how to model a continuous system with states in a C MEX S-function. This S-function is used in the Simulink model *`matlabroot`*`/toolbox/simulink/simdemos/simfeatures/sfcndemo_csfunc.mdl`. In continuous state integration, there is a set of states that the Simulink solvers integrate using the following equations.



$$y = f_0(t, x_c, u) \qquad \text{(output)}$$

$$\dot{x}_c = f_d(t, x_c, u) \qquad \text{(derivative)}$$

S-functions that contain continuous states implement a state-space equation. The output portion is placed in `mdlOutputs` and the derivative portion in `mdlDerivatives`. To visualize how the integration works, refer to the flowchart in "How Simulink Interacts with C S-Functions" on page 3-59. The output equation above 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.

Note that `csfunc.c` 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 isn't 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 beginning of each S-function must include `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. Following these statements, the S-function can include or define any other necessary headers, data, etc. In the `csfunc.c` example shown below, in addition to the required statements, `U` is defined as elements in the pointer to the first input port's signal and static variables containing the state-space matrices are initialized.

```
/*  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/sfuntmpl_doc.c.
 *
 *  Copyright 1990-2004 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` next sets the number of continuous and discrete states using `ssSetNumContStates` and `ssSetNumDiscStates`, respectively. In this example, there are 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. Note that the input port is also set to have direct feedthrough by passing a value of `1` to `ssSetInputPortDirectFeedThrough`.
- `ssSetNumSampleTimes` then specifies that there is one sample time, which will be configured later in the `mdlInitializeSampleTimes` function.
- A value of `0` is passed to `ssSetNumRWork`, `ssSetNumIWork`, etc., to indicate that none of the work vectors are used by this S-function. Note that these lines could be omitted since zero is the default value for all of these macros. For clarity, it is preferable to explicitly set the number of work vectors.
- Lastly, any applicable options are set using `ssSetOptions`. 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 `CONTINOUS_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:
 *    Specifiy 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 or Simulink will not call this function. In the example below, `ssGetContStates` is used to obtain a pointer to the continuous state vector. The length of this vector is two, as determined by the value passed to `ssSetNumContStates` in `mdlInitializeSizes`. 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 data in these arrays is used 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. Since this is an optional method, it must be proceeded by a `#define` statement. The beginning of the function obtains pointers to the S-function's continuous states, state derivatives, and first input port. The data in these arrays is then used 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);
}
```

All S-functions must 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 */
}
```

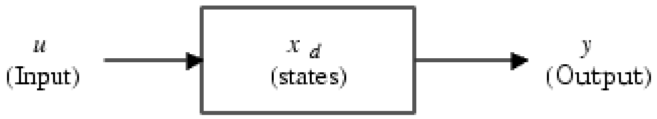
The trailer of this S-function must include the files necessary for simulation or code generation, as follows.

```
#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 both use the macro `UNUSED_ARG`. This macro is defined in *`matlabroot`*`/simulink/include/simstruc_types.h` and is used to indicate that one of the input arguments to these callbacks is required even though it is not used in the callbacks. The macro `UNUSED_ARG` accepts only a single input argument so must be called once for each callback input argument that is not used in the callback.

Example of a Discrete State S-Function

The *`matlabroot`*`/simulink/src/dsfunc.c` example shows how to model a discrete system in a C MEX S-function. This S-function is used in the Simulink model *`matlabroot`*`/toolbox/simulink/simdemos/simfeatures/sfcndemo_dsfunc.mdl`. Discrete systems can be modeled by the following set of equations.



$$y = f_0(t, x_d, u) \qquad \text{(Output)}$$

$$x_{d+1} = f_u(t, x_d, u) \qquad \text{(Update)}$$

`dsfunc.c` implements a discrete state-space equation. The output portion is placed in `mdlOutputs` and the update portion in `mdlUpdate`. To visualize how the simulation works, refer to the flowchart in "How Simulink Interacts with C S-Functions" on page 3-59. 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, the integration phase is skipped and time is moved forward to the next discrete sample hit.

matlabroot/simulink/src/dsfunc.c

The beginning of each S-function must include `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. Following these statements, the S-function can include or define any other necessary headers, data, etc. In the `dsfunc.c` example shown below, in addition to the required statements, `U` is defined as elements in the pointer to the first input port's signal and static variables containing the state-space matrices are initialized.

```
/*  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 1990-2004 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 `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. In this example, there are no 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. Note that the input port is also set to have direct feedthrough by passing a value of `1` to `ssSetInputPortDirectFeedThrough`.
- `ssSetNumSampleTimes` then specifies that there is one sample time, which will be configured later in the `mdlInitializeSampleTimes` function.
- A value of `0` is passed to `ssSetNumRWork`, `ssSetNumIWork`, etc., to indicate that none of the work vectors are used by this S-function. Note that these lines could be omitted since zero is the default value for all of these macros. For clarity, it is preferable to explicitly set the number of work vectors.
- Lastly, any applicable options are set using `ssSetOptions`. 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:
```

```
 *    Specifiy 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 or Simulink will not call this function. In the example below, `ssGetRealDiscStates` is used to obtain a pointer to the state vector. The length of this vector is two, as determined by the value passed to `ssSetNumDiscStates` in `mdlInitializeSizes`. The `for` loop then initializes each 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 data in these arrays is then used 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);
}
```

The `mdlUpdate` function is called once every major integration time step to update the discrete states' values. Since this is an optional method, it must be proceeded by a `#define` statement. The beginning of the function obtains pointers to the S-function's discrete states and first input port. The data in these arrays is then used 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];
}
```

All S-functions must 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 trailer of this S-function must include 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
```

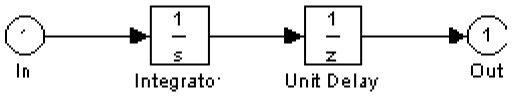
Note The `mdlOutputs` and `mdlTerminate` functions both use the macro `UNUSED_ARG`. This macro is defined in*`matlabroot`*`/simulink/include/simstruc_types.h` and is used to indicate that one of the input arguments to these callbacks is required even though it is not used in the callbacks. The macro `UNUSED_ARG` accepts only a single input argument so must be called once for each callback input argument that is not used in the callback.

Example of a Hybrid System S-Function

The S-function *`matlabroot`*`/simulink/src/mixedm.c` is an example of a hybrid (a combination of continuous and discrete states) system. `mixedm.c` combines elements of `csfunc.c` and `dsfunc.c`. This S-function is used in the Simulink model *`matlabroot`*`/toolbox/simulink/simdemos/simfeatures/sfcndemo_mixedm.mdl`.

If you have a hybrid system, place your continuous equations in mdlDerivatives and your discrete equations in mdlUpdate. In addition, you need to check for sample hits to determine at what point your 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.

Because there are no tasks to complete at termination, mdlTerminate is an empty function. mdlDerivatives calculates the derivatives of the continuous states of the state vector, x, and mdlUpdate contains the equations used to update the discrete state vector, xD.

matlabroot/simulink/src/mixedm.c

The beginning of each S-function must include #define statements for the S-function's name and level, along with a #include statement for the simstruc.h header. Following these statements, the S-function can include or define any other necessary headers, data, etc. In the mixedm.c example shown below, in addition to the required statements, U is defined as elements in the 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/sfuntmpl_doc.c
 *
 *  Copyright 1990-2004 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. In this example, there is one continuous state and one discrete state.
- A value of `1` is passed to `ssSetNumRWork` to specify that the length of the floating-point work vector is one. Note that none of the other work vectors are initialized in this function so their widths are set to their default values of zero.
- 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. Note that the input port is also set to have direct feedthrough by passing a value of `1` to `ssSetInputPortDirectFeedThrough`.
- This S-function assigns sample times using a hybrid block-based and port-based method. The macro `ssSetNumSampleTimes` specifies that there are two block-based sample times, which will be configured later in the `mdlInitializeSampleTimes` function. The macros `ssSetInputPortSampleTime` and `ssSetInputPortOffsetTime` initializes the input port to have a continuous sample time with an offset of zero. Similarly, `ssSetOutputPortSampleTime` and `ssSetOutputPortOffsetTime` initializes the output port sample time to `1` with an offset of zero.
- Lastly, any applicable options are set using `ssSetOptions`. In this case, two options are set. `SS_OPTION_EXCEPTION_FREE_CODE` stipulates that

the code is exception free and `SS_OPTION_PORT_SAMPLE_TIMES_ASSIGNED` indicates that there is 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. Note, 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 or Simulink will not call this function. In the example below, `ssGetContStates` is used to obtain a pointer to the continuous state vector and `ssGetRealDiscStates` is similarly used for the discrete state vector. The state's initialize conditions are then set 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 macros also returns `true`, the value stored in the floating-point work vector is set equal to the current value of the continuous state, via pointers obtained using `ssGetRWork` and `ssGetContStates`, respectively. The floating-point work vector is later used in `mdlUpdate` as the input to the zero-order hold. Updating the work vector in `mdlOutputs` ensures that the correct values are available during the call to `mdlUpdate`. Finally, if the S-function is running at its discrete rate, i.e., the call to `ssIsSampleHit` returns `true`, the output is set to be 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 */
```

The `mdlUpdate` function is called once every major integration time step to update the discrete states' values. Since this is an optional method, it must be proceeded by a `#define` statement. The heart of the function is wrapped in a call to `ssIsSampleHit` to ensure the code is called only when the S-function is operating at its discrete rate. The function then obtains pointers to the S-function's discrete states and floating-point work vector. The value of the discrete state is updated 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. Since this is an optional method, it must be proceeded by a `#define` statement. The beginning of the function obtains pointers to the S-function's state derivatives and first input port. The value of the state derivative is then set equal to the value of the first input.

```
#define MDL_DERIVATIVES
/* Function: mdlDerivatives =================================================
 * Abstract:
 *      xdot = U
 */
static void mdlDerivatives(SimStruct *S)
{
    real_T            *dx   = ssGetdX(S);
    InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,0);

    /* xdot=U */
    dx[0]=U(0);

} /* end mdlDerivatives */
```

All S-functions must 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 trailer of this S-function must include 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 both use the macro `UNUSED_ARG`. This macro is defined in*`matlabroot`*`/simulink/include/simstruc_types.h` and is used to indicate that one of the input arguments to these callbacks is required even though it is not used in these callbacks. The macro `UNUSED_ARG` accepts only a single input argument so must be called once for each callback input argument that is not used in the callback.

Example of a Variable-Step S-Function

The example S-function *`matlabroot`*`/simulink/src/vsfunc.c` uses a variable-step sample time. This S-function is used in the Simulink model *`matlabroot`*`/toolbox/simulink/simdemos/simfeatures/sfcndemo_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 only be used with variable-step solvers. `vsfunc` is a discrete S-function that delays its first input by an amount of time determined by the second input.

The output of `vsfunc` is simply 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`, an S-function routine that calculates and sets the time of the next hit, that is, the time when `vsfunc` is next called. In `mdlGetTimeOfNextVarHit`, the macro `ssGetInputPortRealSignalPtrs` is used to get 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 beginning of each S-function must include `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. Following these statements, the S-function can include or define any other necessary headers, data, etc. . In the `vsfunc.c` example shown below, in addition to the required statements, U is defined as elements in the 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 1990-2004 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 `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. In this example, there are 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. The input port is assigned a width of two using ssSetInputPortWidth, while the output port is assigned a width of one using ssSetOutputPortWidth. Note that the input port is also set to have direct feedthrough by passing a value of 1 to ssSetInputPortDirectFeedThrough.
- ssSetNumSampleTimes then specifies that there is one sample time, which will be configured later in the mdlInitializeSampleTimes function.
- A value of 0 is passed to ssSetNumRWork, ssSetNumIWork, etc., to indicate that none of the work vectors are used by this S-function. Note that these lines could be omitted since zero is the default value for all of these macros. For clarity, it is preferable to explicitly set the number of work vectors.
- Next, ssGetSimMode is used to check if the S-function is being run in a simulation or with Real-Time Workshop. If the return value is SS_SIMMODE_RTWGEN, indicating use with Real-Time Workshop, and a variable-step solver is being used (a value of true is returned from ssIsVariableStepSolver) then the S-function errors out.
- Lastly, any applicable options are set using ssSetOptions. 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. In this case, `vsfunc.c` must implement the `mdlGetTimeOfNextVarHit` method to calculate the time of the next sample hit. `ssSetOffsetTime` then 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.

```
    /* 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 or Simulink will not call this function. In the example below, `ssGetRealDiscStates` is used to obtain a pointer to the discrete state vector. The value of the first state is then initialized 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` calculates the time of the next sample hit. Since this is generally an optional method for S-functions, although required for S-functions using a variable-step solver, it must be proceeded by a `#define` statement. First, this method obtains a pointer to the first input port's signal using `ssGetInputPortRealSignalPtrs`. The input signal's second element is checked to ensure it is positive. If the check passes, the macro `ssGetT` gets the simulation time and 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 output signal of this S-function. The beginning of the function obtains pointers to the first output port and discrete state. The output is then assigned the current value of the state.

```
/* 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. Since this is an optional method, it must be proceeded by a `#define` statement. The beginning of the function obtains pointers to the S-function's discrete state and first input port. The value of the first element of the first input port signal is then assigned 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);
}
```

All S-functions must 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 trailer of this S-function must include 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
```

Example of a Zero Crossing S-Function

The example S-function *`matlabroot`*`/simulink/src/sfun_zc_sat.c` demonstrates how to implement a Saturation block. This S-function is used in the Simulink model *`matlabroot`*`/toolbox/simulink/simdemos/simfeatures/-sfcndemo_sfun_zc_sat.mdl`. This S-function is designed to work with either fixed- or variable-step solvers. When this S-function inherits a continuous sample time and a variable-step solver is being used, a zero-crossings algorithm is used to locate the exact points at which the saturation occurs.

matlabroot/simulink/src/sfun_zc_sat.c

The beginning of each S-function must include `#define` statements for the S-function's name and level, along with a `#include` statement for the `simstruc.h` header. Following these statements, the S-function can include or define 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 1990-2004 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. Since this is an optional method, it must be proceeded by a `#define` statement. The `#if defined` statement then checks that this function is being compiled as a MEX-file, instead of for use with Real-Time Workshop. The body of the function performs basic checks to ensure 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` then 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 `ssGetNumSFcnParams`, 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. In this example, there are no continuous or discrete states.
- `ssSetNumOutputPorts` specifies that the S-function has a single output port. The width of this output port, set using `ssSetOutputPortWidth`, is either equal to the maximum number of elements in the upper or lower saturation limit or is dynamically sized. Similar code is then included to specify a single input port. Note that the input port is also set to have direct feedthrough by passing a value of `1` to `ssSetInputPortDirectFeedThrough`.
- `ssSetNumSampleTimes` then specifies that there is one sample time, which will be configured later in the `mdlInitializeSampleTimes` function.
- A value of `0` is passed to `ssSetNumRWork`, `ssSetNumIWork`, and `ssSetNumPWork` to indicate that these work vectors are not used by this S-function. Note that these lines could be omitted since zero is the default value for all of these macros. For clarity, it is preferable to explicitly set the number of work vectors.
- The work vectors necessary for zero-crossing detection are initialized using `ssSetNumModes` and `ssSetNumNonsampledZCs`. The length of these dynamically sized vectors will be specified later in `mdlSetWorkWidths`.
- Lastly, any applicable options are set using `ssSetOptions`. 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);

#if defined(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 size of the zero-crossing detection work vectors is set in `mdlSetWorkWidths`. Since this is an optional method, it must be proceeded by a `#define` statement. The `#if defined` statement then checks that this function is being compiled as a MEX-file. Zero-crossing detection can only be done 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 number of modes is set equal to the width of the first output port and the number of nonsampled zero crossings is set to twice this amount. Otherwise, both values are set to zero.

```
#define     MDL_SET_WORK_WIDTHS
#if defined(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` functions 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 crossings work 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. Note, if the mode changed between the previous and current time step, then a zero-crossing occurred. The `mdlZeroCrossings` function, not `mdlOutputs`, is used to indicate 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 continusous 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. Here, a pointer to the input signal is obtained using `ssGetInputPortRealSignalPtrs`. A simple test of the difference between this signal's value and the value of the upper and lower saturation limits is used as the nonsampled zero crossing mode vector values. A zero crossing is detected if any element of the nonsampled zero crossings work vector switches from negative to positive, or positive to negative. In the event of a zero crossing, the simulation 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%*(-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 */
```

All S-functions must 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 trailer of this S-function must include 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 both use the macro `UNUSED_ARG`. This macro is defined in*`matlabroot`*`/simulink/include/simstruc_types.h` and is used to indicate that one of the input arguments to these callbacks is required even though it is not used in these callbacks. The macro `UNUSED_ARG` accepts only a single input argument so must be called once for each callback input argument that is not used in the callback.

Example of a Time-Varying Continuous Transfer Function

The S-function *matlabroot*/simulink/src/stvctf.c is an example of a time-varying continuous transfer function. This S-function is used in the Simulink model *matlabroot*/toolbox/simulink/simdemos/simfeatures/sfcndemo_stvctf.mdl. It 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 beginning of each S-function must include #define statements for the S-function's name and level, along with a #include statement for the simstruc.h header. Following these statements, the S-function can include or define any other necessary headers, data, etc. This example defines parameters for the transfer function'z numerator and denominator, which are entered into the S-function's dialog. Note, 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 1990-2005 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 next implements the `mdlCheckParameters` method to check the validity of the S-function dialog parameters. Since this is an optional method, it must be proceeded by a `#define` statement. The `#if defined` statement then checks that this function is being compiled as a MEX-file, instead of for use with Real-Time Workshop. The body of the function performs basic checks to ensure the user entered real vectors for the numerator and denominator, and that the denominator is of 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   el;
          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 (el = 0; el < nEls; el++) {
                if (!mxIsFinite(pr[el])) {
                    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 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 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. In this example, there are no discrete states. The number of continuous states is set based on the number of coefficients in the transfer function's denominator.
- Next, `ssSetNumInputPorts` specifies that the S-function has a single input port whose width is set by `ssSetInputPortWidth` to be two times the length of the denominator plus one. The input port's sample time is then set to the value provided by the third S-function dialog parameter and indicates the rate at which the transfer function will be modified. The input port's offset time is set to zero. Note that the input port is also set to have direct feedthrough by passing a value of `1` to `ssSetInputPortDirectFeedThrough`.
- `ssSetNumOutputPorts` specifies that the S-function has a single output port. The width of this output port is set to one using `ssSetOutputPortWidth`. `ssSetOutputPortSampleTime` specifies that the output port has a continuous sample time and `ssSetOutputPortOffsetTime` sets the offset time to zero.
- `ssSetNumSampleTimes` then specifies that there are two sample times, which will be configured later in the `mdlInitializeSampleTimes` function.
- A value of four times the number of denominator coefficients is passed 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 is used to storetwo banks of transfer function coefficients, while the IWork vector is used to indicate which bank in the RWork vector is currently in use. The other work vectors are initialized with lengths of zero to indicate that these work vectors are not used by this S-function. Note that these lines could be omitted since zero is the default value for all of these macros. For clarity, it is preferable to explicitly set the number of work vectors.
- Lastly, any applicable options are set using `ssSetOptions`. 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. */
#if defined(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, 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 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 continous 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 or Simulink will not 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 value stored in the IWork vector is set 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:
 *      Initalize 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 output is calculated 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 */
```

The `mdlUpdate` function is used to update the transfer function coefficients at every major time step. Note, in this example there are no discrete states to update. Since this is an optional method, it must be proceeded by a `#define` statement. A pointer to the input signal is obtained using `ssGetInputPortRealSignalPtrs`. The input signal's values are used to update the transfer function coefficients. The new coefficients are stored in the bank of the RWork vector that is currently inactive. When the `mdlOutputs` function is later called at this major time step, it will update 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 then calculates the continuous state derivatives. The coefficients from the active bank are used 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 */
```

All S-functions must 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 trailer of this S-function must include 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 `mdlTerminate` function uses the macro `UNUSED_ARG`. This macro is defined in `*matlabroot*/simulink/include/simstruc_types.h` and is used to indicate that one of the input arguments to this callback is required even though it is not used in the callback. The macro `UNUSED_ARG` accepts only a single input argument so must be called once for each callback input argument that is not used in the callback.

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.

mdlCheckParameters

Purpose Check the validity of an S-function's parameters

Required No

C Syntax

```
void mdlCheckParameters(SimStruct *S)
```

C Arguments

`S`
    SimStruct representing an S-Function block.

M Syntax

```
CheckParameters(s)
```

M Arguments

`s`
    Instance of `Simulink.MSFcnRunTimeBlock` class representing an S-Function block.

Description Verifies new parameter settings whenever parameters change or are reevaluated during a simulation.

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.

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.

```
#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 in your S-function by using `ssSetNumSFcnParams`, use this code in `mdlInitializeSizes`:

```
static void mdlInitializeSizes(SimStruct *S)
{
  ssSetNumSFcnParams(S, 1);  /* Number of expected parameters */
#if defined(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

```
void mdlDerivatives(SimStruct *S)
```

C Arguments

`S`

SimStruct representing an S-Function block.

M Syntax

```
Derivatives(s)
```

M Arguments

`s`

Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block

Description

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 `ssGetdX` to get a pointer to the derivatives vector.

Each time the `mdlDerivatives` 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.

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`

mdlDisable

Purpose Respond to disabling of an enabled system containing this block

Required No

C Syntax

```
void mdlDisable(SimStruct *S)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

M Syntax

```
Disable(s)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` 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 `mdlEnable`

Purpose

Respond to enabling of an enabled system containing this block

Required

No

C Syntax

```
void mdlEnable(SimStruct *S)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

M Syntax

```
Enable(s)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` 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

`mdlDisable`

mdlGetTimeOfNextVarHit

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);
}
```

Languages C, M

See Also `mdlInitializeSampleTimes`, `ssGetT`, `ssSetTNext`

Purpose

Initialize the state vectors of this S-function

Required

No

C Syntax

`void mdlInitializeConditions(SimStruct *S)`

C Arguments

`S`

SimStruct representing an S-Function block.

M Syntax

`InitializeConditions(s)`

M Arguments

`s`

Instance of `Simulink.MSFcnRunTimeBlock` 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 `ssGetContStates` and/or `ssGetDiscStates` to get the states. This method can also perform any other initialization activities that this S-function requires.

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 `ssIsFirstInitCond` macro to determine whether it is being called for the first time.

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`

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]
  ```

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) {
}
```

Languages

C

See Also

`mdlSetInputPortSampleTime`, `mdlSetOutputPortSampleTime`

mdlInitializeSizes

Purpose

Specify the number of inputs, outputs, states, parameters, and other characteristics of the S-function

Required

Yes

C Syntax

`void mdlInitializeSizes(SimStruct *S)`

C Arguments

`S`

SimStruct representing an S-Function block.

M Syntax

`setup(s)`

M Arguments

`s`

Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description

This is the first of the S-function's callback methods that Simulink calls. This method should perform the following tasks:

- Specify the number of parameters that this S-function supports, using `ssSetNumSFcnParams`.

  Use `ssSetSFcnParamTunable(S,paramIdx, 0)` when a parameter cannot change during simulation, where `paramIdx` 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 `ssSetNumContStates` and `ssSetNumDiscStates`.

- Configure the block's input ports.

  This entails the following tasks:

- 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 7-20 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))
  ```

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 aparameter 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;
    /*
     * 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

mdlOutputs

Purpose Compute the signals that this block emits

Required Yes

C Syntax

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

C Arguments

`S`
: SimStruct representing an S-Function block.

`tid`
: Task ID.

M Syntax

```
Outputs(s)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description 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.

The `tid` (task ID) argument specifies the task running when the `mdlOutputs` routine is invoked. You can use this argument in the `mdlOutports` routine of a multirate S-Function block to encapsulate task-specific blocks of code (see "Multirate S-Function Blocks" on page 7-30).

For an example of an `mdlOutputs` routine that works with multiple input and output ports, see *`matlabroot`*`/simulink/src/sfun_multiport.c`.

Languages Ada, C, C++, M

See Also `ssGetOutputPortComplexSignal`, `ssGetOutputPortRealSignal`, `ssGetOutputPortSignal`

Purpose Process the S-function's parameters

Required No

C Syntax `void mdlProcessParameters(SimStruct *S)`

C Arguments

`S`
: SimStruct representing an S-Function block.

M Syntax `ProcessParameters(s)`

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description

This is an optional routine that Simulink calls after `mdlCheckParameters` changes and verifies parameters. The processing is done at the top of the simulation loop when it is safe to process the changed parameters.

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 "Real-Time Workshop Target Language Compiler" for information on inlining S-functions.

The synopsis is

```
#define MDL_PROCESS_PARAMETERS   /* Change to #undef to remove function */
#if defined(MDL_PROCESS_PARAMETERS) && defined(MATLAB_MEX_FILE)
static void mdlProcessParameters(SimStruct *S)
{
}
#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`

Purpose

Perturb the solver's solution of a system's states to better satisfy time-invariant solution relationships

Required

No

C Syntax

`void mdlProjection(SimStruct *S)`

C Arguments

S

SimStruct representing an S-Function block.

M Syntax

`Projection(s)`

M Arguments

s

Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description

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 `mdlProjection` 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.

Your `mdlProjection` 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 `mdlProjection` 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

8-27 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.

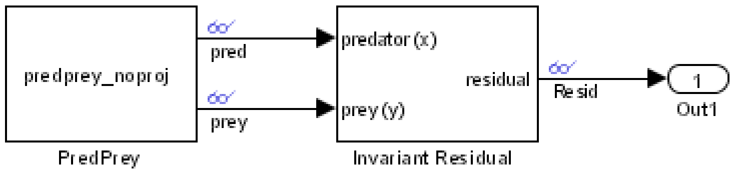
Given a continuous, differentiable invariant function for the system that your S-function models, this formula allows your S-function's `mdlProjection` method to compute a perturbation

$$J_n^T (J_n J_n^T)^{-1} R_n$$

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

$$\dot{x} = ax(1-y)$$
$$\dot{y} = -cy(1-x)$$

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

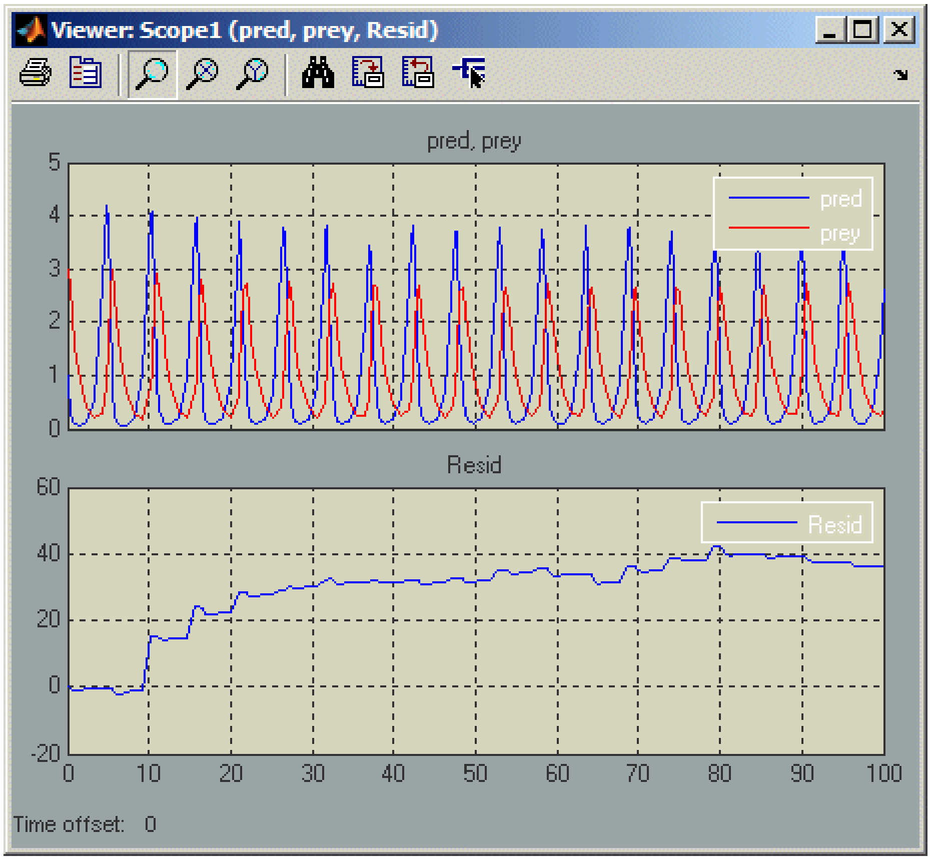
$$x^{-c}e^{cx}y^{-a}e^{ay} = d$$

where a, c, and d are constants. The S-function assumes `a = 1`, `c = 2`, and `d = 121.85`.

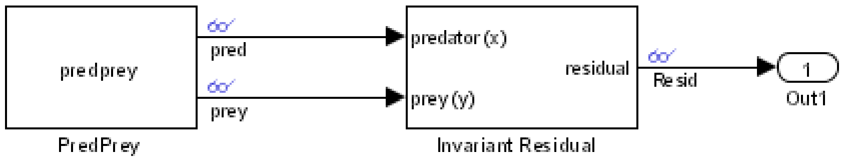
The Invariant Residual block in this model computes the residual between the invariant function evaluated along the system's ideal trajectory through state space and its simulated trajectory:

$$R_n = d - x_n^{-c}e^{cx_n}y_n^{-a}e^{ay_n}$$

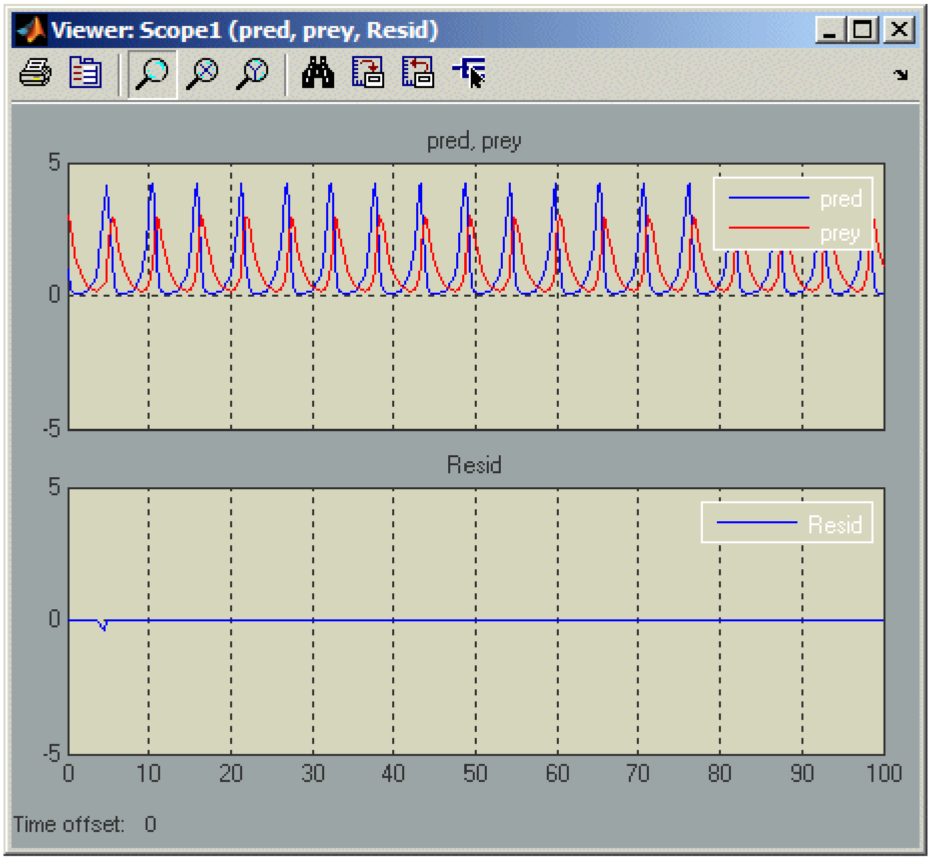
where x_n and y_n are the values computed by the model's solver for the predator and prey population densities, respectively, at the current time step. Ideally, the residual should be zero throughout simulation of the model, but simulating the model reveals that the residual actually strays considerably from zero:



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 8-27 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

`void mdlRTW(SimStruct *S)`

C Arguments

`S`
: SimStruct representing an S-Function block.

M Syntax

`WriteRTW(s)`

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description

This function is called when Real-Time Workshop is generating the *`model`*`.rtw` file. In this method, you can call the following functions that add fields to the *`model`*`.rtw` file:

- `ssWriteRTWParameters`
- `ssWriteRTWParamSettings`
- `ssWriteRTWWorkVect`
- `ssWriteRTWStr`
- `ssWriteRTWStrParam`
- `ssWriteRTWScalarParam`
- `ssWriteRTWStrVectParam`
- `ssWriteRTWVectParam`
- `ssWriteRTW2dMatParam`
- `ssWriteRTWMxVectParam`

- `ssWriteRTWMx2dMatParam`

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 `void mdlSetDefaultPortComplexSignals(SimStruct *S)`

C Arguments `S`

SimStruct representing an S-Function block.

Description 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.

If the block does not implement this method and at least one port is known to be complex, Simulink sets the unknown ports to `COMPLEX_YES`; otherwise, it sets the unknown ports to `COMPLEX_NO`.

Languages C

See Also `ssSetOutputPortComplexSignal`, `ssSetInputPortComplexSignal`

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.

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.

Languages

C

See Also

`ssSetOutputPortDataType`, `ssSetInputPortDataType`

mdlSetDefaultPortDimensionInfo

Purpose Set the default dimensions of the signals accepted or emitted by an S-function's ports

Required No

C Syntax `void mdlSetDefaultPortDimensionInfo(SimStruct *S)`

C Arguments `S`

SimStruct representing an S-Function block.

Description 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. If `S` does not implement this method, Simulink sets the dimensions of dynamically sized ports for which dimension information is unavailable to scalar, i.e., 1-D signals containing one element.

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

```
void mdlSetInputPortComplexSignal(SimStruct *S, int_T port,
 CSignal_T csig)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

port
: Index of a port.

csig
: Numeric type of signal, either `COMPLEX_NO` (real) or `COMPLEX_YES` (complex).

M Syntax

```
SetInputPortComplexSignal(s, port, typeId)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying index of port to be set.

`typeId`
: Integer value specifying whether the port accepts real (0) or complex (1) signals.

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. 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/sfun_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

```
void mdlSetInputPortDataType(SimStruct *S, int_T port, DTypeId id)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`id`
: Data type ID.

M Syntax

```
SetInputPortDataType(s, port, typeId)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying index of port to be set.

`typeId`
: Integer value specifying ID of port’s data type. Use `s.getDatatypeName(typeId)` to get the data type’s name.

Description Simulink calls this routine to set the data type of `port` when `port` has an inherited data type. The data type `id` is the proposed data type for this port. Data type IDs for the built-in data types can be found in *`matlabroot`*`/simulink/include/simstruc_types.h`. 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

```
void mdlSetInputPortDimensionInfo(SimStruct *S, int_T port,
  const DimsInfo_T *dimsInfo)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`dimsInfo`
: Structure that specifies the signal dimensions supported by the port.

See `ssSetInputPortDimensionInfo` for a description of this structure.

M Syntax

```
SetInputPortDimensions(s, port, dims)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying index of port to be set.

`dims`
: 1-D array that specifies the signal dimensions supported by the port, e.g., [5] for a 5-element vector signal or [3 3] for a 3-by-3 matrix signal.

Description

Simulink calls this method during dimension propagation with candidate dimensions `dimsInfo` for `port`. If the proposed dimensions are acceptable, this method should go ahead and set the actual port dimensions, using `ssSetInputPortDimensionInfo`. If they are unacceptable, this method should generate an error via `ssSetErrorStatus`.

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

```
void mdlSetInputPortFrameData(SimStruct *S, int_T port,
 Frame_T frameData)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`frameData`
: Frame data.

M Syntax

```
SetInputPortSamplingMode(s, port, mode)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying the index of port whose sampling mode is to be set.

`mode`
: Integer value specifying the sampling mode of the port (0 = sample, 1 = frame).

Description

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 go ahead and set the actual frame data setting using `ssSetInputPortFrameData`. If the setting is unacceptable, an error should be generated via `ssSetErrorStatus`. Note that any other input or output ports whose frame data settings are implicitly defined by virtue of knowing the frame data setting of the given port can also have their frame data settings configured.

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

```
void mdlSetInputPortSampleTime(SimStruct *S, int_T port,
 real_T sampleTime, real_T offsetTime)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`sampleTime`
: Inherited sample time for `port`.

`offsetTime`
: Inherited offset time for `port`.

M Syntax

```
SetInputPortSampleTime(s, port, time)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying the index of port whose sampling mode is to be set.

`time`
: Two-element array, `[period offset]`, that specifies the period and offset of the times that this port samples its input.

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 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.

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 < period < inf` and `0.0 <= offset < 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 `[0.2499999999999, 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

```
void mdlSetInputPortWidth(SimStruct *S, int_T port, int_T width)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`width`
: Width of signal.

Description 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 `ssSetInputPortWidth`. If the size is unacceptable, an error should be generated via `ssSetErrorStatus`. 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 `ssSetInputPortWidth` or `ssSetOutputPortWidth`.

Simulink invokes this method until all dynamically sized input ports are configured.

Languages C

See Also `ssSetInputPortWidth`, `ssSetOutputPortWidth`, `ssSetErrorStatus`

Purpose

Set the numeric types (real, complex, or inherited) of the signals accepted by an output port

Required

No

C Syntax

```
void mdlSetOutputPortComplexSignal(SimStruct *S, int_T port,
CSignal_T csig)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`csig`
: Numeric type of signal, either `COMPLEX_NO` (real) or `COMPLEX_YES` (complex).

M Syntax

```
SetOutputPortComplexSignal(s, port, typeId)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying the index of port to be set.

`typeId`
: Integer value specifying whether the port produces real (0) or complex (1) signals.

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 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.

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/sfun_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

```
void mdlSetOutputPortDataType(SimStruct *S, int_T port,
DTypeId id)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of an output port.

`id`
: Data type ID.

M Syntax

```
SetOutputPortDataType(s, port, typeId)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying index of port to be set.

`typeId`
: Integer value specifying ID of port's data type. Use `s.getDatatypeName(typeId)` to get the data type's name.

Description

Simulink calls this routine to set the data type of `port` when `port` has an inherited data type. The data type ID`id` is the proposed data type for this port. Data type IDs for the built-in data types can be found in *`matlabroot`*`/simulink/include/simstruc_types.h`. 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 `ssSetOutputPortDataType`. Otherwise, it must report an error, using `ssSetErrorStatus`.

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

```
void mdlSetOutputPortDimensionInfo(SimStruct *S, int_T port,
  const DimsInfo_T *dimsInfo)
```

C Arguments

`S`
: SimStruct representing an S-Function block or a Simulink model.

`port`
: Index of a port.

`dimsInfo`
: Structure that specifies the signal dimensions supported by `port`.

See `ssSetInputPortDimensionInfo` for a description of this structure.

M Syntax

```
SetOutputPortDimensions(s, port, dims)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying the index of the port to be set.

`dims`
: 1-D array that specifies the signal dimensions supported by the port, e.g., [5] for a 5-element vector signal or [3 3] for a 3-by-3 matrix signal.

Description

Simulink calls this method with candidate dimensions `dimsInfo` for `port`. If the proposed dimensions are acceptable, this method should go ahead and set the actual port dimensions, using ssSetOutputPortDimensionInfo. If they are unacceptable, this method should generate an error via ssSetErrorStatus.

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

```
void mdlSetOutputPortSampleTime(SimStruct *S, int_T port,
 real_T sampleTime, real_T offsetTime)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`sampleTime`
: Inherited sample time for `port`.

`offsetTime`
: Inherited offset time for `port`.

M Syntax

```
SetOutputPortSampleTime(s, port, time)
```

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

`port`
: Integer value specifying the index of port whose sampling mode is to be set.

`time`
: Two-element array, `[period offset]`, that specifies the period and offset of the times that this port produces output.

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 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.

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`

mdlSetOutputPortWidth

Purpose

Set the width of an output port that outputs 1-D (vector) signals

Required

No

C Syntax

```
void mdlSetOutputPortWidth(SimStruct *S, int_T port, int_T width)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

`port`
: Index of a port.

`width`
: Width of signal.

Description

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 `ssSetOutputPortWidth`. If the size is unacceptable, an error should be generated via `ssSetErrorStatus`. 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 `ssSetInputPortWidth` or `ssSetOutputPortWidth`.

Languages

C

See Also

`ssSetInputPortWidth`, `ssSetOutputPortWidth`, `ssSetErrorStatus`

Purpose

Specify the sizes of the work vectors and create the run-time parameters required by this S-function

Required

No

C Syntax

`void mdlSetWorkWidths(SimStruct *S)`

C Arguments

`S`

SimStruct representing an S-Function block.

M Syntax

`PostPropagationSetup(s)`

M Arguments

`s`

Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description

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 `ssGetNumContStates`, `ssSetNumDiscStates`, `ssSetNumRWork`, `ssSetNumIWork`, `ssSetNumPWork`, `ssSetNumModes`, and `ssSetNumNonsampledZCs`.

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 `mdlInitializeSizes` method. If this S-function implements `mdlSetWorkWidths`, it should initialize the sizes of any work vectors that it needs to `DYNAMICALLY_SIZED` in `mdlInitializeSizes`, even for those whose exact size it knows at that point. The S-function should then specify the actual size in `mdlSetWorkWidths`.

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 an 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

```
void mdlSimStatusChange(SimStruct *S,
 ssSimStatusChangeType simStatus)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

simStatus
: Status of the simulation, either `SIM_PAUSE` or `SIM_CONTINUE`.

Description Simulink calls this routine when a simulation of the model containing `S` pauses or resumes.

Example

```
#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) {
     slPrintf("Continue has been called! \n");
 }
}
#endif
```

Languages C

Purpose

Initialize the state vectors of this S-function

Required

No

C Syntax

```
void mdlStart(SimStruct *S)
```

C Arguments

`S`

SimStruct representing an S-Function block.

M Syntax

```
Start(s)
```

M Arguments

`s`

Instance of `Simulink.MSFcnRunTimeBlock` 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 `ssGetContStates` and/or `ssGetDiscStates` 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 *`matlabroot`*`/simulink/src/sfun_directlook.c` for an example of how to use this function.

See Also

`mdlInitializeConditions`, `ssGetContStates`, `ssGetDiscStates`

Purpose

Perform any actions required at termination of the simulation

Required

Yes

C Syntax

```
void mdlTerminate(SimStruct *S)
```

C Arguments

S

SimStruct representing an S-Function block.

Description

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 `SS_OPTION_CALL_TERMINATE_ON_EXIT` (see `ssSetOptions`) determines whether Simulink invokes this method. If this option is not set, Simulink invokes `mdlTerminate` at the end of the simulation only if the `mdlStart` 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 `mdlTerminate` method at the end of a simulation run and whenever it destroys a block.

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

C Arguments

`S`
: SimStruct representing an S-Function block.

`tid`
: Task ID.

M Syntax `Update(s)`

M Arguments

`s`
: Instance of `Simulink.MSFcnRunTimeBlock` class representing the S-Function block.

Description

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.

Use this code if your S-function has one or more discrete states or does *not* have direct feedthrough.

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.

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 `ssSetNumDiscStates` macro in the `mdlInitializeSizes` function.

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 7-30).

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`

Purpose Update zero-crossing vector

Required No

C Syntax

```
void mdlZeroCrossings(SimStruct *S)
```

C Arguments

`S`
: SimStruct representing an S-Function block.

M Syntax

```
ProcessParameters(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 7-38 in the Simulink documentation.

Languages

C, C++, M

See Also

`mdlInitializeSizes`, `ssGetNonsampledZCs`

SimStruct Functions — By Category

Introduction (p. 9-2)	Overview of SimStruct macros and functions.
SimStruct Macros and Functions Listed by Usage (p. 9-3)	SimStruct functions listed by usage.

Introduction

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.

This reference describes the syntax and usage of each SimStruct function. The descriptions appear alphabetically by name to facilitate location of a particular function. This section also provides listings of functions by usage to speed location of macros and functions for specific purposes, such as implementing data type support.

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

This section groups SimStruct macros 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
`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.
`ssGetOutputPortDimensions`	Get the dimensions of the signal leaving an output port.

I/O Port — Signal Dimensions (Continued)

Macro	Description
`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
`ssGetOutputPortSampleTime`	Determine the sample time of an output port.
`ssGetPortBasedSampleTimeBlockIs-Triggered`	Determine whether a block that uses port-based sample times resides in a triggered subsystem.
`ssGetSampleTime`	Determine one of an S-function's sample times.
`ssGetSampleTimeOffset`	Get the offset of the current sample time (Ada only).
`ssGetSampleTimePeriod`	Get the period of the current sample time (Ada only).
`ssGetTNext`	Get the time of the next sample hit in a discrete S-function with a variable sample time.
`ssIsContinuousTask`	Determine whether a specified rate is the continuous rate.
`ssIsSampleHit`	Determine the sample rate at which an S-function is operating.
`ssIsSpecialSampleHit`	Determine whether the current sample time hits two specified rates.
`ssSampleAndOffsetAreTriggered`	Determine whether a sample time and offset value pair indicate a triggered sample time.
`ssSetInputPortSampleTime`	Set the sample time of an input port.
`ssSetModelReferenceSampleTime-InheritanceRule`	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 (`int_T`) 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 (`int_T`) 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 (`void *`) work vector.
`ssSetNumRWork`	Specify the size of an S-function’s real (`real_T`) 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 *model.rtw* file.
`ssWriteRTWMx2dMatParam`	Write a MATLAB matrix parameter to the S-function's *model.rtw* file.
`ssWriteRTWMxVectParam`	Write a MATLAB vector parameter to the S-function's *model.rtw* file.
`ssWriteRTWParameters`	Write tunable parameters to the S-function's *model.rtw* file.
`ssWriteRTWParamSettings`	Write settings for the S-function's parameters to the *model.rtw* file.
`ssWriteRTWScalarParam`	Write a scalar parameter to the S-function's *model.rtw* file.
`ssWriteRTWStr`	Write a string to the S-function's *model.rtw* file.
`ssWriteRTWStrParam`	Write a string parameter to the S-function's *model.rtw* file.
`ssWriteRTWStrVectParam`	Write a string vector parameter to the S-function's *model.rtw* file.
`ssWriteRTWVectParam`	Write a Simulink vector parameter to the S-function's *model.rtw* file.
`ssWriteRTWWorkVect`	Write the S-function's work vectors to the *model.rtw* file.

Examples

Use this list to find examples in the documentation.

S-Function Features

“Passing Parameters to S-Functions” on page 1-4
“Multirate S-Function Blocks” on page 7-30
“Example Involving a Pointer Work Vector” on page 7-41

S-Function Examples

“S-Function Examples” on page 1-19
“Example of a Continuous State S-Function” on page 7-56
“Example of a Discrete State S-Function” on page 7-63
“Example of a Hybrid System S-Function” on page 7-69
“Example of a Variable-Step S-Function” on page 7-77
“Example of a Zero Crossing S-Function” on page 7-83
“Example of a Time-Varying Continuous Transfer Function” on page 7-101

S-Function Builder

“Building S-Functions Automatically” on page 3-6
“Library/Object/Source files” on page 3-23
“Enable access to SimStruct” on page 3-34

Writing S-Functions in C

“Example of a Basic C MEX S-Function” on page 3-35

Creating C++ S-Functions

“Source File Format” on page 4-2

Creating Ada S-Functions

"Ada S-Function Specification" on page 5-3
"Ada S-Function Body" on page 5-4
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Creating Fortran S-Functions

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