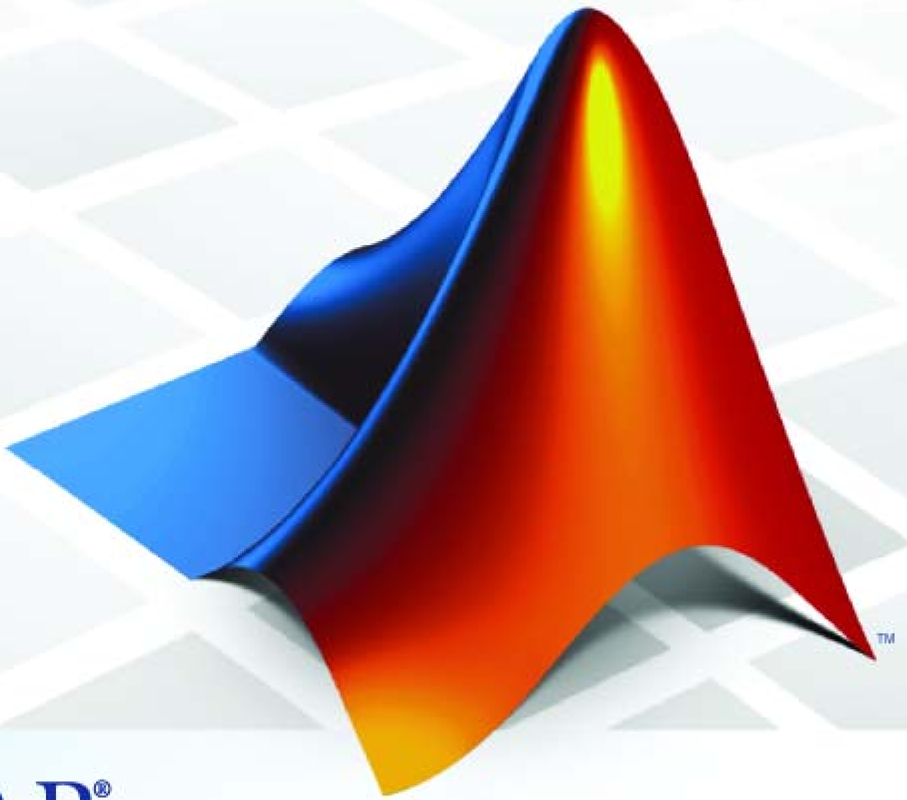
# Real-Time Workshop® Embedded Coder™ 5
User's Guide



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# Introduction to the Real-Time Workshop Embedded Coder Product

The Real-Time Workshop® Embedded Coder™ product *extends* the Real-Time Workshop® product with features that are important for embedded software development. Using the Real-Time Workshop Embedded Coder add-on product, you gain access to all aspects of Real-Time Workshop technology and can generate code that has the clarity and efficiency of professional handwritten code. For example, you can

- Generate code that is compact and fast, which is essential for real-time simulators, on-target rapid prototyping boards, microprocessors used in mass production, and embedded systems
- Customize the appearance of the generated code
- Optimize the generated code for a specific target environment
- Integrate existing (legacy) applications, functions, and data
- Enable tracing, reporting, and testing options that facilitate code verification activities

For detailed information on how the Real-Time Workshop Embedded Coder product fits into the complete Real-Time Workshop technology picture, see "Getting Started with Real-Time Workshop Technology" in the Real-Time Workshop documentation. That topic positions the Real-Time Workshop Embedded Coder in terms of what you can accomplish with it, how it can fit into your development process, how you might apply it to the V-model for system development, and how you might apply it to relevant use cases.

Because Real-Time Workshop Embedded Coder extends Real-Time Workshop for code generation, to use the Real-Time Workshop Embedded Coder product effectively, you should be familiar with information in parts of the Real-Time Workshop documentation that align with corresponding parts in the Real-Time Workshop Embedded Coder documentation.

- "Introduction to Real-Time Workshop Technology"
- "Developing Models for Code Generation"
- "Defining Data Representation and Storage for Code Generation"
- "Preparing Models for Code Generation"
- "Generating Code and Building Executables"
- "Integrating External Code With Generated C and C++ Code"
- "Setting Up Generated Code To Interface With Components in the Run-Time Environment"
- "Verifying Generated Code Applications"

# Developing Models for Code Generation

# Setting Up Your Modeling Environment

When developing a system, it is important to use the correct combination of products to model each system component based on the domain to which it applies.

The following table guides you to information and demos that pertain to use of the Real-Time Workshop Embedded Coder product to meet goals for specific domains.

| Goals | Related Product Information | Demos |
|---|---|---|
| Generate a software design description | Simulink® Report Generator™<br><br>Simulink Report Generator documentation | `rtwdemo_codegenrpt` |
| Trace model requirements to generated code | Simulink® Verification and Validation™<br><br>"Including Requirements Information with Generated Code" in the Simulink Verification and Validation documentation | `rtwdemo_requirements` |

| Goals | Related Product Information | Demos |
|---|---|---|
| Implement application on fixed-point processors | Simulink® Fixed Point™<br>“Data Types and Scaling” and “Code Generation” in the Simulink Fixed Point documentation | `rtwdemo_fixpt1`<br>`rtwdemo_fuelsys_fxp_publish`<br>`rtwdemo_dspanc_fixpt` |
| Use an integrated development environment (IDE) to integrate an application on a target processor automatically | Embedded IDE Link™<br>“Embedded IDE Link” documentation<br>Target Support Package™<br>“Target Support Package” documentation | See help for Embedded IDE Link and Target Support Package products |

# Architecture Considerations

## Generating Code Variants for Variant Models

**In this section...**

### Prerequisites

The Real-Time Workshop Embedded Coder software generates code variants from a Simulink® model containing model reference variants. To learn how to create a model containing model reference variants, see "Using Model Reference Variants" in the Simulink documentation. The Real-Time Workshop Embedded Coder software generates code for all variants of a referenced model. In the generated code, variants are preprocessor conditional directives that determine the active variant and the sections of code to execute.

### Why Generate Code Variants?

When you implement variants in the generated code, you can:

- Reuse generated code from a set of application models that share functionality with minor variations.
- Share generated code with a third party that activates one of the variants in the code.
- Validate all of the supported variants for a model and then choose to activate one variant for a particular application, without regenerating and revalidating the code.

## How to Generate Code Variations for Model Variants

### Defining Variant Control Variables and Variant Objects for Generating Code

To learn about variant control variables and variant objects see Implementing Model Reference Variants in the Simulink documentation. Variant control variables used for code generation have different requirements than variant control variables used for simulation. Perform the following steps to define variant control variables for generating code.

1 Open the Model Explorer and click the **Base Workspace**.

2 A variant control variable can be a `Simulink.Parameter` object or a `mpt.Parameter` object. In the Model Explorer, select **Add** and choose either **Simulink Parameter** or **MPT Parameter**. Specify a name for the new parameter.

3 On the `Simulink.Parameter` or `mpt.Parameter` property dialog box, specify the **Storage class** parameter by choosing one of the following:

   - `ImportedDefine(Custom)` custom storage class.
   - `CompilerFlag(Custom)` custom storage class.
   - A user-defined storage class created using the Custom Storage Class Designer. Your storage class must have the **Data initialization** parameter set to `Macro` and the **Data scope** parameter set to `Imported`. See "Using the Custom Storage Class Designer" on page 7-12 for more information.

**Note** If the storage class is `CompilerFlag(Custom)` then the makefile options (for example, `OPTOPTS`) must specify the macro and its value.

4 If the storage class is either `ImportedDefine(Custom)` or a user-defined custom storage class, specify the **Header File** parameter as an external header file in the Custom Attributes section of the `Simulink.Parameter` property dialog box.

5. Supply the values of the variant control variables in the external header file. The generated code refers to a variant control variable as a user-defined macro. The generated code does not contain the value of the macro. The value of the variant control variable determines the active variant in the compiled code.

6. Follow the instructions for "Implementing Variant Objects" for model reference variants to implement variant objects for code generation. Ensure that only one variant object is active in the generated code by implementing the condition expressions of the variant objects such that only one evaluates to `true`. The generated code includes a test of the variant objects to determine that there is only one active variant. If this test fails, your code might not compile.

## Generating Preprocessor Conditional Directives

In order to generate preprocessor conditional directives configure your model as follows:

1. On the **Optimization** pane of the Configuration Parameters dialog box, select **Inline parameters**.

2. On the **Real-Time Workshop** pane of the Configuration Parameter dialog box, clear "Ignore custom storage classes". Otherwise, the code generator ignores all custom storage class specifications, and treats all data objects as if their storage class were `Auto`.

3. On the **Interface** pane of the Configuration Parameter dialog box, select the `Use Local Settings` option of the **Generate preprocessor conditionals** parameter. This parameter is a global setting for the parent model. This setting enables the **Generate preprocessor conditionals** parameter located in the Model block parameters dialog box. See "Generate preprocessor conditionals" for more information.

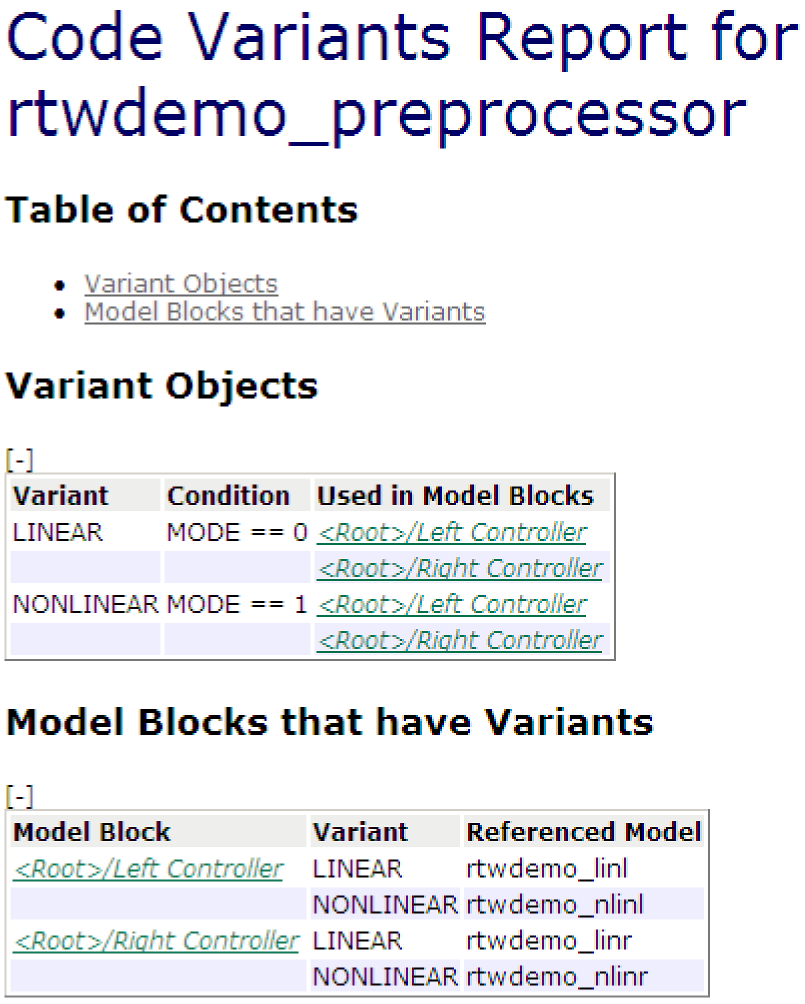
4. Open the Model block parameters dialog box for a variant model block. Select the **Generate preprocessor conditionals** parameter.

5. In the Model block parameters dialog box, clear the **Override variant conditions and use following variant** parameter.

6. Build your model.

## Reviewing Code Variants in the Code Generation Report

The Code Variants Report displays a list of the variant objects, their condition, and the model blocks that use them. The Code Variants Report also includes a section that lists the model blocks that have variants. In the contents section of the code generation report, click the link to the Code Variants Report:



Code Variants Report for rtwdemo_preprocessor

Table of Contents

- Variant Objects
- Model Blocks that have Variants

Variant Objects

[-]

| Variant | Condition | Used in Model Blocks |
|---|---|---|
| LINEAR | MODE == 0 | <Root>/Left Controller |
| | | <Root>/Right Controller |
| NONLINEAR | MODE == 1 | <Root>/Left Controller |
| | | <Root>/Right Controller |

Model Blocks that have Variants

[-]

| Model Block | Variant | Referenced Model |
|---|---|---|
| <Root>/Left Controller | LINEAR | rtwdemo_linl |
| | NONLINEAR | rtwdemo_nlinl |
| <Root>/Right Controller | LINEAR | rtwdemo_linr |
| | NONLINEAR | rtwdemo_nlinr |

## Example of Variants in the Generated Code

To open a model for generating preprocessor conditionals, enter rtwdemo_preprocessor.

After building the model, look at the variants in the generated code. `rtwdemo_preprocessor_types.h` includes the following:

- Call to external header file, `rtwdemo_preprocessor_macros.h`, which contains the macro definition for the variant control variable, `MODE`.

  ```
  /* Includes for objects with custom storage classes. */
  #include "rtwdemo_importedmacros.h"
  ```

- Preprocessor directives defining the variant objects, `LINEAR` and `NONLINEAR`. The values of these macros depend on the value of the variant control variable, `MODE`. The condition expression associated with each macro, LINEAR and NONLINEAR, determine the active variant.

  ```
  /* Model Code Variants */
  #ifndef LINEAR
  #define LINEAR                          (MODE == 0)
  #endif

  #ifndef NONLINEAR
  #define NONLINEAR                       (MODE == 1)
  #endif
  ```

- A check to ensure that exactly one variant is active at a time:

  ```
  /* Exactly one variant for '<Root>/Left Controller' should be active */
  #if (LINEAR) + (NONLINEAR) != 1
  #error Exactly one variant for '<Root>/Left Controller' should be active
  #endif
  ```

Calls to the step and initialization functions are conditionally compiled as shown in a portion of the step function, `rtwdemo_preprocessor_step`, in `ModRefVar.c`:

```
/* ModelReference: '<Root>/Left Controller' */
#if LINEAR

mr_rtwdemo_linl(&rtb_Add, &rtb_LeftController_merge_1,
                &(rtwdemo_preprocessor_DWork.LeftController_1_DWORK1.rtdw));

#endif                               /* LINEAR */
```

```
/* ModelReference: '<Root>/Left Controller' */
#if NONLINEAR

mr_rtwdemo_nlinl(&rtb_Add, &rtb_LeftController_merge_1,
                 &(rtwdemo_preprocessor_DWork.LeftController_2_DWORK1.rtdw));

#endif                                  /* NONLINEAR */
```

and

```
/* ModelReference: '<Root>/Right Controller' */
#if LINEAR

mr_rtwdemo_linr(&rtb_Add1, &rtb_RightController_merge_1,
                &(rtwdemo_preprocessor_DWork.RightController_1_DWORK1.rtdw));

#endif                                  /* LINEAR */

/* ModelReference: '<Root>/Right Controller' */
#if NONLINEAR

mr_rtwdemo_nlinr(&rtb_Add1, &rtb_RightController_merge_1,
                 &(rtwdemo_preprocessor_DWork.RightController_2_DWORK1.rtdw));

#endif                                  /* NONLINEAR */
```

## Demo for Code Variants Using Model Blocks

To construct model reference variants step by step and generate preprocessor directives in the generated code, see the demo rtwdemo_preprocessor_script.

## Creating and Using Host-Based Shared Libraries

**In this section...**

### Overview

The Real-Time Workshop Embedded Coder product provides an ERT target, `ert_shrlib.tlc`, for generating a host-based shared library from your Simulink model. Selecting this target allows you to generate a shared library version of your model code that is appropriate for your host platform, either a Windows® dynamic link library (`.dll`) file or a UNIX® shared object (`.so`) file. This feature can be used to package your source code securely for easy distribution and shared use. The generated `.dll` or `.so` file is shareable among different applications and upgradeable without having to recompile the applications that use it.

Code generation for the `ert_shrlib.tlc` target exports

- Variables and signals of type `ExportedGlobal` as data
- Real-time model structure (`model_M`) as data
- Functions essential to executing your model code

To view a list of symbols contained in a generated shared library file, you can

- On Windows, use the Dependency Walker utility, downloadable from http://www.dependencywalker.com
- On UNIX, use `nm -D model.so`

To generate and use a host-based shared library, you

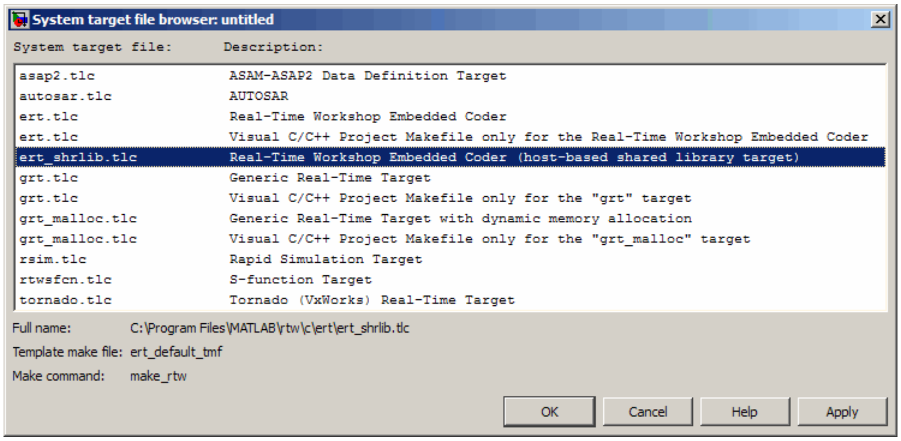
1 Generate a shared library version of your model code

**2** Create application code to load and use your shared library file

## Generating a Shared Library Version of Your Model Code

This section summarizes the steps needed to generate a shared library version of your model code.

**1** To configure your model code for shared use by applications, open your model and select the `ert_shrlib.tlc` target on the **Real-Time Workshop** pane of the Configuration Parameters dialog box. Click **OK**.



| System target file: | Description: |
|---|---|
| asap2.tlc | ASAM-ASAP2 Data Definition Target |
| autosar.tlc | AUTOSAR |
| ert.tlc | Real-Time Workshop Embedded Coder |
| ert.tlc | Visual C/C++ Project Makefile only for the Real-Time Workshop Embedded Coder |
| ert_shrlib.tlc | Real-Time Workshop Embedded Coder (host-based shared library target) |
| grt.tlc | Generic Real-Time Target |
| grt.tlc | Visual C/C++ Project Makefile only for the "grt" target |
| grt_malloc.tlc | Generic Real-Time Target with dynamic memory allocation |
| grt_malloc.tlc | Visual C/C++ Project Makefile only for the "grt_malloc" target |
| rsim.tlc | Rapid Simulation Target |
| rtwsfcn.tlc | S-function Target |
| tornado.tlc | Tornado (VxWorks) Real-Time Target |

Full name: C:\Program Files\MATLAB\rtw\c\ert\ert_shrlib.tlc
Template make file: ert_default_tmf
Make command: make_rtw

Selecting the `ert_shrlib.tlc` target causes the build process to generate a shared library version of your model code into your current working folder. The selection does not change the code that is generated for your model.

**2** Build the model.

**3** After the build completes, you can examine the generated code in the model subfolder, and the `.dll` file or `.so` file that has been generated into your current folder.

## Creating Application Code to Load and Use Your Shared Library File

To illustrate how application code can load an ERT shared library file and access its functions and data, The MathWorks™ provides the demo model `rtwdemo_shrlib`. Clicking the blue button in the demo model runs a script that:

1. Builds a shared library file from the model (for example, `rtwdemo_shrlib_win32.dll` on 32-bit Windows)

2. Compiles and links an example application, `rtwdemo_shrlib_app`, that will load and use the shared library file

3. Executes the example application

---

**Note** It is recommended that you change directory to a new or empty folder before running the `rtwdemo_shrlib` script.

---

The demo model uses the following example application files, which are located in *`matlabroot`*`/toolbox/rtw/rtwdemos/shrlib_demo`.

| File | Description |
|---|---|
| `rtwdemo_shrlib_app.h` | Example application header file |
| `rtwdemo_shrlib_app.c` | Example application that loads and uses the shared library file generated for the demo model |
| `run_rtwdemo_shrlib_app.m` | Script to compile, link, and execute the example application |

You can view each of these files by clicking white buttons in the demo model window. Additionally, running the script places the relevant source and generated code files in your current folder. The files can be used as templates for writing application code for your own ERT shared library files.

The following sections present key excerpts of the example application files.

### Example Application Header File

The example application header file `rtwdemo_shrlib_app.h` contains type declarations for the demo model's external input and output.

```
#ifndef _APP_MAIN_HEADER_
#define _APP_MAIN_HEADER_

typedef struct {
    int32_T Input;
} ExternalInputs_rtwdemo_shrlib;

typedef struct {
    int32_T Output;
} ExternalOutputs_rtwdemo_shrlib;

#endif /*_APP_MAIN_HEADER_*/
```

### Example Application C Code

The example application `rtwdemo_shrlib_app.c` includes the following code for dynamically loading the shared library file. Notice that, depending on platform, the code invokes Windows or UNIX library commands.

```
#if (defined(_WIN32)||defined(_WIN64)) /* WINDOWS */
#include <windows.h>
#define GETSYMBOLADDR GetProcAddress
#define LOADLIB LoadLibrary
#define CLOSELIB FreeLibrary

#else /* UNIX */
#include <dlfcn.h>
#define GETSYMBOLADDR dlsym
#define LOADLIB dlopen
#define CLOSELIB dlclose

#endif

int main()
{
    void* handleLib;
...
#if defined(_WIN64)
    handleLib = LOADLIB("./rtwdemo_shrlib_win64.dll");
#else
#if defined(_WIN32)
    handleLib = LOADLIB("./rtwdemo_shrlib_win32.dll");
#else /* UNIX */
    handleLib = LOADLIB("./rtwdemo_shrlib.so", RTLD_LAZY);
#endif
#endif
...
    return(CLOSELIB(handleLib));
}
```

The following code excerpt shows how the C application accesses the demo model's exported data and functions. Notice the hooks for adding user-defined initialization, step, and termination code.

```
    int32_T i;
 ...
    void (*mdl_initialize)(boolean_T);
    void (*mdl_step)(void);
    void (*mdl_terminate)(void);

    ExternalInputs_rtwdemo_shrlib (*mdl_Uptr);
    ExternalOutputs_rtwdemo_shrlib (*mdl_Yptr);

    uint8_T (*sum_outptr);
...
#if (defined(LCCDLL)||defined(BORLANDCDLL))
    /* Exported symbols contain leading underscores when DLL is linked with
       LCC or BORLANDC */
    mdl_initialize =(void(*)(boolean_T))GETSYMBOLADDR(handleLib ,
                     "_rtwdemo_shrlib_initialize");
    mdl_step       =(void(*)(void))GETSYMBOLADDR(handleLib ,
                     "_rtwdemo_shrlib_step");
    mdl_terminate  =(void(*)(void))GETSYMBOLADDR(handleLib ,
                     "_rtwdemo_shrlib_terminate");
    mdl_Uptr       =(ExternalInputs_rtwdemo_shrlib*)GETSYMBOLADDR(handleLib ,
                     "_rtwdemo_shrlib_U");
    mdl_Yptr       =(ExternalOutputs_rtwdemo_shrlib*)GETSYMBOLADDR(handleLib ,
                     "_rtwdemo_shrlib_Y");
    sum_outptr     =(uint8_T*)GETSYMBOLADDR(handleLib , "_sum_out");
#else
    mdl_initialize =(void(*)(boolean_T))GETSYMBOLADDR(handleLib ,
                     "rtwdemo_shrlib_initialize");
    mdl_step       =(void(*)(void))GETSYMBOLADDR(handleLib ,
                     "rtwdemo_shrlib_step");
    mdl_terminate  =(void(*)(void))GETSYMBOLADDR(handleLib ,
                     "rtwdemo_shrlib_terminate");
    mdl_Uptr       =(ExternalInputs_rtwdemo_shrlib*)GETSYMBOLADDR(handleLib ,
                     "rtwdemo_shrlib_U");
    mdl_Yptr       =(ExternalOutputs_rtwdemo_shrlib*)GETSYMBOLADDR(handleLib ,
                     "rtwdemo_shrlib_Y");
    sum_outptr     =(uint8_T*)GETSYMBOLADDR(handleLib , "sum_out");
#endif

    if ((mdl_initialize && mdl_step && mdl_terminate && mdl_Uptr && mdl_Yptr &&
         sum_outptr)) {
        /* === user application initialization function === */
        mdl_initialize(1);
        /* insert other user defined application initialization code here */

        /* === user application step function === */
        for(i=0;i<=12;i++){
            mdl_Uptr->Input = i;
            mdl_step();
            printf("Counter out(sum_out): %d\tAmplifier in(Input): %d\tout(Output): %d\n",
                   *sum_outptr, i, mdl_Yptr->Output);
            /* insert other user defined application step function code here */
        }

        /* === user application terminate function === */
        mdl_terminate();
        /* insert other user defined application termination code here */
    }
    else {
        printf("Cannot locate the specified reference(s) in the shared library.\n");
        return(-1);
    }
```

### Example Application M-Script

The application script `run_rtwdemo_shrlib_app.m` loads and rebuilds the demo model, and then compiles, links, and executes the demo model's shared library target file. You can view the script source file by opening `rtwdemo_shrlib` and clicking the appropriate white button. The script constructs platform-dependent command strings for compilation, linking, and execution that may apply to your development environment. To run the script, click the blue button.

## Host-Based Shared Library Limitations

The following limitations apply to using ERT host-based shared libraries:

- Code generation for the `ert_shrlib.tlc` target exports only the following as data:
  - Variables and signals of type `ExportedGlobal`
  - Real-time model structure (*`model`*`_M`)
- Code generation for the `ert_shrlib.tlc` target supports the C language only (not C++). When you select the `ert_shrlib.tlc` target, language selection is greyed out on the **Real-Time Workshop** pane of the Configuration Parameters dialog box.
- On Windows systems, the `ert_shrlib` target by default does not generate or retain the `.lib` file for implicit linking (explicit linking is preferred for portability).

  You can change the default behavior and retain the `.lib` file by modifying the corresponding template makefile (TMF). If you do this, be aware that the generated *`model`*`.h` file will need a small modification to be used together with the generated `ert_main.c` for implicit linking. For example, if you are using Visual C++®, you will need to declare `__declspec(dllimport)` in front of all data to be imported implicitly from the shared library file.
- To reconstruct a model simulation using a generated host-based shared library, the application author must maintain the timing between system and shared library function calls in the original application. The timing needs to be consistent to ensure correct simulation and integration results.

# Scheduling Considerations

## Using Discrete and Continuous Time

**In this section...**

### Generating Code for Discrete and Continuous Time Blocks

The ERT target supports code generation for discrete and continuous time blocks. If the **Support continuous time** option is selected, you can use any such blocks in your models, without restriction.

Note that use of certain blocks is not recommended for production code generation for embedded systems. The Simulink Block Data Type Support table summarizes characteristics of blocks in the Simulink and Simulink Fixed Point block libraries, including whether or not they are recommended for use in production code generation. To view this table, execute the following command and see the "Code Generation Support" column of the table that appears:

```
showblockdatatypetable
```

### Generating Code that Supports Continuous Solvers

The ERT target supports continuous solvers. In the **Solver** options dialog, you can select any available solver in the **Solver** menu. (Note that the solver **Type** must be `fixed-step` for use with the ERT target.)

**Note** Custom targets must be modified to support continuous time. The required modifications are described in the Developing Embedded Targets documentation.

## Generating Code that Honors a Stop Time

The ERT target supports the stop time for a model. When generating host-based executables, the stop time value is honored when any one of the following is true:

- **GRT compatible call interface** is selected on the **Interface** pane
- **External mode** is selected in the **Data exchange** subpane of the **Interface** pane
- **MAT-file logging** is selected on the **Interface** pane

Otherwise, the executable runs indefinitely.

---

**Note** The ERT target provides both generated and static examples of the `ert_main.c` file. The `ert_main.c` file controls the overall model code execution by calling the *`model`*`_step` function and optionally checking the `ErrorStatus`/`StopRequested` flags to terminate execution. For a custom target, if you provide your own custom static `main.c`, you should consider including support for checking these flags.

---

## Optimizing Task Scheduling for Multirate Multitasking Models on RTOS Targets

**In this section...**

### Overview

Using the `rtmStepTask` macro, targets that employ the task management mechanisms of an RTOS can eliminate certain redundant scheduling calls during the execution of tasks in a multirate, multitasking model, thereby improving performance of the generated code.

To understand the optimization that is available for an RTOS target, consider how the ERT target schedules tasks for bareboard targets (where no RTOS is present). The ERT target maintains *scheduling counters* and *event flags* for each subrate task. The scheduling counters are implemented within the real-time model (rtM) data structure as arrays, indexed on task identifier (`tid`).

The scheduling counters are updated by the base-rate task. The counters are, in effect, clock rate dividers that count up the sample period associated with each subrate task. When a given subrate counter reaches a value that indicates it has a hit, the sample period for that rate has elapsed and the counter is reset to zero. When this occurs, the subrate task must be scheduled for execution.

The event flags indicate whether or not a given task is scheduled for execution. For a multirate, multitasking model, the event flags are maintained by code in the model's generated example main program (`ert_main.c`) . For each task, the code maintains a task counter. When the counter reaches 0, indicating that the task's sample period has elapsed, the event flag for that task is set.

On each time step, the counters and event flags are updated and the base-rate task executes. Then, the scheduling flags are checked in `tid` order, and any task whose event flag is set is executed. This ensures that tasks are executed in order of priority.

For bareboard targets that cannot rely on an external RTOS, the event flags are mandatory to allow overlapping task preemption. However, an RTOS target uses the operating system itself to manage overlapping task preemption, making the maintenance of the event flags redundant.

## Using rtmStepTask

The `rtmStepTask` macro is defined in `model.h` and its syntax is as follows:

```
   boolean task_ready = rtmStepTask(rtm, idx);
```

The arguments are:

- `rtm`: pointer to the real-time model structure (`rtM`)
- `idx`: task identifier (`tid`) of the task whose scheduling counter is to be tested

`rtmStepTask` returns `TRUE` if the task's scheduling counter equals zero, indicating that the task should be scheduled for execution on the current time step. Otherwise, it returns `FALSE`.

If your target supports the **Generate an example main program** parameter, you can generate calls to `rtmStepTask` using the TLC function `RTMTaskRunsThisBaseStep`.

## Task Scheduling Code for Multirate Multitasking Model on Wind River Systems VxWorks Target

The following task scheduling code, from `ertmainlib.tlc`, is designed for multirate multitasking operation on a Wind River® Systems VxWorks® target. The example uses the TLC function `RTMTaskRunsThisBaseStep` to generate calls to the `rtmStepTask` macro. A loop iterates over each subrate task, and `rtmStepTask` is called for each task. If `rtmStepTask` returns `TRUE`, the VxWorks `semGive` function is called, and the VxWorks RTOS schedules the task to run.

```
%assign ifarg = RTMTaskRunsThisBaseStep("i")
for (i = 1; i < %<FcnNumST>; i++) {
   if (%<ifarg>) {
     semGive(taskSemList[i]);
     if (semTake(taskSemList[i],NO_WAIT) != ERROR) {
       logMsg("Rate for SubRate task %d is too fast.\n",i,0,0,0,0,0);
       semGive(taskSemList[i]);
     }
   }
}
```

## Suppressing Redundant Scheduling Calls

Redundant scheduling calls are still generated by default for backward compatibility. To change this setting and suppress them, add the following TLC variable definition to your system target file before the `%include "codegenentry.tlc"` statement:

```
%assign SuppressSetEventsForThisBaseRateFcn = 1
```

# Developing Model Patterns that Generate Specific C Constructs

## About Modeling Patterns

Several standard methods are available for setting up a model to generate specific C Constructs in your code. For preparing your model for code generation, some of these methods include: configuring signals and ports, initializing states, and setting up configuration parameters for code generation. Depending on the components of your model, some of these methods are optional. Methods for configuring a model to generate specific C constructs are organized by category, for example, the Control Flow category includes constructs `if-else`, `switch`, `for`, and `while`. Refer to the name of a construct to see how you should configure blocks and parameters in your model. Different modeling methodologies are available, such as Simulink blocks, Stateflow® charts, and Embedded MATLAB™ blocks, to implement a C construct.

Model examples have the following naming conventions:

| Model Components | Naming Convention |
|---|---|
| Inputs | `u1`, `u2`, `u3`, and so on |
| Outputs | `y1`, `y2`, `y3`, and so on |
| Parameters | `p1`, `p2`, `p3`, and so on |
| States | `x1`, `x2`, `x3`, and so on |

Input ports are named to reflect the signal names that they propagate.

## Standard Methods to Prepare a Model for Code Generation

**In this section...**

### Configuring Signals

1. Create a model in Simulink. See "Creating a Model" in the Simulink documentation.

2. Right-click a signal line. Select **Signal Properties**. A Signal Properties dialog box opens. See "Signal Properties Dialog Box" for more information.

3. Specify a signal name.

4. On the same Signal Properties dialog box, select the **Real-Time Workshop** tab and specify a storage class for the signals. (Examples use models with signals that are `Exported Global`).

### Configuring Input and Output Ports

1. In your model,

   Double-click an `Inport` or `Outport` block. A block parameters dialog box opens.

2. Select the **Signal Attributes** tab.

3. Specify the **Port dimensions** and **Data type**.

## Initializing States

1. Double-click a block.
2. In the block parameters dialog box, select the **Main** tab.
3. Specify the **Initial conditions** and **Sample time**. See "Working with Sample Times".
4. Select the **State Attributes** pane. Specify the state name. See "Block State Storage and Interfacing Considerations"
5. You can also use the Data Object Wizard for creating data objects. A part of this process initializes states. See "Creating Simulink Data Objects with Data Object Wizard" on page 11-5.

## Setting Up Configuration Parameters for Code Generation

1. Open the Configuration Parameter dialog box by selecting **Simulation > Configuration parameters**. You can also use the keyboard shortcut `Ctrl + E`.
2. Open the **Solver** pane and select
   - **Solver type**: `Fixed-Step`
   - **Solver**: `Discrete (no continuous states)`
3. Open the **Optimization** pane, and select the **Inline parameters** parameter.
4. Open the **Real-Time Workshop** pane, and specify `ert.tlc` as the **System Target File**.
5. Clear **Generate makefile**.
6. Select **Generate code only**.
7. Enable the HTML report generation by opening the **Real-Time Workshop > Report** pane and selecting **Generate HTML Report**, **Launch report**

**automatically**, and **Code-to-block highlighting**. Enabling the HTML report generation is optional.

8. Click **Apply** and then **OK** to exit.

## Configuring Stateflow Charts

If you have a Stateflow chart in your model, initialize the inputs, outputs, local variables, and parameters of the Stateflow chart for code generation.

1. In your model, double-click a Stateflow. If you are not familiar with Stateflow, see the *Stateflow Getting Started Guide*.
2. Select **Tools > Explore** or **Ctrl+R** to launch the Chart Explorer.
3. On the Chart Explorer, select **Add > Data** or enter **Ctrl+D**. From the drop-down list, select an input, output, local variable, parameter, or function call. You see a Data dialog box.
4. In the Data dialog box, enter the **Name** of the data.
5. Specify the **Scope**.
6. Specify the **Type**. Choose a built-in data type or inherit the data type.
7. Click **Apply** and close the dialog box.

## Control Flow

**In this section...**

### If-Else

#### C Construct

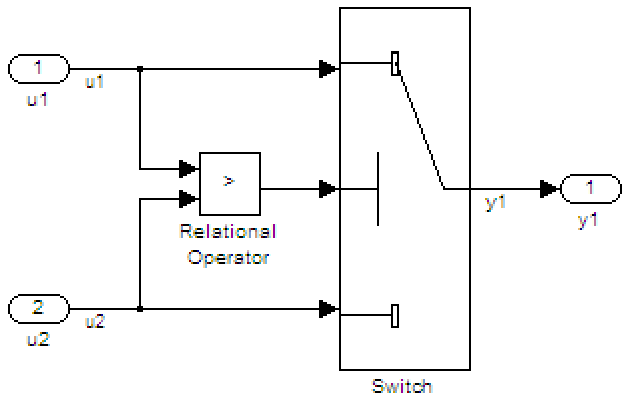
```
if (u1 > u2)
{
  y1 = u1;
}
else
{
  y1 = u2;
}
```

#### Modeling Patterns

- "Modeling Pattern for If-Else: Switch block" on page 5-7
- "Modeling Pattern for If-Else: Stateflow Chart" on page 5-9
- "Modeling Pattern for If-Else: Embedded MATLAB Block" on page 5-12

## Modeling Pattern for If-Else: Switch block

One method to create an `if-else` statement is to use a Switch block from the **Simulink > Signal Routing** library.



**Model If_Else_SL**

**Procedure.**

1 Drag the Switch block from the **Simulink>Signal Routing** library into your model.

2 Connect the data inputs and outputs to the block.

3 Drag a Relational Operator block from the Logic & Bit Operations library into your model.

4 Connect the signals that are used in the if-expression to the Relational Operator block. The order of connection determines the placement of each signal in the if-expression.

5 Configure the Relational Operator block to be a greater than operator.

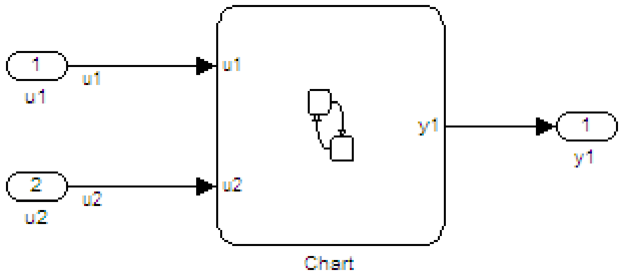
6 Connect the controlling input to the middle input port of the Switch block.

7 Double-click the Switch block and set **Criteria for passing first input** to `u2~=0`. This condition ensures that Simulink selects `u1` if `u2` is `TRUE`; otherwise `u2` passes.

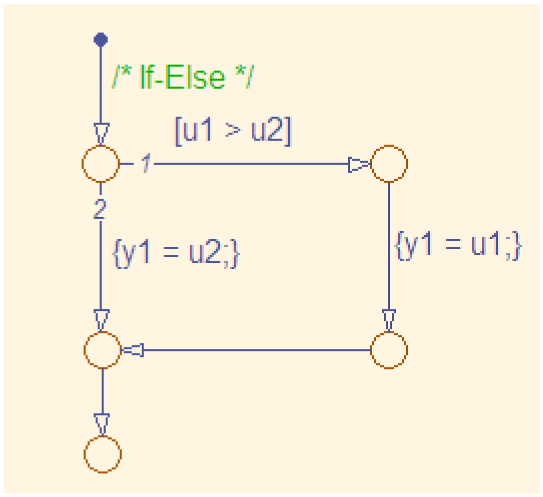
**Results.** Real-Time Workshop software generates the following `If_Else_SL_step` function in the file `If_Else_SL.c`:

```
/* External inputs (root inport signals with auto storage) */
ExternalInputs U;

/* External outputs (root outports fed by signals with auto storage) */
ExternalOutputs Y;

/* Model step function */
void If_Else_SL_step(void)
{
  /* Switch: '<Root>/Switch' incorporates:
   *  Inport: '<Root>/u1'
   *  Inport: '<Root>/u2'
   *  Outport: '<Root>/y1'
   *  RelationalOperator: '<Root>/Relational Operator'
   */
 if (U.u1 > U.u2) {
    Y.y1 = U.u1;
  } else {
    Y.y1 = U.u2;
  }
}
```

## Modeling Pattern for If-Else: Stateflow Chart



**Model If_Else_SF**



**If-Else Stateflow Chart**

**Procedure.**

**1** Drag a Stateflow chart from the Stateflow library into your model. Follow the steps in “Configuring Stateflow Charts” on page 5-5.

2 Double-click the chart and select **Tools > Explore** or enter **Ctrl+R** to open the Model Explorer.

3 Add the inputs and outputs to the chart and specify their data type.

4 Connect the data inputs and outputs to the block.

5 Select **Patterns > Add Decision > If-Else**. The Stateflow Pattern dialog opens. Fill in the fields as follows:

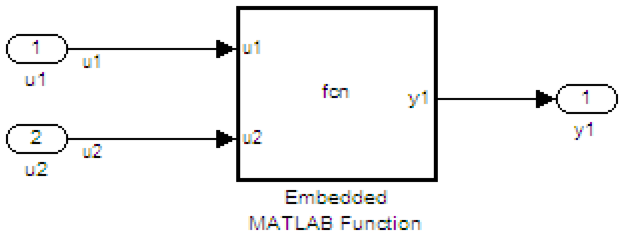
| | |
|---|---|
| **Description** | `If-Else` (optional) |
| **If condition** | `u1 > u2` |
| **If action** | `y1 = u1` |
| **Else action** | `y1 = u2` |

**Results.** Real-Time Workshop software generates the following `If_Else_SF_step` function in the file `If_Else_SF.c`:

```
/* External inputs (root inport signals with auto storage) */
ExternalInputs U;

/* External outputs (root outports fed by signals with auto storage) */
ExternalOutputs Y;

/* Model step function */
void If_Else_SF_step(void)
{
  /* Stateflow: '<Root>/Chart' incorporates:
   *  Inport: '<Root>/u1'
   *  Inport: '<Root>/u2'
   *  Outport: '<Root>/y1'
   */
  /* Gateway: Chart */
  /* During: Chart */
  /* Transition: '<S1>:14' */
  /*  If-Else  */
  if (U.u1 > U.u2) {
    /* Transition: '<S1>:13' */
    /* Transition: '<S1>:12' */
```

```
      Y.y1 = U.u1;

      /* Transition: '<S1>:11' */
    } else {
      /* Transition: '<S1>:10' */
      Y.y1 = U.u2;
    }

    /* Transition: '<S1>:9' */
  }
```

## Modeling Pattern for If-Else: Embedded MATLAB Block



**Model If_Else_EML**

**Procedure.**

1 Add two Inport blocks and an Outport block to your model and configure them.

2 Drag anEmbedded MATLAB Function block from the Simulink User-defined Functions library into the model.

3 Double-click the block and the Embedded MATLAB editor opens. Edit the function to include the statement:

```
function y1 = fcn(u1, u2)
if u1 > u2;
  y1 = u1;
else y1 = u2;
end
```

4 Connect the data inputs and output to the Embedded MATLAB Function block.

5 Click **File > Save** and close the Embedded MATLAB editor.

6 Save your model.

**Results.** Real-Time Workshop software generates the following `If_Else_EML_step` function in the file `If_Else_EML.c`:

```
/* External inputs (root inport signals with auto storage) */
ExternalInputs U;

/* External outputs (root outports fed by signals with auto storage) */
ExternalOutputs Y;

/* Model step function */
void If_Else_EML_step(void)
{
  /* Embedded MATLAB: '<Root>/Embedded MATLAB Function' incorporates:
   *  Inport: '<Root>/u1'
   *  Inport: '<Root>/u2'
   *  Outport: '<Root>/y1'
   */
  /* Embedded MATLAB Function 'Embedded MATLAB Function': '<S1>:1' */
  if (U.u1 > U.u2) {
    /* '<S1>:1:4' */
    /* '<S1>:1:5' */
    Y.y1 = U.u1;
  } else {
    /* '<S1>:1:6' */
    Y.y1 = U.u2;
  }
}
```

## Switch

### C Construct

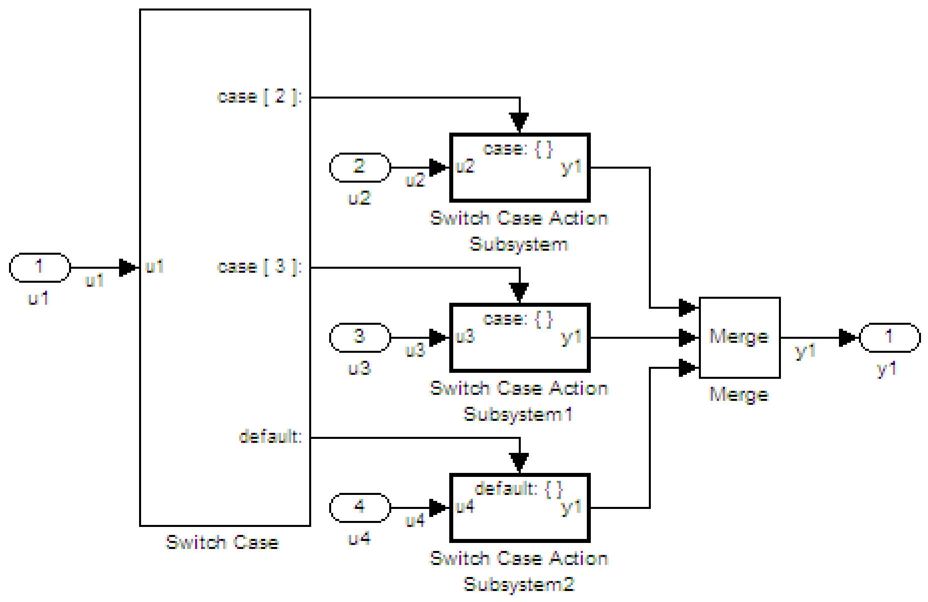
```
switch (u1)
{
 case 2:
    y1 = u2;
    break;
 case 3:
    y1 = u3;
    break;
 default:
    y1 = u4;
    break;
}
```

### Modeling Patterns

- “Modeling Pattern for Switch: Switch Case block” on page 5-15
- “Modeling Pattern for Switch: Embedded MATLAB block” on page 5-18
- “Converting If-Elseif-Else to Switch statement” on page 5-20

## Modeling Pattern for Switch: Switch Case block

One method for creating a `switch` statement is to use a Switch Case block from the **Simulink > Ports and Subsystems** library.



**Model Switch_SL**

**Procedure.**

**1** Drag a Switch Case block from the **Simulink > Ports and Subsystems** library into your model.

**2** Double-click the block. In the Block parameters dialog box, fill in the **Case Conditions** parameter. In this example, the two cases are: `{2,3}`.

**3** Select the **Show default case** parameter. The default case is optional in a `switch` statement.

**4** Connect the condition input `u1` to the input port of the Switch block.

5 Drag Switch Case Action Subsystem blocks from the **Simulink>Ports and Subsystems** library to correspond with the number of cases.

6 Configure the Switch Case Action Subsystem subsystems.

7 Drag a Merge block from the **Simulink > Signal Routing** library to merge the outputs.

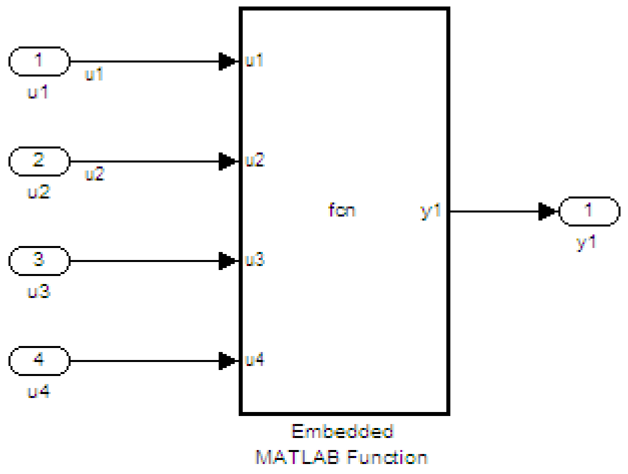
8 The Switch Case block takes an integer input, therefore, the input signal `u1` is type cast to an `int32`.

**Results.** Real-Time Workshop software generates the following `Switch_SL_step` function in the file `Switch_SL.c`:

```
/* Exported block signals */
int32_T u1;                           /* '<Root>/u1' */

/* External inputs (root inport signals with auto storage) */
ExternalInputs U;

/* External outputs (root outports fed by signals with auto storage) */
ExternalOutputs Y;

/* Model step function */
void Switch_SL_step(void)
{
  /* SwitchCase: '<Root>/Switch Case' incorporates:
   *  ActionPort: '<S1>/Action Port'
   *  ActionPort: '<S2>/Action Port'
   *  ActionPort: '<S3>/Action Port'
   *  Inport: '<Root>/u1'
   *  SubSystem: '<Root>/Switch Case Action Subsystem'
   *  SubSystem: '<Root>/Switch Case Action Subsystem1'
   *  SubSystem: '<Root>/Switch Case Action Subsystem2'
   */
  switch (u1) {
   case 2:
    /* Inport: '<S1>/u2' incorporates:
     *  Inport: '<Root>/u2'
     *  Outport: '<Root>/y1'
     */
```

```
      Y.y1 = U.u2;
      break;

     case 3:
      /* Inport: '<S2>/u3' incorporates:
       *  Inport: '<Root>/u3'
       *  Outport: '<Root>/y1'
       */
      Y.y1 = U.u3;
      break;

     default:
      /* Inport: '<S3>/u4' incorporates:
       *  Inport: '<Root>/u4'
       *  Outport: '<Root>/y1'
       */
      Y.y1 = U.u4;
      break;
    }
  }
```

### Modeling Pattern for Switch: Embedded MATLAB block



**Model Switch_EML**

**Procedure.**

1 Add four Inport blocks and one Outport block to your model.

2 Drag an Embedded MATLAB Function block from the **Simulink > User Defined Functions** library into your model.

3 Double-click the Embedded MATLAB Function block. The Embedded MATLAB editor opens.

4 Edit the function to include the statement:

```
function y1 = fcn(u1, u2, u3, u4)

switch u1
    case 2
        y1 = u2;
    case 3
        y1 = u3;
    otherwise
```

```
            y1 = u4;
    end
```

5 Connect the data inputs and outputs to the Embedded MATLAB Function block.

6 Click **File > Save** and close the Embedded MATLAB editor.

7 Save your model.

**Results.** Real-Time Workshop software generates the following `Switch_EML_step` function in the file `Switch_EML.c`:

```
/* External inputs (root inport signals with auto storage) */
   ExternalInputs U;

   /* External outputs (root outports fed by signals with auto storage) */
   ExternalOutputs Y;

   /* Model step function */
   void Switch_EML_step(void)
   {
     /* Embedded MATLAB: '<Root>/Embedded MATLAB Function' incorporates:
      *  Inport: '<Root>/u1'
      *  Inport: '<Root>/u2'
      *  Inport: '<Root>/u3'
      *  Inport: '<Root>/u4'
      *  Outport: '<Root>/y1'
      */
     /* Embedded MATLAB Function 'Embedded MATLAB Function': '<S1>:1' */
     /* '<S1>:1:4' */
     switch (U.u1) {
      case 2:
       /* '<S1>:1:6' */
       Y.y1 = U.u2;
       break;

      case 3:
       /* '<S1>:1:8' */
       Y.y1 = U.u3;
       break;
```

```
        default:
         /* '<S1>:1:10' */
         Y.y1 = U.u4;
         break;
       }
     }
```

## Converting If-Elseif-Else to Switch statement

For an Embedded MATLAB Function block containing an `if-elseif-else` construct, you can select a configuration parameter for your model to convert the `if-elseif-else` to a `switch` statement. In the Configuration Parameters dialog box, on the **Real-Time Workshop > Code Style** pane, select the “Convert if-elseif-else patterns to switch-case statements” parameter. For more information, see “Converting If-Elseif-Else Code to Switch-Case Statements” in the Simulink documentation.

## For loop

### C Construct

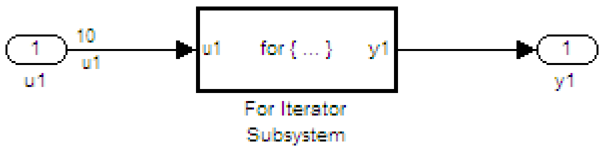
```
y1 = 0;
for(inx = 0; inx <10; inx++)
{
  y1 = u1[inx] + y1;
}
```

### Modeling Patterns:

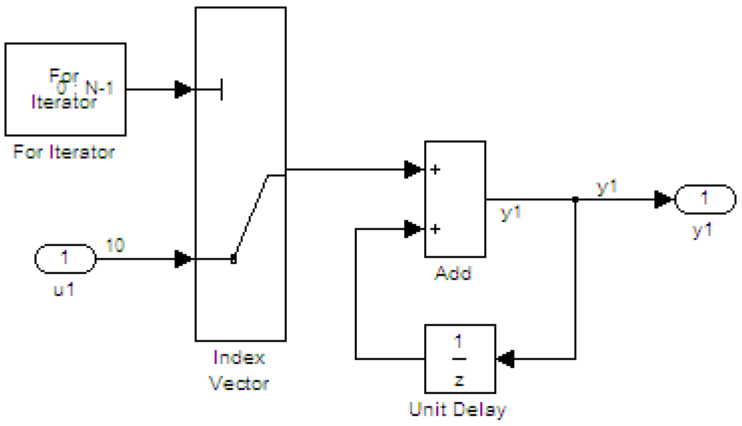
- "Modeling Pattern for For Loop: For-Iterator Subsystem block" on page 5-22
- "Modeling Pattern for For Loop: Stateflow Chart" on page 5-25
- "Modeling Pattern for For Loop: Embedded MATLAB block" on page 5-28

## Modeling Pattern for For Loop: For-Iterator Subsystem block

One method for creating a `for` loop is to use a For Iterator Subsystem block from the **Simulink > Ports and Subsystems** library.



**Model For_Loop_SL**



**For Iterator Subsystem**

### Procedure.

1 Drag a For Iterator Subsystem block from the **Simulink > Ports and Subsystems** library into your model.

2 Connect the data inputs and outputs to the For Iterator Subsystem block.

3 Open the Inport block.

4 In the Block parameter dialog box, select the **Signal Attributes** pane and set the **Port dimensions** parameter to 10.

5 Double-click the For Iterator Subsystem block to open the subsystem.

6 Drag an Index Vector block from the Signal-Routing library into the subsystem.

7 Open the For Iterator block. In the Block parameter dialog box set the **Index-mode** parameter to `Zero-based` and the **Iteration limit** parameter to 10.

8 Connect the controlling input to the topmost input port of the Index Vector block, and the other input to the second port.

9 Drag an Add block from the **Math Operations** library into the subsystem.

10 Drag a Unit Delay block from **Commonly Used Blocks** library into the subsystem.

11 Double-click the Unit Delay block and set the **Initial Conditions** parameter to `0`. This parameter initializes the state to zero.

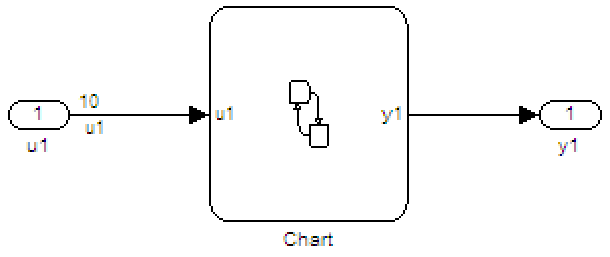
12 Connect the blocks as shown in the model diagram.

13 Save the subsystem and the model.

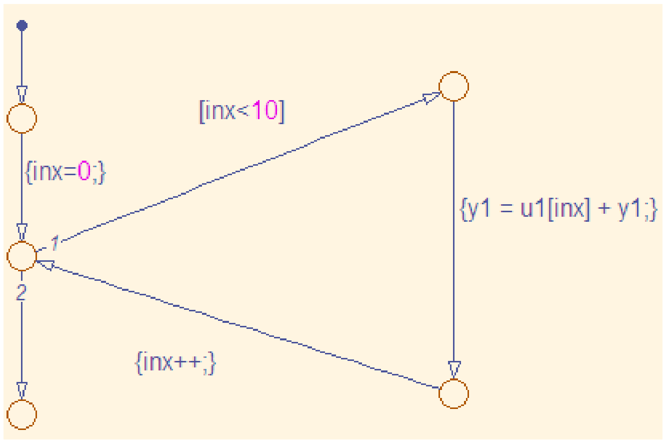
**Results.** Real-Time Workshop software generates the following `For_Loop_SL_step` function in the file `For_Loop_SL.c`:

```
  /* External inputs (root inport signals with auto storage) */
ExternalInputs U;

/* External outputs (root outports fed by signals with auto storage) */
ExternalOutputs Y;

/* Model step function */
void For_Loop_SL_step(void)
{
  int32_T s1_iter;
  int32_T rtb_y1;
  /* Outputs for iterator SubSystem: '<Root>/For Iterator Subsystem' incorporates:
   *  ForIterator: '<S1>/For Iterator'
   */
  for (s1_iter = 0; s1_iter < 10; s1_iter++) {
    /* Sum: '<S1>/Add' incorporates:
     *  Inport: '<Root>/u1'
     *  MultiPortSwitch: '<S1>/Index Vector'
     *  UnitDelay: '<S1>/Unit Delay'
     */
    rtb_y1 = U.u1[s1_iter] + DWork.UnitDelay_DSTATE;

    /* Update for UnitDelay: '<S1>/Unit Delay' */
    DWork.UnitDelay_DSTATE = rtb_y1;
  }

  /* end of Outputs for SubSystem: '<Root>/For Iterator Subsystem' */

  /* Outport: '<Root>/y1' */
  Y.y1 = rtb_y1;
}
```

## Modeling Pattern for For Loop: Stateflow Chart



**Model For_Loop_SF**



**Procedure.**

1 Drag a Stateflow chart from the Stateflow library into your model. Follow the steps in "Configuring Stateflow Charts" on page 5-5.

2 Double-click the chart and select **Tools > Explore** or enter **Ctrl+R** to open the Model Explorer.

3 Add the inputs and outputs to the chart and specify their data type.

**4** Connect the data input and output to the Stateflow chart.

**5** In the Model Explorer, select the output variable, then, in the right pane, select the **Value Attributes** tab and set the **Initial Value** to `0`.

**6** Select **Patterns > Add Loop > For**. The Stateflow Pattern dialog opens.

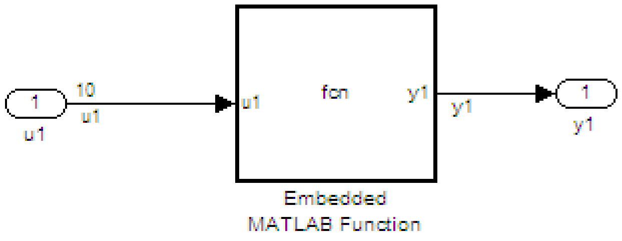
**7** Fill in the fields in the Stateflow Pattern dialog box as follows:

| | |
|---|---|
| **Description** | `For Loop` (optional) |
| **Initializer expression** | `inx = 0` |
| **Loop test expression** | `inx < 10` |
| **Counting expression** | `inx++` |
| **For loop body** | `y1 = u1[inx] + y1` |

**Results.** Real-Time Workshop software generates the following `For_Loop_SF_step` function in the file `For_Loop_SF.c`:

```
/* Block signals (auto storage) */
BlockIO B;

/* External inputs (root inport signals with auto storage) */
ExternalInputs U;

/* External outputs (root outports fed by signals with auto storage) */
ExternalOutputs Y;

/* Model step function */
void For_Loop_SF_step(void)
{
  int32_T sf_inx;

  /* Stateflow: '<Root>/Chart' incorporates:
   *  Inport: '<Root>/u1'
   */
  /* Gateway: Chart */
  /* During: Chart */
  /* Transition: '<S1>:24' */
  /*  For Loop  */
  /* Transition: '<S1>:25' */
  for (sf_inx = 0; sf_inx < 10; sf_inx++) {
    /* Transition: '<S1>:22' */
    /* Transition: '<S1>:23' */
    B.y1 = U.u1[sf_inx] + B.y1;

    /* Transition: '<S1>:21' */
  }

  /* Transition: '<S1>:20' */

  /* Outport: '<Root>/y1' */
  Y.y1 = B.y1;
}
```

## Modeling Pattern for For Loop: Embedded MATLAB block



**Model For_Loop_EML**

**Procedure.**

1 Add an Inport and Outport block to your model.

2 Drag an Embedded MATLAB Function block from the **Simulink > User Defined Functions** library into your model.

3 Double-click the Embedded MATLAB Function block. The Embedded MATLAB editor opens.

4 Edit the function to include the statement:

```
function y1 = fcn(u1)

y1 = 0;

for inx=1:10
    y1 = u1(inx) + y1 ;
end
```

5 Connect the data inputs and outputs to the Embedded MATLAB Function block.

6 Click **File > Save** and close the Embedded MATLAB editor.

7 Save your model.

**Results.** Real-Time Workshop software generates the following `For_Loop_EML_step` function in the file `For_Loop_EML.c`:

```
/* Exported block signals */
real_T u1[10];                        /* '<Root>/u1' */
real_T y1;                            /* '<Root>/Embedded MATLAB Function' */

/* Model step function */
void For_Loop_EML_step(void)
{
  int32_T eml_inx;

  /* Embedded MATLAB: '<Root>/Embedded MATLAB Function' incorporates:
   *  Inport: '<Root>/u1'
   */
  /* Embedded MATLAB Function 'Embedded MATLAB Function': '<S1>:1' */
  /* '<S1>:1:3' */
  y1 = 0.0;
  for (eml_inx = 0; eml_inx < 10; eml_inx++) {
    /* '<S1>:1:5' */
    /* '<S1>:1:6' */
    y1 = u1[eml_inx] + y1;
  }
}
```

## While loop

### C Construct

```
while(flag && (num_iter <= 100)
{
  flag = func ();
  num_iter ++;
}
```

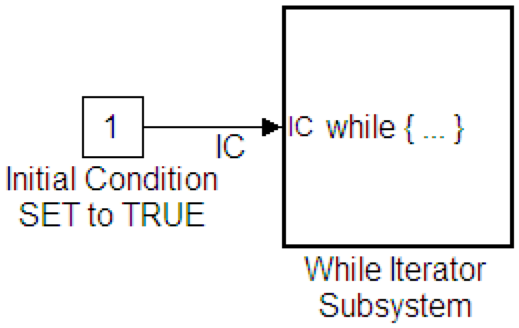
### Modeling Patterns

- "Modeling Pattern for While Loop: While Iterator Subsystem block" on page 5-31

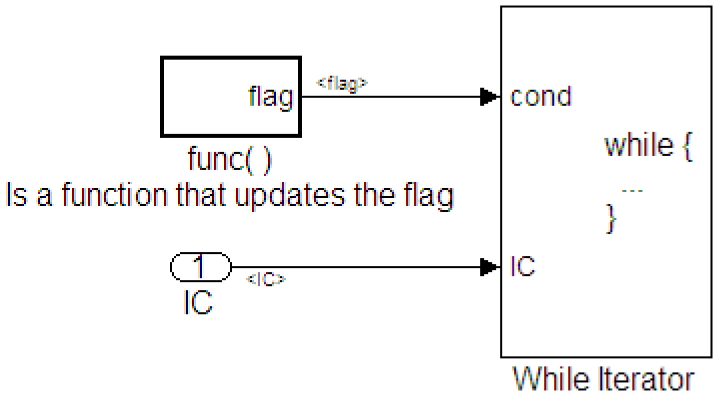
- "Modeling Pattern for While Loop: Stateflow Chart" on page 5-35
- "Modeling Pattern for While Loop: Embedded MATLAB block" on page 5-39

### Modeling Pattern for While Loop: While Iterator Subsystem block

One method for creating a `while` loop is to use a While Iterator Subsystem block from the **Simulink > Ports and Subsystems** library.



**Model While_Loop_SL**



**While_Loop_SL/While Iterator Subsystem**

**Procedure.**

1 Drag a While Iterator Subsystem block from the **Simulink > Ports and Subsystems** library into the model.

2 Drag a Constant block from the **Simulink > Commonly Used Blocks** library into the model. In this case, set the **Initial Condition** to `1` and the **Data Type** to `Boolean`. You do not always have to set the initial condition to `FALSE`. The initial condition can be dependent on the input to the block.

3 Connect the Constant block to the While Iterator Subystem block.

4 Double-click the While Iterator Subsystem block to open the subsystem.

5 Place a Subsystem block next to the While Iterator block.

6 Right-click the subsystem and select **Subsystem Parameters**. The Block parameters dialog box opens.

7 Select the **Treat as atomic unit** parameter to configure the subsystem to generate a function.

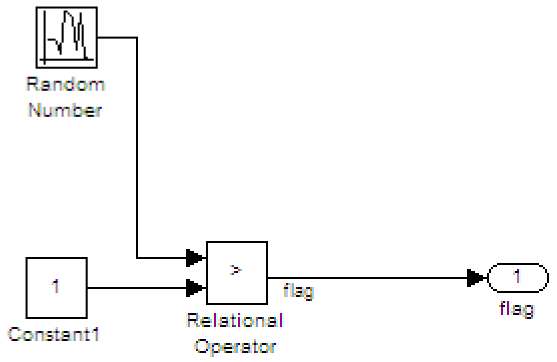
8 From the **Real-Time Workshop system code** list, select the option, `Function`.

9 From the **Real-Time Workshop function name options** list, select the option, `User specified`. The **Real-Time Workshop function name** parameter is displayed.

10 Specify the name as `func`.

11 Click **Apply**.

12 Double-click the `func()` subsystem block. In this example, function `func()` has an output `flag` set to `0` or `1` depending on the result of the algorithm in func( ). Create the func() algorithm as shown in the following diagram:



**func()**

**13** Double-click the While Iterator block to set the **Maximum number of iterations** to 100.

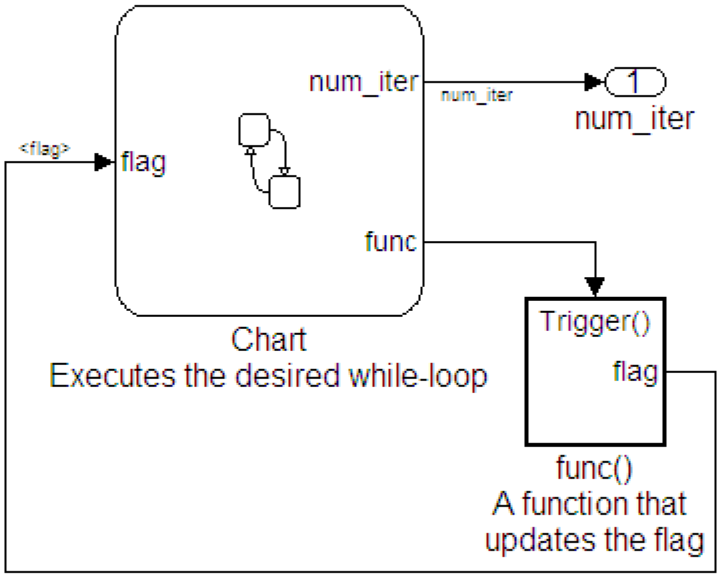
**14** Connect blocks as shown in the model and subsystem diagrams.

**Results.** Real-Time Workshop software generates the following `While_Loop_SL_step` function in the file `While_Loop_SL.c`:

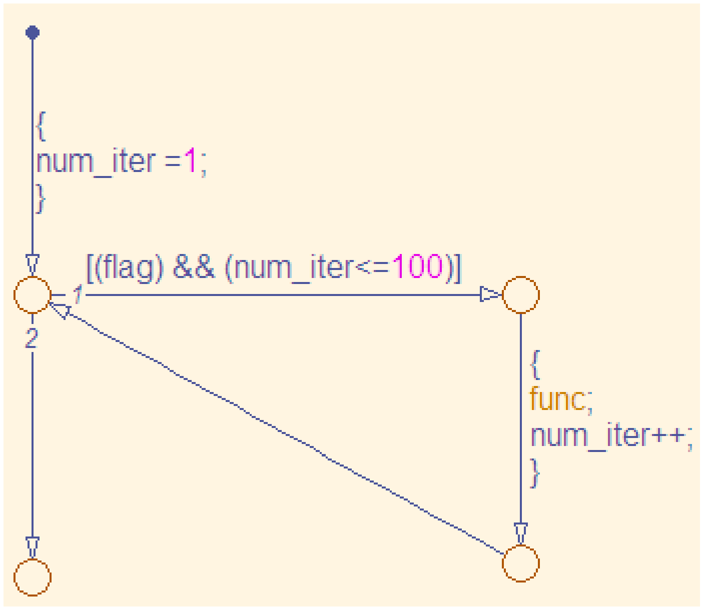
```
/* Exported block signals */
boolean_T IC;                           /* '<Root>/Initial Condition SET to TRUE' */
boolean_T flag;                         /* '<S2>/Relational Operator' */

/* Block states (auto storage) */
D_Work DWork;

/* Start for atomic system: '<S1>/func( ) Is a function that updates the flag' */
void func_Start(void)
{
  /* Start for RandomNumber: '<S2>/Random Number' */
  DWork.RandSeed = 1144108930U;
  DWork.NextOutput = rt_NormalRand(&DWork.RandSeed) * 1.7320508075688772E+000;
}

/* Output and update for atomic system:
 *  '<S1>/func( ) Is a function that updates the flag' */
void func(void)
```

```
{
  /* RelationalOperator: '<S2>/Relational Operator' incorporates:
   *  Constant: '<S2>/Constant1'
   *  RandomNumber: '<S2>/Random Number'
   */
  flag = (DWork.NextOutput > 1.0);

  /* Update for RandomNumber: '<S2>/Random Number' */
  DWork.NextOutput = rt_NormalRand(&DWork.RandSeed) * 1.7320508075688772E+000;
}

/* Model step function */
void While_Loop_SL_step(void)
{
  int32_T s1_iter;
  boolean_T loopCond;

  /* Outputs for iterator SubSystem:
   *     '<Root>/While Iterator Subsystem' incorporates:
   *  WhileIterator: '<S1>/While Iterator'
   */
  s1_iter = 1;
  loopCond = IC;
  while (loopCond && (s1_iter <= 100)) {
    /* Outputs for atomic SubSystem:
     * '<S1>/func( ) Is a function that updates the flag' */
    func();

    /* end of Outputs for SubSystem:
     * '<S1>/func( ) Is a function that updates the flag' */
    loopCond = flag;
    s1_iter++;
  }

  /* end of Outputs for SubSystem: '<Root>/While Iterator Subsystem' */
}
```

### Modeling Pattern for While Loop: Stateflow Chart



**Model While_Loop_SF**



**While_Loop_SF/Chart Executes the desired while-loop**

**Procedure.**

1 Drag a Stateflow chart from the Stateflow library into your model. Follow the steps in "Configuring Stateflow Charts" on page 5-5.

2 Double-click the chart and select **Tools > Explore** or enter **Ctrl+R** to open the Model Explorer.

3 Add the inputs and outputs to the chart and specify their data type.

4 Connect the data input and output to the Stateflow chart.

5 In the Model Explorer, select the output variable, then, in the right pane, select the **Value Attributes** tab and set the **Initial Value** to `0`.

6 Select **Patterns > Add Loop > While**. The Stateflow Pattern dialog opens.

7 Fill in the fields for the Stateflow Pattern dialog box as follows:

| | |
|---|---|
| **Description** | `While Loop` (optional) |
| **While condition** | `(flag) && (num_iter<=100)` |
| **Do action** | `func; num_iter++;` |

8 Place a Subsystem block in your model.

9 Right-click the subsystem and select Subsystem Parameters. The Block parameters dialog box opens.

10 Select the **Treat as atomic unit** parameter to configure the subsystem to generate a function.

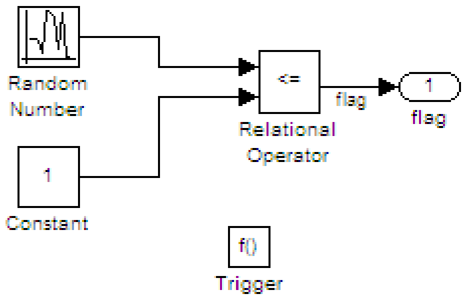
11 From the **Real-Time Workshop system code** list, select the option, `Function`.

12 From the **Real-Time Workshop function name options** list, select the option, `User specified`. The **Real-Time Workshop function name** parameter is displayed.

13 Specify the name as `func`.

14 Click **Apply** to apply all changes.

15 Double-click the `func()` subsystem block. In this example, function `func()` has an output `flag` set to `0` or `1` depending on the result of the algorithm in func( ). The Trigger block parameter **Trigger type** is `function-call`. Create the func() algorithm, as shown in the following diagram:



**While_Loop_SF/func() A function that updates the flag**

**16** Save and close the subsystem.

**17** Connect blocks to the Stateflow chart as shown in the model diagram for `While_Loop_SF`.

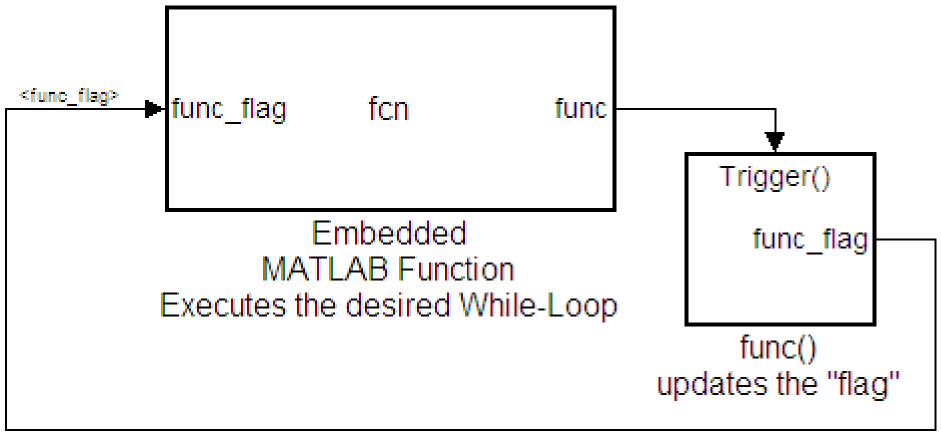
**18** Save your model.

**Results.** Real-Time Workshop software generates the following `While_Loop_SF_step` function in the file `While_Loop_SF.c`:

```
/* Exported block signals */
int32_T num_iter;  /* '<Root>/Chart Executes the desired while-loop' */
boolean_T flag;    /* '<S2>/Relational Operator' */

/* Block states (auto storage) */
D_Work DWork;

/* Model step function */
void While_Loop_SF_step(void)
{
  /* Stateflow: '<Root>/Chart Executes the desired
   * while-loop' incorporates:
   *  SubSystem: '<Root>/func() A function that
   *             updates the flag'
   */
  /* Gateway: Chart
     Executes the desired while-loop */
```

```
    /* During: Chart
       Executes the desired while-loop */
    /* Transition: '<S1>:2' */
    num_iter = 1;
    while (flag && (num_iter <= 100)) {
      /* Transition: '<S1>:3' */
      /* Transition: '<S1>:4' */
      /* Event: '<S1>:12' */
      func();
      num_iter = num_iter + 1;

      /* Transition: '<S1>:5' */
    }

    /* Transition: '<S1>:1' */
  }
```

### Modeling Pattern for While Loop: Embedded MATLAB block



**Model While_Loop_EML**

**Procedure.**

1 Add an Inport and Outport block to your model.

2 In the Simulink Library Browser, click **Simulink > User Defined Functions**, and drag an Embedded MATLAB Function block into your model.

3 Double-click the Embedded MATLAB Function block. The Embedded MATLAB editor opens.

4 Edit the function to include the statement:

```
function fcn(func_flag)

flag = true;
num_iter = 1;

while(flag && (num_iter<=100))
    func;
    flag = func_flag;
    num_iter = num_iter + 1;
end
```

5 Click **File > Save** and close the Embedded MATLAB editor.

6 Place a Subsystem block in your model, right-click the subsystem and select **Subsystem Parameters**. The Block parameters dialog box opens.

7 Select the **Treat as atomic unit** parameter to configure the subsystem to generate a function.

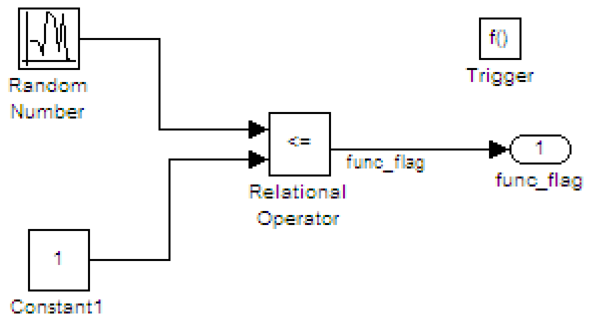
8 From the **Real-Time Workshop system code** list, select the option, `Function`.

9 From the **Real-Time Workshop function name options** list, select the option, `User specified`. The **Real-Time Workshop function name** parameter is displayed.

10 Specify the name as `func`.

11 Click **Apply**.

**12** Double-click the `func()` subsystem block. In this example, function `func()` has an output `flag` set to `0` or `1` depending on the result of the algorithm in func( ). The Trigger block parameter **Trigger type** is `function-call`. Create the func() algorithm, as shown in the following diagram:



**13** Save and close the subsystem.

**14** Connect the Embedded MATLAB Function block to the `func()` subsystem.

**15** Save your model.

**Results.** Real-Time Workshop software generates the following `While_Loop_EML_step` function in the file `While_Loop_EML.c`. In some cases an equivalent `for` loop might be generated instead of a `while` loop.

```
/* Exported block signals */
boolean_T func_flag;               /* '<S2>/Relational Operator' */

/* Block states (auto storage) */
D_Work DWork;

/* Model step function */
void While_Loop_EML_step(void)
{
  boolean_T eml_func_flag;
  boolean_T eml_flag;
  int32_T eml_num_iter;

  /* Embedded MATLAB: '<Root>/Embedded MATLAB Function Executes
```

```
     * the desired While-Loop' incorporates:
     *  SubSystem: '<Root>/func() updates the "flag"'
     */
    eml_func_flag = func_flag;

    /* Embedded MATLAB Function 'Embedded MATLAB Function
     * Executes the desired While-Loop': '<S1>:1' */
    /* '<S1>:1:3' */
     eml_flag = true;

    /* '<S1>:1:4' */
    for (eml_num_iter = 1; eml_flag && (eml_num_iter <= 100);
         eml_num_iter++) {
      /* '<S1>:1:6' */
      /* '<S1>:1:7' */
      func();

      /* '<S1>:1:8' */
      eml_flag = eml_func_flag;

      /* '<S1>:1:9' */
    }
  }
```

# Defining Data Representation and Storage for Code Generation

# Using mpt Data Objects

The following table describes the properties and property values for all `mpt.Parameter` and `mpt.Signal` data objects that appear in the Model Explorer.

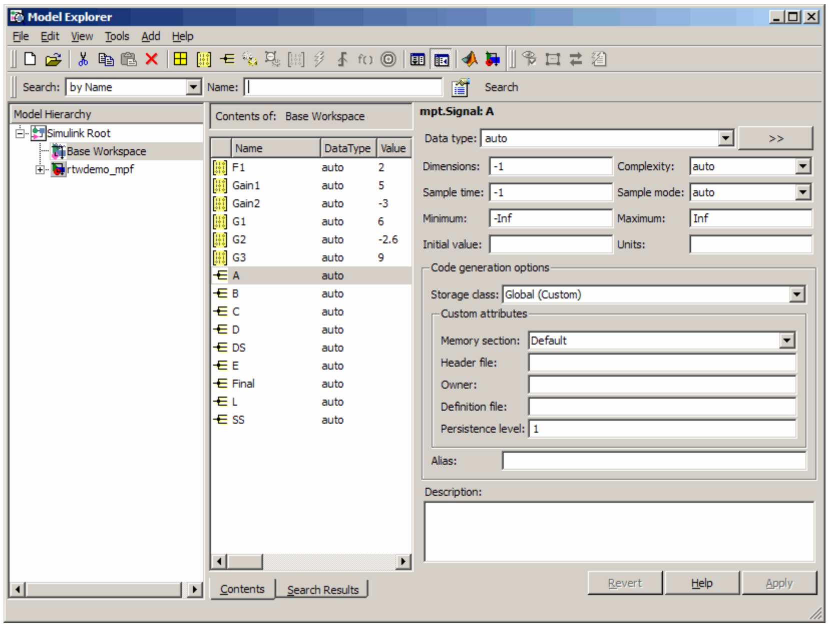
---

**Note** You can create `mpt.Signal` and `mpt.Parameter` objects in the base MATLAB® or model workspace. However, if you create the object in a model workspace, the object's storage class must be set to `auto`.

---

The figure below shows an example of the Model Explorer. When you select an `mpt.Parameter` or `mpt.Signal` data object in the middle pane, its properties and property values display in the rightmost pane.

In the Properties column, the table lists the properties in the order in which they appear on the Model Explorer. Another table describes the effects that example changes to property values have on the generated code.



Contents of: Base Workspace

| Name | DataType | Value |
|---|---|---|
| F1 | auto | 2 |
| Gain1 | auto | 5 |
| Gain2 | auto | -3 |
| G1 | auto | 6 |
| G2 | auto | -2.6 |
| G3 | auto | 9 |
| A | auto | |
| B | auto | |
| C | auto | |
| D | auto | |
| DS | auto | |
| E | auto | |
| Final | auto | |
| L | auto | |
| SS | auto | |

mpt.Signal: A

Data type: auto
Dimensions: -1
Complexity: auto
Sample time: -1
Sample mode: auto
Minimum: -Inf
Maximum: Inf
Initial value:
Units:
Code generation options
Storage class: Global (Custom)
Custom attributes
Memory section: Default
Header file:
Owner:
Definition file:
Persistence level: 1
Alias:
Description:

## Parameter and Signal Property Values

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Both | User object type | *`auto` | Prenamed and predefined property sets that are registered in the `sl_customization.m` file. (See “Registering mpt User Object Types” on page 11-49.) This field is unavailable if no user object type is registered.<br><br>Select `auto` if this field is available but you do not want to apply the properties of a user object type to a selected data object. The fields on the Model Explorer are populated with default values. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| | | Any user object type name listed | Select a user object type name to apply the properties and values that you associated with this name in the `sl_customization.m` file. The fields on the Model Explorer are automatically populated with those values. |
| Parameter | `Value` | `*0` | The data type and numeric value of the data object. For example, `int8(5)`. The numeric value is used as an initial parameter value in the generated code. |
| Both | Data type | | Used to specify the data type for an `mpt.Signal` data object, but not for an `mpt.Parameter` data object. The data type for an `mpt.Parameter` data object is specified in the **Value** field above. See "Working with Data Types" in the Simulink documentation. |
| Both | Units | `*null` | Units of measurement of the signal or parameter. (Enter text in this field.) |
| Both | Dimensions | `*-1` | The dimension of the signal or parameter. For a parameter, the dimension is derived from its value. |
| Both | Complexity | `*auto`<br>`real`<br>`complex` | Complexity specifies whether the signal or parameter is a real or complex number. Select `auto` for the code generator to decide. For a parameter, the complexity is derived from its value. |
| Signal | Sample time | `*-1` | Model or block execution rate. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Signal | Sample mode | `*auto` | Determines how the signal propagates through the model. Select `auto` for the code generator to decide. |
| | | `Sample based` | The signal propagates through the model one sample at a time. |
| | | `Frame based` | The signal propagates through the model in batches of samples. |
| Both | Minimum | `*0.0` | The minimum value to which the parameter or signal is expected to be bound. |
| | | Any number within the minimum range of the parameter or signal. (Based on the data type and resolution of the parameter or signal.) | |
| Both | Maximum | `*0.0` | Maximum value to which the parameter or signal is expected to be bound. (Enter information using a dialog box.) |
| | Code generation options | | |
| | Storage class | | Note that an `auto` selection for a storage class tells the Real-Time Workshop build process to decide how to declare and store the selected parameter or signal. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Both | Default (Custom) | | Real-Time Workshop Embedded Coder software decides how to declare the data object. |
| Both | Global (Custom) | `Global (Custom)` is the default storage class for `mpt` data objects. | Ensures that the code generator places no qualifier in the data object's declaration. |
| Both | Memory section | `*Default` | **Memory section** allows you to specify storage directives for the data object. `Default` ensures that the code generator places no type qualifier and no `pragma` statement with the data object's declaration. |
| Parameter | | `MemConst` | Places the `const` type qualifier in the declaration. |
| Both | | `MemVolatile` | Places the `volatile` type qualifier in the declaration. |
| Parameter | | `MemConstVolatile` | Places the `const volatile` type qualifier in the declaration. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Both | Header file | | Name of the file used to import or export the data object. This file contains the declaration (`extern`) to the data object.<br><br>Also, you can specify this header filename between the double-quotation or angle-bracket delimiter. You can specify the delimiter with or without the `.h` extension. For example, `"object.h"` or `"object"` has the same effect. For the selected data object, this overrides the general delimiter selection in the **#include file delimiter** field on the Configuration Parameters dialog box. |
| Both | Owner | *Blank | The name of the module that owns this signal or parameter. This is used to help determine the ownership of a definition. For details, see "Ownership Settings" on page 12-10 and "Effects of Ownership Settings" on page 12-22. |
| Both | Definition file | *Blank | Name of the file that defines the data object. |
| | | Any valid text string | |

**Parameter and Signal Property Values (Continued)**

| **Class: Parameter, Signal, or Both** | **Property** | **Available Property Values (* Indicates Default)** | **Description** |
|---|---|---|---|
| Both | Persistence level | | The number you specify is relative to **Signal display level** or **Parameter tune level** on the **Data Placement** pane of the Configuration Parameters dialog box. For a signal, allows you to specify whether or not the code generator declares the data object as global data. For a parameter, allows you to specify whether or not the code generator declares the data object as tunable global data. See **Signal display level** and **Parameter tune level** in "Real-Time Workshop Pane: Data Placement". |
| Both | Bitfield (Custom) | | Embeds Boolean data in a named bit field. |
| | Struct name | | Name of the `struct` into which the object's data will be packed. |
| Parameter | Const (Custom) | | Places the `const` type qualifier in the declaration. |
| Parameter | Header file | | See above. |
| Parameter | Owner | | See above. |
| Parameter | Definition file | | See above. |
| Parameter | Persistence level | | See above. |
| Both | Volatile (Custom) | | Places the `volatile` type qualifier in the declaration. |
| Both | Header file | | See above. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Both | Owner | | See above. |
| Both | Definition file | | See above. |
| Both | Persistence level | | See above. |
| Parameter | ConstVolatile (Custom) | | Places the `const volatile` type qualifier in declaration. |
| Parameter | Header file | | See above. |
| Parameter | Owner | | See above. |
| Parameter | Definition file | | See above. |
| Parameter | Persistence level | | See above. |
| Parameter | Define (Custom) | | Represents parameters with a `#define` macro. |
| Parameter | Header file | | See above. |
| Both | ExportToFile (Custom) | | Generates global variable definition, and generates a user-specified header (`.h`) file that contains the declaration (`extern`) to that variable. |
| Both | Memory section | | See above. |
| Both | Header file | | See above. |
| Both | Definition file | | See above. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Both | ImportFromFile (Custom) | | Includes predefined header files containing global variable declarations, and places the `#include` in a corresponding file. Assumes external code defines (allocates memory) for the global variable. |
| Both | Data access | `*Direct` | Allows you to specify whether the identifier that corresponds to the selected data object stores data of a data type (`Direct`) or stores the address of the data (a pointer). |
| Both | | `Pointer` | If you select `Pointer`, the code generator places `*` before the identifier in the generated code. |
| | Header file | | See above. |
| Both | Struct (Custom) | | Embeds data in a named `struct` to encapsulate sets of data. |
| Both | Struct name | | See above. |
| Signal | GetSet (Custom) | | Reads (gets) and writes (sets) data using functions. |
| Signal | Header file | | See above. |
| Signal | Get function | | Specify the Get function. |
| Signal | Set function | | Specify the Set function. |

**Parameter and Signal Property Values (Continued)**

| Class: Parameter, Signal, or Both | Property | Available Property Values (* Indicates Default) | Description |
|---|---|---|---|
| Both | Alias | `*null` | As explained in detail in "Applying Naming Rules to Identifiers Globally" on page 11-31, for a Simulink or `mpt` data object (identifier), specifying a name in the **Alias** field overrides the global naming rule selection you make on the Configuration Parameters dialog box. |
| | | Any valid ANSI®[1] C/C++ variable name | |
| Both | `Description` | `*null` | Text description of the parameter or signal. Appears as a comment beside the signal or parameter's identifier in the generated code. |
| | | Any text string | |

1. ANSI® is a registered trademark of the American National Standards Institute, Inc.

**Some Examples of the Effect of Property Value Changes on Generated Code**

| What I noticed when inspecting the .c/.cpp file | Change I made to property value settings | What I noticed after regenerating and reinspecting the file |
|---|---|---|
| Example 1:<br>Parameter data objects can be declared or defined as constants. I know that the data object `GAIN` is a parameter. I want this to be declared or defined in the `.c` file as a variable. But I notice that `GAIN` is declared as a constant by the statement `const real_T GAIN = 5.0;`. Also, this statement is in the constant section of the file. | In the Model Explorer, I clicked the data object `GAIN`. I noticed that the property value for its **Memory section** property is set at `MemConst`. I changed this to `Default`. | I notice two differences. One is that now `GAIN` is declared as a variable with the statement `real_T GAIN = 5.0;`. The second difference is that the declaration now is located in the `MemConst` memory section in the `.c` or `.cpp` file. |
| Example 2:<br>I notice again the declaration of `GAIN` in the `.c` file mentioned in Example 1. It appears as `real_T GAIN = 5.0;`. But I have changed my mind. I want data object `GAIN` to be `#define`. | I changed the **Storage class** selection to `Define (Custom)`. | `GAIN` is no longer declared in the `.c` file as a `MemConst` parameter. Rather, it now is defined as a `#define` macro by the code `#define GAIN 5.0`, and this is located near the top of the `.c` file with the other preprocessor directives. |

**Some Examples of the Effect of Property Value Changes on Generated Code (Continued)**

| What I noticed when inspecting the .c/.cpp file | Change I made to property value settings | What I noticed after regenerating and reinspecting the file |
|---|---|---|
| Example 3:<br>I changed my mind again after doing Example 2. I do want `GAIN` defined using the `#define` preprocessor directive. But I do not want to include the `#define` in this file. I know it exists in another file and I want to reference that file. | On the Model Explorer, I notice that the property value for the **Header file** property is blank. I changed this to `filename.h`. (I chose the ANSI C/C++ double quote mechanism for the `#include`, but could have chosen the angle bracket mechanism.) Also, it is necessary that I make the user-defined `filename.h` available to the compiler, placing it either in the system path or local directory. | The `#define GAIN 5.0` is no longer in this `.c` file. Instead, the `#include filename.h` code appears as a preprocessor directive at the top of the file. |
| Example 4:<br>I have one more change I want to make. Let us say that we have declared the data object `data_in`, and that its declaration statement in the `.c` file reads `real_T data_in = 0.0;`. I want to replace this in all locations in the `.c` file with an alias. | In the Model Explorer, I selected the data object `data_in`. I noticed that the **Alias** field is blank. I changed this to `data_in_alias`, which I know is a valid ANSI C/C++ variable name. | The identifier `data_in_alias` now appears in the `.c` file everywhere `data_in` appeared. |

# Creating and Using Custom Storage Classes

## Introduction to Custom Storage Classes

**In this section...**

During the Real-Time Workshop build process, the *storage class* specification of a signal, tunable parameter, block state, or data object specifies how that entity is declared, stored, and represented in generated code. Note that in the context of the Real-Time Workshop build process, the term "storage class" is not synonymous with the term "storage class specifier", as used in the C language.

The Real-Time Workshop software defines four built-in storage classes for use with all targets: `Auto`, `ExportedGlobal`, and `ImportedExtern`, and `ImportedExternPointer`. These storage classes provide limited control over the form of the code generated for references to the data. For example, data of storage class `Auto` is typically declared and accessed as an element of a structure, while data of storage class `ExportedGlobal` is declared and accessed as unstructured global variables. For information about built-in storage classes, see "Signal Considerations" and "Simulink Data Object Considerations" in the Real-Time Workshop documentation.

The built-in storage classes are suitable for many applications, but embedded system designers often require greater control over the representation of data. Real-Time Workshop Embedded Coder *custom storage classes* (CSCs) extend the built-in storage classes provided by the Real-Time Workshop software. CSCs can provide application-specific control over the constructs required to represent data in an embedded algorithm. For example, you can use CSCs to:

### Custom Storage Class Memory Sections

Every custom storage class has an associated *memory section* definition. A memory section is a named collection of properties related to placement of an object in memory; for example, in RAM, ROM, or flash memory. Memory section properties let you specify storage directives for data objects. For example, you can specify `const` declarations, or compiler-specific `#pragma` statements for allocation of storage in ROM or flash memory sections.

See "Creating and Editing Memory Section Definitions" on page 7-31 for details about using the Custom Storage Class designer to define memory sections. While memory sections are often used with data in custom storage classes, they can also be used with various other constructs. See Chapter 8, "Inserting Comments and Pragmas in Generated Code" for more information about using memory sections with custom storage classes, and complete information about using memory sections with other constructs.

## Registering Custom Storage Classes

CSCs are associated with Simulink data class packages (such as the `Simulink` package) and with classes within packages (such as the `Simulink.Parameter` and `Simulink.Signal` classes). The custom storage classes associated with a package are defined by a *CSC registration file*. For example, a CSC registration file is provided for the `Simulink` package. This registration file provides predefined CSCs for use with the `Simulink.Signal` and `Simulink.Parameter` classes and with subclasses derived from these classes. The predefined CSCs are sufficient for a wide variety of applications.

If you use only predefined CSCs, you do not need to be concerned with CSC registration files. By default, you cannot add or change CSCs associated with built-in packages and classes, but you can create your own packages and subclasses, then associate CSCs with those. See "Custom Storage Class Implementation" on page 7-70 for more information.

## Custom Storage Class Demos

Three demos are available that show Custom Storage Class capabilities:

`rtwdemo_cscpredef` — Shows predefined custom storage classes and embedded signal objects

`rtwdemo_importstruct` — Shows custom storage classes used to access imported data efficiently

`rtwdemo_advsc` — Shows how custom storage classes can support data dictionary driven modeling

To launch a demo, click the demo's name above, or type its name in the MATLAB Command Window.

## Resources for Defining Custom Storage Classes

The resources for working with custom storage class definitions are:

- The Simulink Data Class Designer, which you can use to create a data object package and enable the ability to define your own CSC definitions for classes contained in the package. For information about the Data Class Designer, see "Subclassing Simulink Data Classes" and "Creating Packages that Support CSC Definitions" on page 7-8.
- A set of ready-to-use CSCs. These CSCs are designed to be useful in code generation for embedded systems development. CSC functionality is integrated into the `Simulink.Signal` and `Simulink.Parameter` classes; you do not need to use special object classes to generate code with CSCs. If you are unfamiliar with the `Simulink.Signal` and `Simulink.Parameter` classes and objects, read the "Simulink Data Object Considerations" section of the Real-Time Workshop documentation.
- The Custom Storage Class Designer (`cscdesigner`) tool, which is described in this chapter. This tool lets you define CSCs that are tailored to your code generation requirements. The Custom Storage Class Designer provides a graphical user interface that you can use to implement CSCs. You can use your CSCs in code generation immediately, without any Target Language Compiler (TLC) or other programming. See "Designing Custom Storage Classes and Memory Sections" on page 7-12 for details.

## Simulink Package Custom Storage Classes

The `Simulink` package includes a set of built-in custom storage classes. These are categorized custom storage classes, even though they are built-in, because they extend the storage classes provided by the Real-Time Workshop software. By default, you cannot change the CSCs in the `Simulink` package, but you can subclass the package and add CSCs to the subclass, following the steps in “Resources for Defining Custom Storage Classes” on page 7-5.

Some CSCs in the `Simulink` package are valid for parameter objects but not signal objects and vice versa. For example, you can assign the storage class `Const` to a parameter but not to a signal, because signal data is not constant. The next table defines the CSCs built into the `Simulink` package and shows where each of the CSCs can be used.

| CSC Name | Purpose | Signals? | Parameters? |
|---|---|---|---|
| `BitField` | Generate a `struct` declaration that embeds Boolean data in named bit fields. | Y | Y |
| `CompilerFlag` | Supports preprocessor conditionals defined via compiler flag. See “Generating Code Variants for Variant Models” on page 3-2. | N | Y |
| `Const` | Generate a constant declaration with the `const` type qualifier. | N | Y |
| `ConstVolatile` | Generate declaration of volatile constant with the `const volatile` type qualifier. | N | Y |
| `Default` | `Default` is a placeholder CSC that the code generator assigns to the `RTWInfo.CustomStorageClass` property of signal and parameter objects when they are created. You cannot edit the default CSC definition. | Y | Y |
| `Define` | Generate `#define` directive. | N | Y |

| CSC Name | Purpose | Signals? | Parameters? |
|---|---|---|---|
| `ExportToFile` | Generate header (`.h`) file, with user-specified name, containing global variable declarations. | Y | Y |
| `GetSet` | Supports specialized function calls to read and write the memory associated with a Data Store Memory block. See "GetSet Custom Storage Class for Data Store Memory" on page 7-66. | Y | Y |
| `ImportedDefine` | Supports preprocessor conditionals defined via legacy header file. See "Generating Code Variants for Variant Models" on page 3-2. | N | Y |
| `ImportFromFile` | Generate directives to include predefined header files containing global variable declarations. | Y | Y |
| `Struct` | Generate a `struct` declaration encapsulating parameter or signal object data. | Y | Y |
| `Volatile` | Use `volatile` type qualifier in declaration. | Y | Y |

## Creating Packages that Support CSC Definitions

You can create a package and associate your own CSC definitions with classes contained in the package. You do this by creating a data object package containing classes derived from `Simulink.Parameter` or `Simulink.Signal`. The procedure below shows how to create and configure such a package. For additional information, see "Subclassing Simulink Data Classes".

1 Open the Simulink Data Class Designer by choosing **Tools > Data Class Designer** in the model window, or typing the following at the MATLAB command prompt:

```
sldataclassdesigner
```

2 The Data Class Designer loads all packages that exist on the MATLAB path.

3 To create a new package, click **New** next to the **Package name** field. If desired, edit the **Package name**. Then, click **OK**.

4 In the **Parent directory** field, enter the path to the directory where you want to store the new package.

---

**Note** Do not create class package directories under *`matlabroot`*. Packages in these directories are treated as built-in and will not be visible in the Data Class Designer.

---

5 Click on the **Classes** tab.

6 Create a new class by clicking **New** next to the **Class name** field. If desired, edit the **Class name**. Then, click **OK**.

7 In the **Derived from** menus, select `Simulink.Signal` or `Simulink.Parameter`.

8 The **Create your own custom storage classes for this class** option is now enabled. This option is enabled when the selected class is derived from `Simulink.Signal` or `Simulink.Parameter`. You must select this option to create CSCs for the new class. If the **Create your own custom storage**

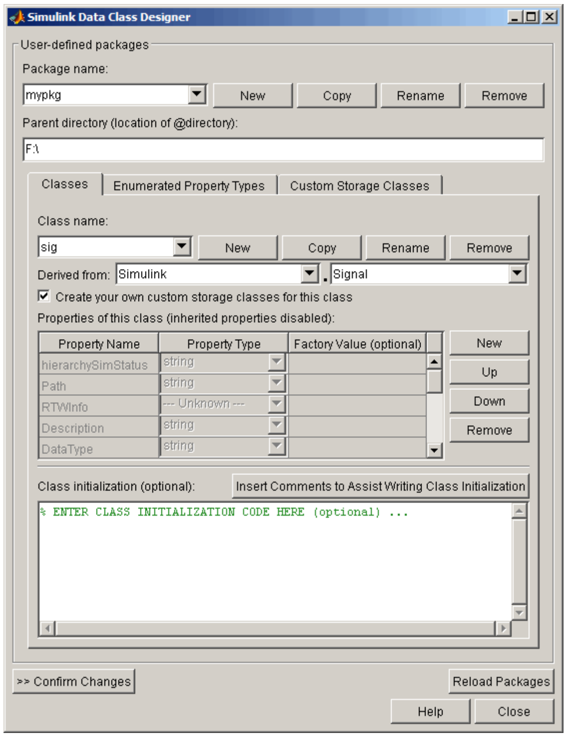
**classes for this class** option is not selected, the new class inherits the CSCs of the parent class.

---

**Note** To create a CSC registration file for a package, the **Create your own custom storage classes for this class** option must be selected for at least one of the classes in the package.

---

In the figure below, a new package called `mypkg` has been created. This package contains a new class, derived from `Simulink.Signal`, called `sig`. The **Create your own custom storage classes for this class** option is selected.



Package name: mypkg

Parent directory (location of @directory): F:\

Class name: sig

Derived from: Simulink . Signal

[✓] Create your own custom storage classes for this class

Properties of this class (inherited properties disabled):

| Property Name | Property Type | Factory Value (optional) |
|---|---|---|
| hierarchySimStatus | string | |
| Path | string | |
| RTWInfo | --- Unknown --- | |
| Description | string | |
| DataType | string | |

Class initialization (optional):

```
% ENTER CLASS INITIALIZATION CODE HERE (optional) ...
```

Complete instructions for using the Data Class Designer appear in “Subclassing Simulink Data Classes” in the Simulink documentation. See also the instructions that appear when you click the **Custom Storage Classes** tab.

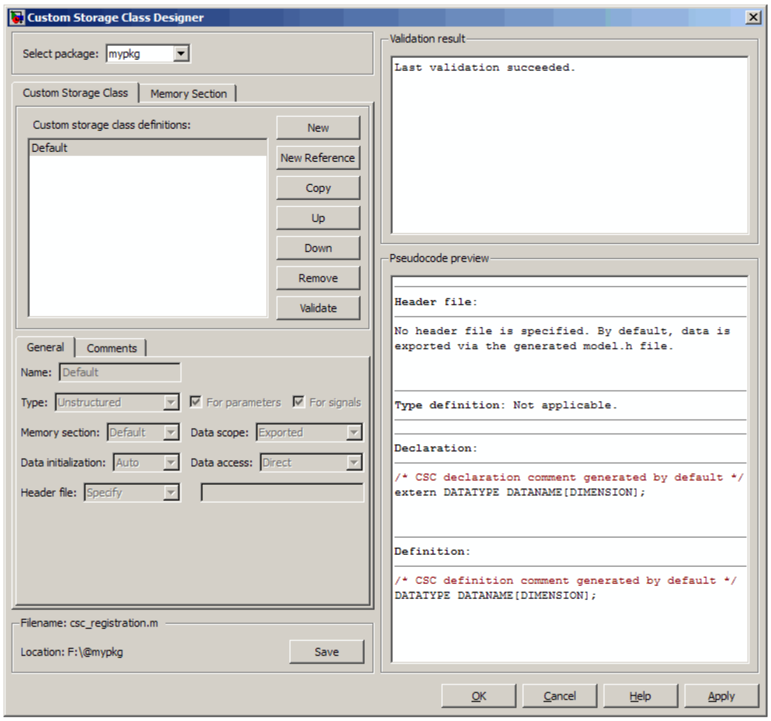
9 If desired, repeat steps 6–8 to add other derived classes to the package and associate CSCs with them.

10 Click **Confirm Changes**. In the **Confirm Changes** pane, select the package you created. Add the parent directory to the MATLAB path if necessary. Then, click **Write Selected**.

The package directories and files, including the CSC registration file, are written out to the parent directory.

11 Click **Close**.

12 You can now view and edit the CSCs belonging to your package in the Custom Storage Class Designer, which you open with the MATLAB command `cscdesigner`. Initially, the package contains only the `Default` CSC definition, as shown in the figure below.



Select package: mypkg

Custom storage class definitions: Default

Name: Default

Type: Unstructured ☑ For parameters ☑ For signals

Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

Filename: csc_registration.m

Location: F:\@mypkg

Validation result

```
Last validation succeeded.
```

Pseudocode preview

```
Header file:

No header file is specified. By default, data is
exported via the generated model.h file.

Type definition: Not applicable.

Declaration:

/* CSC declaration comment generated by default */
extern DATATYPE DATANAME[DIMENSION];

Definition:

/* CSC definition comment generated by default */
DATATYPE DATANAME[DIMENSION];
```

**13** Add and edit your CSC and memory section definitions, as described in “Designing Custom Storage Classes and Memory Sections” on page 7-12. After you have created CSC definitions for your package, you can instantiate objects of the classes belonging to your package, and assign CSCs to them.

You need to restart your MATLAB session before you can use the new CSCs with objects of your new classes.

## Designing Custom Storage Classes and Memory Sections

**In this section...**

### Using the Custom Storage Class Designer

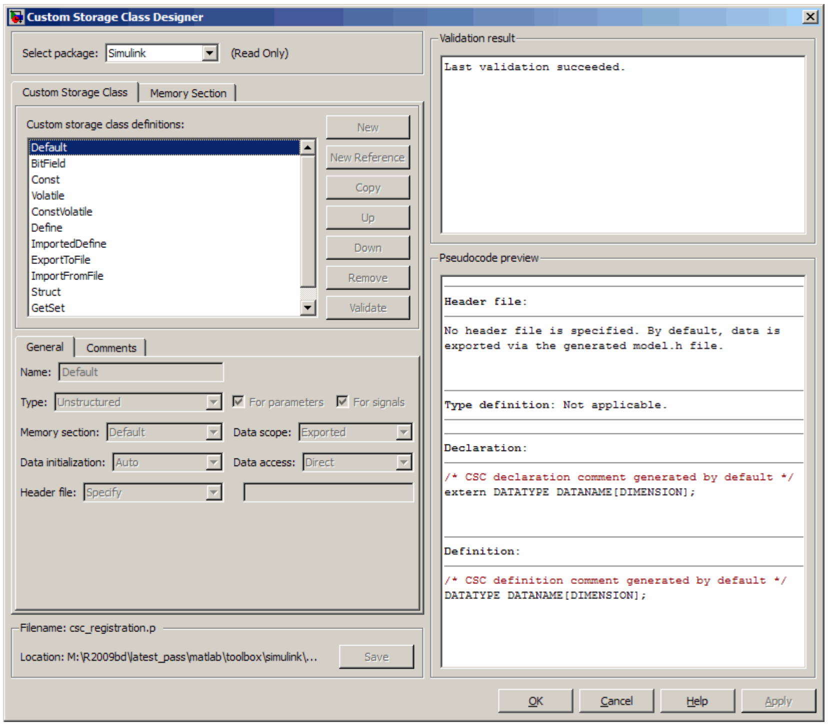
The Custom Storage Class Designer (`cscdesigner`) is a tool for creating and managing custom storage classes and memory sections. You can use the Custom Storage Class Designer to:

- Load existing custom storage classes and memory sections and view and edit their properties
- Create new custom storage classes and memory sections
- Create references to custom storage classes and memory sections defined in other packages
- Copy and modify existing custom storage class and memory section definitions
- Verify the correctness and consistency of custom storage class and memory section definitions
- Preview pseudocode generated from custom storage class and memory section definitions
- Save custom storage class and memory section definitions

To open the Custom Storage Class Designer, type the following command at the MATLAB prompt:

```
cscdesigner
```

When first opened, the Custom Storage Class Designer scans all data class packages on the MATLAB path to detect packages that have a CSC registration file. A message is displayed while scanning proceeds. When the scan is complete, the Custom Storage Class Designer window appears:



Select package: Simulink (Read Only)

Custom storage class definitions:

Default
BitField
Const
Volatile
ConstVolatile
Define
ImportedDefine
ExportToFile
ImportFromFile
Struct
GetSet

Name: Default

Type: Unstructured ☑ For parameters ☑ For signals

Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

Filename: csc_registration.p

Location: M:\R2009bd\latest_pass\matlab\toolbox\simulink\...

Validation result

```
Last validation succeeded.
```

Pseudocode preview

```
Header file:

No header file is specified. By default, data is
exported via the generated model.h file.

Type definition: Not applicable.

Declaration:

/* CSC declaration comment generated by default */
extern DATATYPE DATANAME[DIMENSION];

Definition:

/* CSC definition comment generated by default */
DATATYPE DATANAME[DIMENSION];
```

The Custom Storage Class Designer window is divided into several panels:

- **Select package**: Lets you select from a menu of data class packages that have CSC definitions associated with them. See “Selecting a Data Class Package” on page 7-14 for details.
- **Custom Storage Class / Memory Section** properties: Lets you select, view, edit, copy, verify, and perform other operations on CSC definitions or memory section definitions. The common controls in the **Custom Storage Class / Memory Section** properties panel are described in “Selecting and Editing CSCs, Memory Sections, and References” on page 7-15.

  - When the **Custom Storage Class** tab is selected, you can select a CSC definition or reference from a list and edit its properties. See "Editing Custom Storage Class Properties" on page 7-19 for details.
  - When the **Memory Section** tab is selected, you can select a memory section definition or reference from a list and edit its properties. See "Creating and Editing Memory Section Definitions" on page 7-31 for details.
- **Filename**: Displays the filename and location of the current CSC registration file, and lets you save your CSC definition to that file. See "Saving Your Definitions" on page 7-18 for details.
- **Pseudocode preview**: Displays a preview of code that is generated from objects of the given class. The preview is pseudocode, since the actual symbolic representation of data objects is not available until code generation time. See "Previewing Generated Code" on page 7-33 for details.
- **Validation result**: Displays any errors encountered when the currently selected CSC definition is validated. See "Validating CSC Definitions" on page 7-25 for details.

### Selecting a Data Class Package

A CSC or memory section definition or reference is uniquely associated with a Simulink data class package. The link between the definition/reference and the package is formed when a CSC registration file (`csc_registration.m`) is located in the package directory.

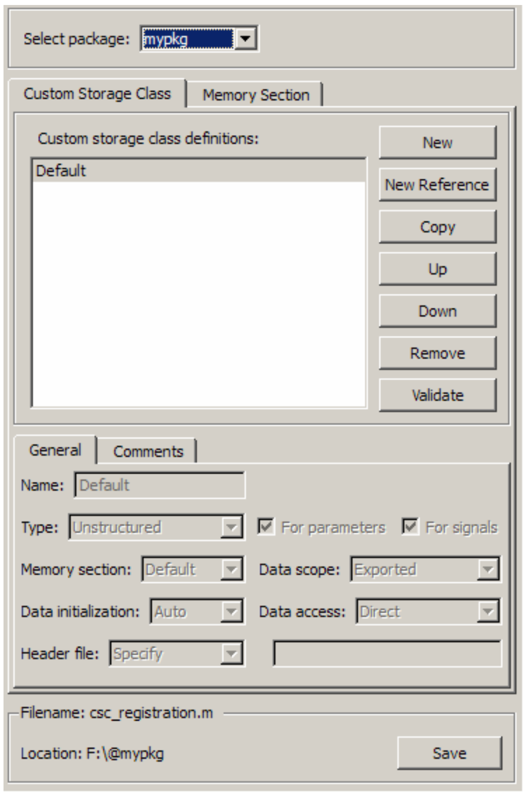
You never need to search for or edit a CSC registration file directly: the Custom Storage Class Designer locates all available CSC registration files. The **Select package** menu contains names of all data class packages that have a CSC registration file on the MATLAB search path. At least one such package, the `Simulink` package, is always present.

When you select a package, the CSCs and memory section definitions belonging to the package are loaded into memory and their names are displayed in the scrolling list in the **Custom storage class** panel. The name and location of the CSC registration file for the package is displayed in the **Filename** panel.

If you select a user-defined package, by default you can use the Custom Storage Class Designer to edit its custom storage classes and memory sections. If you select a built-in package, by default you cannot edit its custom storage classes or memory sections. See “Custom Storage Class Implementation” on page 7-70 for more information.

## Selecting and Editing CSCs, Memory Sections, and References

The **Custom Storage Class / Memory Section** panel lets you select, view, and (if the CSC is writable) edit CSC and memory section definitions and references. In the next figure and the subsequent examples, the selected package is `mypkg`. Instructions for creating a user-defined package like `mypkg` appear in “Creating Packages that Support CSC Definitions” on page 7-8.



Select package: mypkg

Custom storage class definitions:
Default

Name: Default
Type: Unstructured  ✓ For parameters  ✓ For signals
Memory section: Default  Data scope: Exported
Data initialization: Auto  Data access: Direct
Header file: Specify

Filename: csc_registration.m
Location: F:\@mypkg

The list at the top of the panel displays the definitions/references for the currently selected package. To select a definition/reference for viewing and editing, click on the desired list entry. The properties of the selected definition/reference appear in the area below the list. The number and type of properties vary for different types of CSC and memory section definitions. See:

- "Editing Custom Storage Class Properties" on page 7-19 for information about the properties of the predefined CSCs.
- "Creating and Editing Memory Section Definitions" on page 7-31 for information about the properties of the predefined memory section definitions.

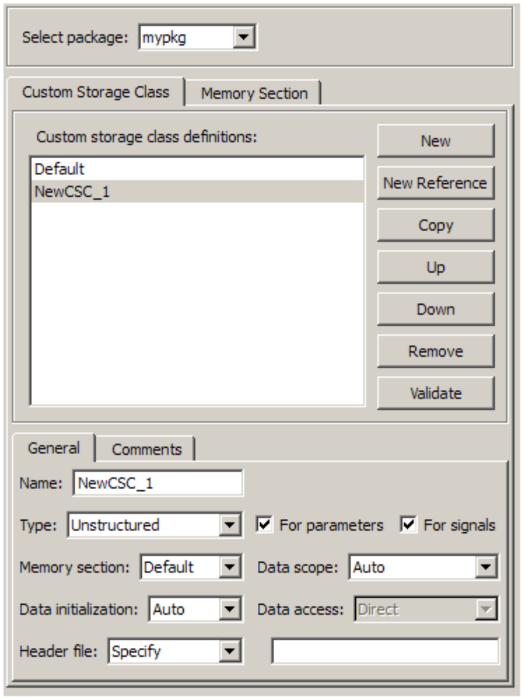
The buttons to the right of the list perform these functions, which are common to both custom storage classes and memory definitions:

- **New**: Creates a new CSC or memory section with default values.
- **New Reference:** Creates a reference to a CSC or memory section definition in another package. The default initially has a default name and properties. See "Using Custom Storage Class References" on page 7-26 and "Using Memory Section References" on page 7-34.
- **Copy**: Creates a copy of the selected definition / reference. Copies are given a default name using the convention:

  ```
  definition_name_n
  ```

  where `definition_name` is the name of the original definition, and `n` is an integer indicating successive copy numbers (for example: `BitField_1`, `BitField_2`, ...)
- **Up**: Moves the selected definition one position up in the list.
- **Down**: Moves the selected definition one position down in the list
- **Remove**: Removes the selected definition from the list.
- **Validate**: Performs a consistency check on the currently selected definition. Errors are reported in the **Validation result** panel.

For example, if you click **New**, a new custom storage class is created with a default name:



Select package: mypkg

Custom storage class definitions:
Default
NewCSC_1

Name: NewCSC_1

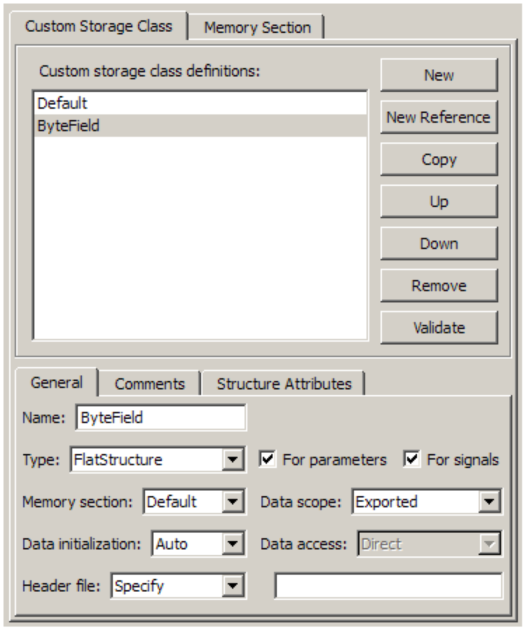
Type: Unstructured ☑ For parameters ☑ For signals

Memory section: Default Data scope: Auto

Data initialization: Auto Data access: Direct

Header file: Specify

You can now rename the new class by typing the desired name into the **Name** field, and set other fields as needed. The changes take effect when you click **Apply** or **OK**. For example, you could set values for the new custom storage class as follows:



Custom storage class definitions:

Default
ByteField

Name: ByteField

Type: FlatStructure ☑ For parameters ☑ For signals

Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

## Saving Your Definitions

After you have created or edited a CSC or memory section definition or reference, you must save the changes to the CSC registration file. To do this, click **Save** in the **Filename** panel. When you click **Save**, the current CSC and memory section definitions that are in memory are validated, and the definitions are written out.

If errors occur, they are reported in the **Validation result** panel. The definitions are saved whether or not errors exist. However, you should correct any validation errors and resave your definitions. Trying to use definitions that were saved with validation errors can cause additional errors. Such problems can occur even it you do not try to use the specific parts of the definition that contain the validation errors, making the problems difficult to diagnose.

## Restarting MATLAB After Changing Definitions

If you add, change, or delete custom storage class or memory section definitions for any user-defined class, and objects of that class already exist, you must restart MATLAB to put the changed definitions into effect and eliminate obsolete objects. A message warning you to restart MATLAB appears when you save the changed definitions. This warning message does not affect the success of the save operation itself.

## Editing Custom Storage Class Properties

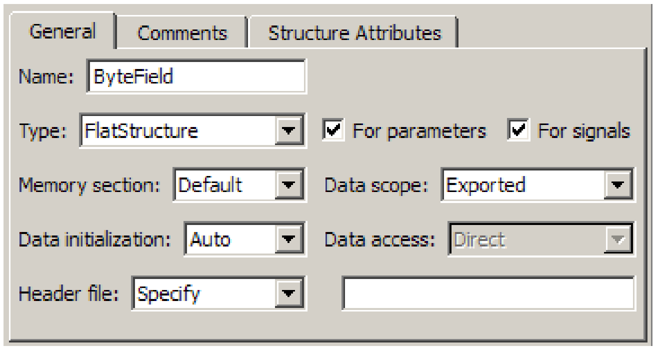
To view and edit the properties of a CSC, click the **Custom Storage Class** tab in the **Custom Storage Class / Memory Section** panel. Then, select a CSC name from the **Custom storage class definitions** list.

The CSC properties are divided into several categories, selected by tabs. Selecting a class, and setting property values for that class, can change the available tabs, properties, and values. As you change property values, the effect on the generated code is immediately displayed in the **Pseudocode preview** panel. In most cases, you can define your CSCs quickly and easily by selecting the **Pseudocode preview** panel and using the **Validate** button frequently.

The property categories and corresponding tabs are as follows:

### General

Properties in the **General** category are common to all CSCs. In the next figure and the subsequent examples, the selected custom storage class is `ByteField`. Instructions for creating a user-defined custom storage class like `ByteField` appear in "Selecting and Editing CSCs, Memory Sections, and References" on page 7-15.



Name: ByteField

Type: FlatStructure ✓ For parameters ✓ For signals

Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

Properties in the **General** category, and the possible values for each property, are as follows:

- **Name**: The CSC name, selected from the **Custom storage class definitions** list. The name cannot be any TLC keyword. Violating this rule causes an error.
- **Type**: Specifies how objects of this class are stored. Values:
  - `Unstructured`: Objects of this class generate unstructured storage declarations (for example, scalar or array variables), for example:

    ```
    datatype dataname[dimension];
    ```

  - `FlatStructure`: Objects of this class are stored as members of a struct. A **Structure Attributes** tab is also displayed, allowing you to specify additional properties such as the struct name. See "Structure Attributes" on page 7-23.
  - `Other`: Used for certain data layouts, such as nested structures, that cannot be generated using the standard `Unstructured` and `FlatStructure` custom storage class types. If you want to generate other types of data, you can create a new custom storage class from scratch by writing the necessary TLC code. See "Defining Advanced Custom Storage Class Types" on page 7-62 for more information.
- **For parameters** and **For signals**: These options let you enable a CSC for use with only certain classes of data objects. For example, it does not make sense to assign storage class `Const` to a `Simulink.Signal` object. Accordingly, the **For signals** option for the `Const` class is deselected, while the **For parameters** is selected.
- **Memory section**: Selects one of the memory sections defined in the **Memory Section** panel. See "Creating and Editing Memory Section Definitions" on page 7-31.
- **Data scope**: Controls the scope of symbols generated for data objects of this class. Values:
  - `Auto`: Symbol scope is determined internally by the Real-Time Workshop software. If possible, symbols have `File` scope. Otherwise, they have `Exported` scope.

  - `Exported`: Symbols are exported to external code in the header file specified by the **Header File** field. If no **Header File** is specified, symbols are exported to external code in *`model`*`.h`.
  - `Imported`: Symbols are imported from external code in the header file specified by the **Header File** field. If you do not specify a header file, an `extern` directive is generated in *`model`*`_private.h`. For imported data, if the **Data initialization** value is `Macro`, a header file *must* be specified.
  - `File`: The scope of each symbol is the file that defines it. File scope requires each symbol to be used in a single file. If the same symbol is referenced in multiple files, an error occurs at code generation time.
  - `Instance specific`: Symbol scope is defined by the **Data scope** field of the `RTWInfo.CustomAttributes` property of each data object.

- **Data initialization**: Controls how storage is initialized in generated code. Values:
  - `Auto`: Storage initialization is determined internally by the Real-Time Workshop software. Parameters have `Static` initialization, and signals have `Dynamic` initialization.
  - `None`: No initialization code is generated.
  - `Static`: A static initializer of the following form is generated:

    ```
    datatype dataname[dimension] = {...};
    ```

  - `Dynamic`: Variable storage is initialized at runtime, in the *`model`*`_initialize` function.
  - `Macro`: A macro definition of the following form is generated:

    ```
    #define data numeric_value
    ```

    The `Macro` initialization option is available only for use with unstructured parameters. It is not available when the class is configured for generation of structured data, or for signals. If the **Data scope** value is `Imported`, a header file *must* be specified.
  - `Instance specific`: Initialization is defined by the **Data initialization** property of each data object.

---

**Note** When necessary, the Real-Time Workshop Embedded Coder software generates dynamic initialization code for signals and states even if the CSC has **Data initialization** set to `None` or `Static`.

---

- **Data access**: Controls whether imported symbols are declared as variables or pointers. This field is enabled only when **Data scope** is set to `Imported` or `Instance-specific`. Values:
  - `Direct`: Symbols are declared as simple variables, such as

    ```
    extern myType myVariable;
    ```

  - `Pointer`: Symbols are declared as pointer variables, such as

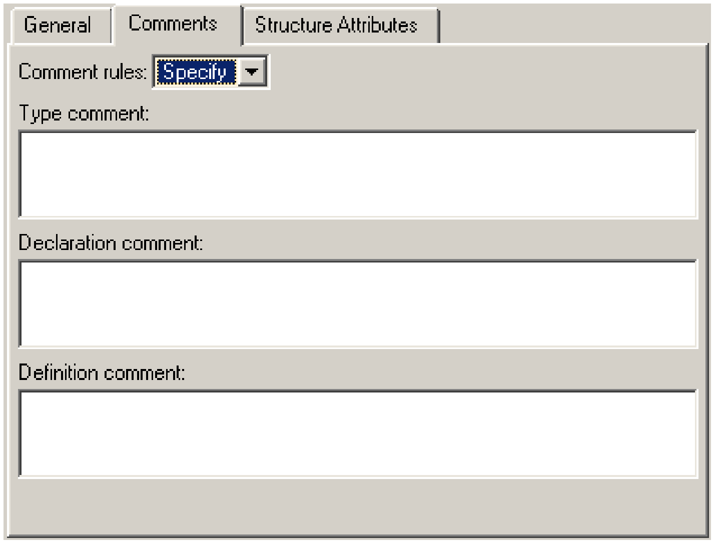
    ```
    extern myType *myVariable;
    ```

  - `Instance specific`: Data access is defined by the **Data access** property of each data object.
- **Header file**: Defines the name of a header file that contains exported or imported variable declarations for objects of this class. Values:
  - `Specify`: An edit field is displayed to the right of the property. This lets you specify a header file for exported or imported storage declarations. Specify the full filename, including the filename extension (such as `.h`). Use quotes or brackets as in C code to specify the location of the header file. Leave the edit field empty to specify no header file.
  - `Instance specific`: The header file for each data object is defined by the **Header file** property of the object. Leave the property undefined to specify no header file for that object.

  If the **Data scope** is `Exported`, specifying a header file is optional. If you specify a header file name, the custom storage class generates a header file containing the storage declarations to be exported. Otherwise, the storage declarations are exported in *`model`*`.h`.

  If the **Data scope** of the class is `Imported`, and **Data initialization** is `Macro`, you *must* specify a header file name. A `#include` directive for the header file is generated.

**Comments.** The **Comments** panel lets you specify comments to be generated with definitions and declarations.



Comment rules: Specify
Type comment:
Declaration comment:
Definition comment:

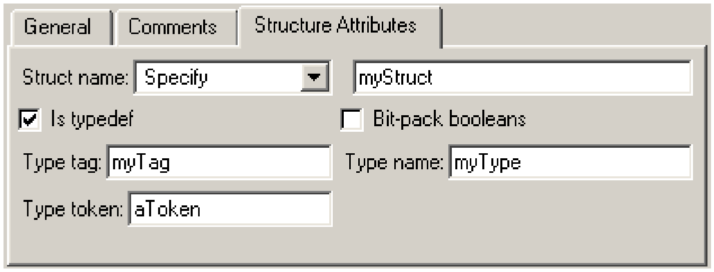
Comments must conform to the ANSI C standard (`/*...*/`). Use `\n` to specify a new line.

Properties in the **Comments** tab are as follows:

- **Comment rules**: If `Specify` is selected, edit fields allowing you to enter comments are displayed. If `Default` is selected, comments are generated under control of the Real-Time Workshop software.
- **Type comment**: The comment entered in this field precedes the `typedef` or `struct` definition for structured data.
- **Declaration comment**: Comment that precedes the storage declaration.
- **Definition comment**: Comment that precedes the storage definition.

### Structure Attributes

The **Structure Attributes** panel gives you detailed control over code generation for structs (including bitfields). The **Structure Attributes** tab is displayed for CSCs whose **Type** parameter is set to `FlatStructure`. The following figure shows the **Structure Attributes** panel.



Struct name: Specify myStruct
[✓] Is typedef
[ ] Bit-pack booleans
Type tag: myTag
Type name: myType
Type token: aToken

**Structure Attributes Panel**

The **Structure Attributes** properties are as follows:

- **Struct name**: If you select `Instance specific`, specify the struct name when configuring each instance of the class.

  If you select `Specify`, an edit field appears (as shown in Structure Attributes Panel on page 7-24) for entry of the name of the structure to be used in the `struct` definition. Edit fields **Type tag**, **Type token**, and **Type name** are also displayed.

- **Is typedef**: When this option is selected a `typedef` is generated for the struct definition, for example:

```
typedef struct {
   ...
} SignalDataStruct;
```

  Otherwise, a simple struct definition is generated.

- **Bit-pack booleans**: When this option is selected, signals and/or parameters that have Boolean data type are packed into bit fields in the generated struct.

- **Type tag**: Specifies a tag to be generated after the `struct` keyword in the struct definition.

- **Type token**: Some compilers support an additional token (which is simply another string) after the type tag. To generate such a token, enter the string in this field.

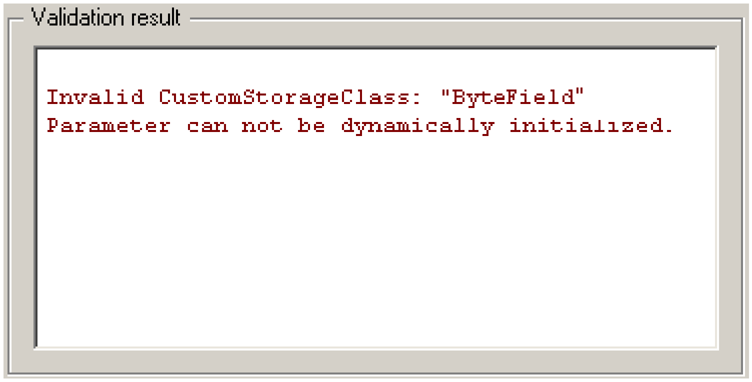
- **Type name**: Specifies the string to be used in `typedef` definitions. This field is visible if **Is typedef** is selected.

The following listing is the pseudocode preview corresponding to the **Structure Attributes** properties displayed in Structure Attributes Panel on page 7-24.

```
Header file:

No header file is specified. By default, data is
exported with the generated model.h file.


Type definition:

/* CSC type comment generated by default */

typedef struct aToken myTag {
   :
} myType;


Declaration:

/* CSC declaration comment generated by default */

extern myType MyStruct;


Definition:

/* CSC definition comment generated by default */

myType MyStruct = {...};
```

## Validating CSC Definitions

To validate a CSC definition, select the definition on the **Custom Storage Class** panel and click **Validate**. The Custom Storage Class Designer then checks the definition for consistency. The **Validation result** panel displays any errors encountered when the selected CSC definition is validated. The next figure shows the **Validation result** panel with a typical error message:



```
Invalid CustomStorageClass: "ByteField"
Parameter can not be dynamically initialized.
```

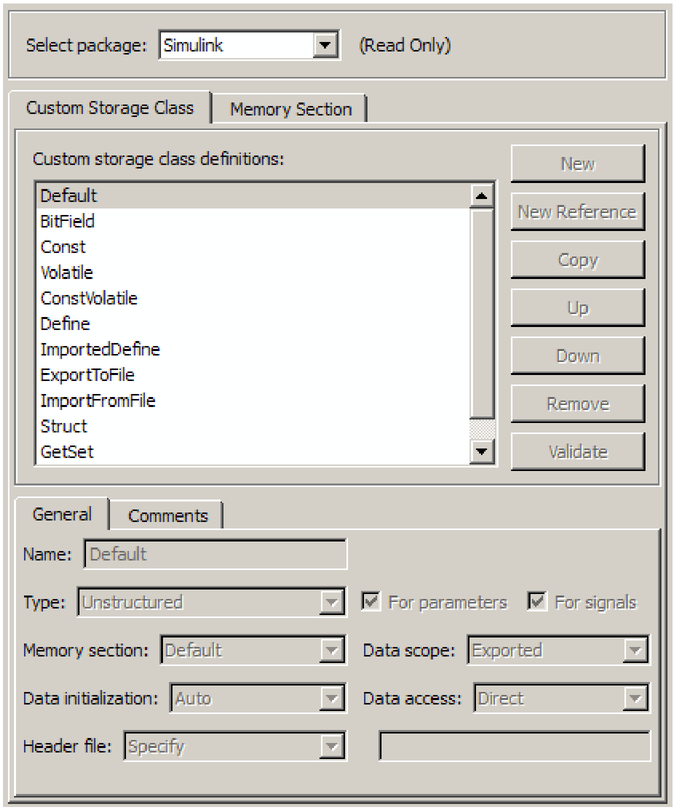
Validation is also performed whenever CSC definitions are saved. In this case, all CSC definitions are validated. (See “Saving Your Definitions” on page 7-18.)

## Using Custom Storage Class References

Any package can access and use custom storage classes that are defined in any other package, including both user-defined packages and predefined packages such as `Simulink` and `mpt`. Only one copy of the storage class exists, in the package that first defined it. Other packages refer to it by pointing to it in its original location. Thus any changes to the class, including changes to a predefined class in later MathWorks™ product releases, are immediately available in every referencing package.

To configure a package to use a custom storage class that is defined in another package:

1 Type `cscdesigner` to launch the Custom Storage Class Designer. The relevant part of the designer window initially looks like this:


Select package: Simulink (Read Only)

Custom Storage Class | Memory Section

Custom storage class definitions:

Default
BitField
Const
Volatile
ConstVolatile
Define
ImportedDefine
ExportToFile
ImportFromFile
Struct
GetSet

Name: Default

Type: Unstructured ☑ For parameters ☑ For signals

Memory section: Default Data scope: Exported

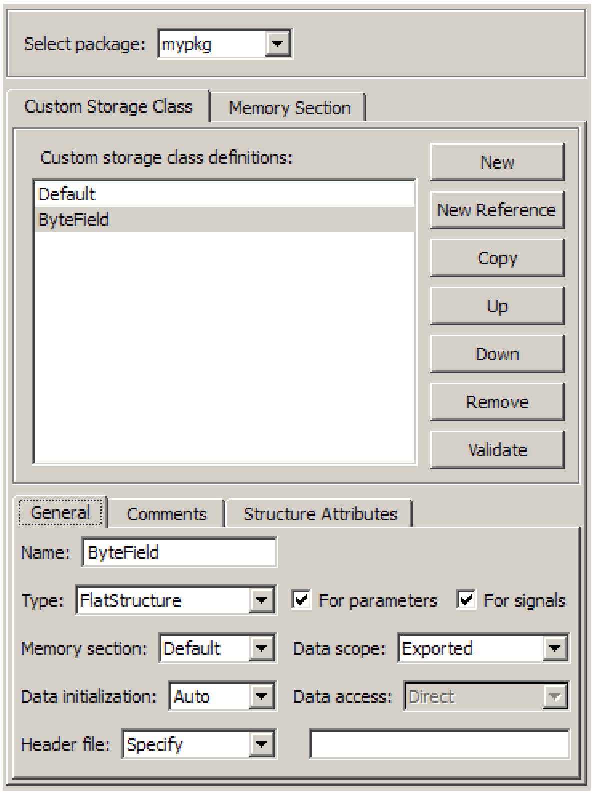
Data initialization: Auto Data access: Direct

Header file: Specify

2 Select the **Custom Storage Class** tab.

3 Use **Select Package** to select the package in which you want to reference a class or section defined in some other package. The selected package must be writable.

4 In the **Custom storage class definitions** pane, select the existing definition below which you want to insert the reference. For example:



Name: ByteField

Type: FlatStructure ☑ For parameters ☑ For signals

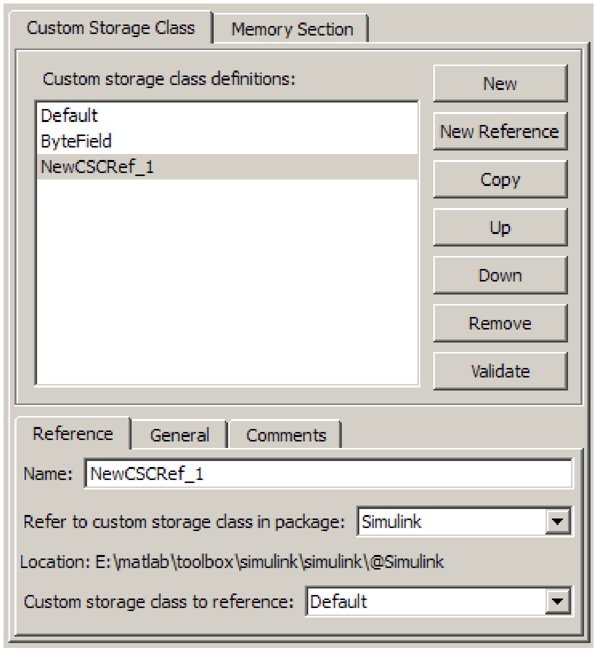
Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

**5** Click **New Reference**.

A new reference with a default name and properties appears below the previously selected definition. The new reference is selected, and a **Reference** tab appears that shows the reference's initial properties. A typical appearance is:



Custom storage class definitions:

Default
ByteField
NewCSCRef_1

Name: NewCSCRef_1

Refer to custom storage class in package: Simulink

Location: E:\matlab\toolbox\simulink\simulink\@Simulink

Custom storage class to reference: Default

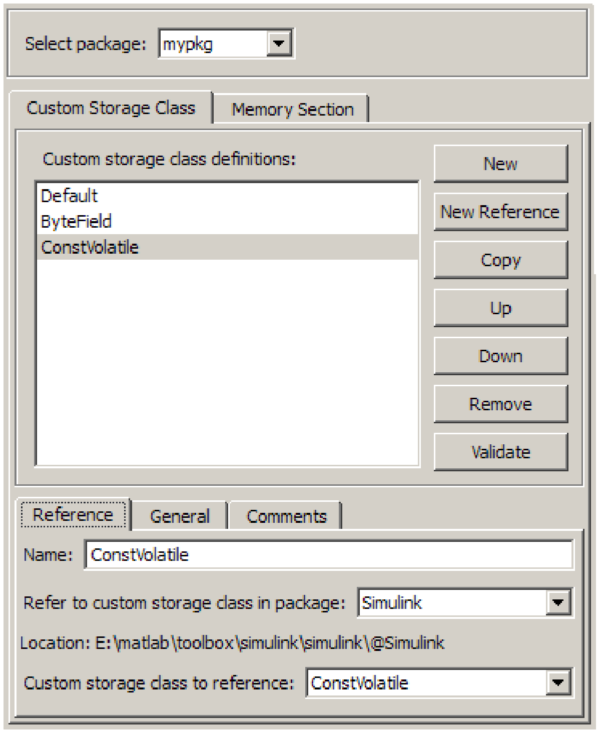
**6** Use the **Name** field to enter a name for the new reference. The name must be unique in the importing package, but can duplicate the name in the source package. The name cannot be any TLC keyword. Violating this rule causes an error.

**7** Set **Refer to custom storage class in package** to specify the package that contains the custom storage class you want to reference.

**8** Set **Custom storage class to reference** to specify the custom storage class to be referenced. Trying to create a circular reference generates an error and leaves the package unchanged.

**9** Click **OK** or **Apply** to save the changes to memory. See "Saving Your Definitions" on page 7-18 for information about saving changes permanently.

For example, the next figure shows the custom storage class `ConstVolatile` imported from the `Simulink` package into `mypkg`, and given the same name that it has in the source package. Any other name could have been used without affecting the properties of the storage class.



Name: ConstVolatile

Refer to custom storage class in package: Simulink

Location: E:\matlab\toolbox\simulink\simulink\@Simulink

Custom storage class to reference: ConstVolatile

You can use Custom Storage Class Designer capabilities to copy, reorder, validate, and otherwise manage classes that have been added to a class by reference. However, you cannot change the underlying definitions. You can change a custom storage class only in the package where it was originally defined.

## Changing Existing CSC References

To change an existing CSC reference, select it in the **Custom storage class definitions** pane. The **Reference** tab appears, showing the current properties of the reference. Make any needed changes, then click **OK** or **Apply** to save the changes to memory. See “Saving Your Definitions” on page 7-18 for information about saving changes permanently.

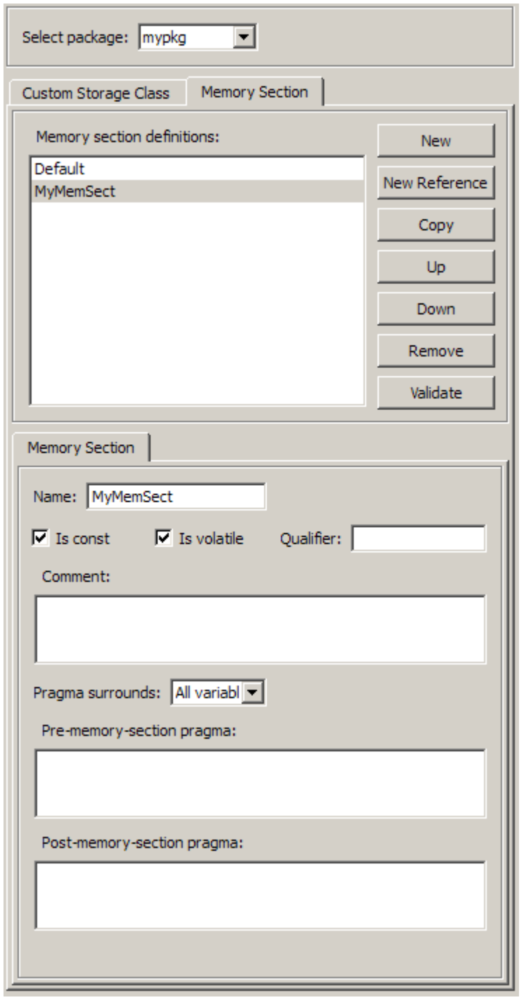
## Creating and Editing Memory Section Definitions

Memory section definitions add comments, qualifiers, and `#pragma` directives to generated symbol declarations. The **Memory Section** tab lets you create, view, edit, and verify memory section definitions. The steps for creating a memory section definition are essentially the same as for creating a custom storage class definition:

1. Select a writable package in the **Select package** field.
2. Select the **Memory Section** tab. In a new package, only a `Default` memory section initially appears.
3. Select the existing memory section below which you want to create a new memory section.
4. Click **New**.

   A new memory section definition with a default name appears below the selected memory section.
5. Set the name and other properties of the memory section as needed.
6. Click **OK** or **Apply**.

The next figure shows `mypkg` with a memory section called `MyMemSect`:



Select package: mypkg

Memory section definitions:

Default
MyMemSect

Name: MyMemSect

[✓ Is const] [✓ Is volatile] Qualifier:

Pragma surrounds: All variabl

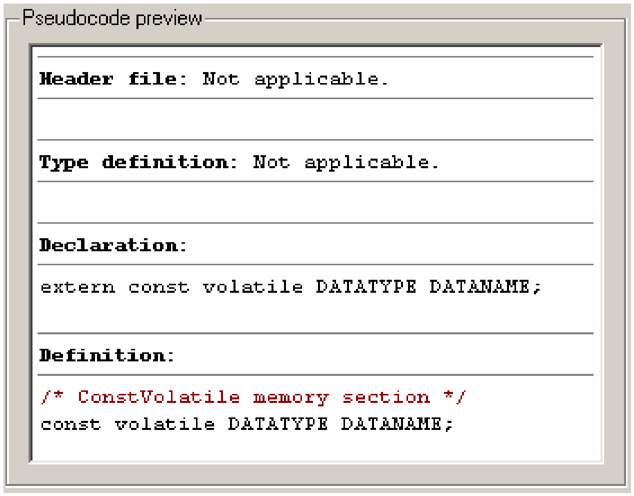
The **Memory section definitions** list lets you select a memory section definition to view or edit. The available memory section definitions also appear in the **Memory section name** menu in the **Custom Storage Class** panel. The properties of a memory section definition are as follows:

- **Memory section name**: Name of the memory section (displayed in **Memory section definitions** list).

- **Is const**: If selected, a `const` qualifier is added to the symbol declarations.
- **Is volatile**: If selected, a `volatile` qualifier is added to the symbol declarations.
- **Qualifier**: The string entered into this field is added to the symbol declarations as a further qualifier. Note that no verification is performed on this qualifier.
- **Memory section comment**: Comment inserted before declarations belonging to this memory section. Comments must conform to the ANSI C standard (`/*...*/`). Use `\n` to specify a new line.
- **Pragma surrounds**: Specifies whether the pragma should surround `All variables` or `Each variable`. When **Pragma surrounds** is set to `Each variable`, the `%<identifier>` token is allowed in pragmas and will be replaced by the variable or function name.
- **Pre-memory section pragma**: `pragma` directive that precedes the storage definition of data belonging to this memory section. The directive must begin with `#pragma`.
- **Post-memory section pragma**: `pragma` directive that follows the storage definition of data belonging to this memory section. The directive must begin with `#pragma`.

## Previewing Generated Code

If you click **Validate** on the **Memory Section** panel, the **Pseudocode preview** panel displays a preview of code that is generated from objects of the given class. The panel also displays messages (in blue) to highlight changes as they are made. The code preview changes dynamically as you edit the class properties. The next figure shows a code preview for the `MemConstVolatile` memory section.



```
Header file: Not applicable.

Type definition: Not applicable.

Declaration:
extern const volatile DATATYPE DATANAME;

Definition:
/* ConstVolatile memory section */
const volatile DATATYPE DATANAME;
```

## Using Memory Section References

Any package can access and use memory sections that are defined in any other package, including both user-defined packages and predefined packages such as `Simulink` and `mpt`. Only one copy of the section exists, in the package that first defined it; other packages refer to it by pointing to it in its original location. Thus any changes to the section, including changes to a predefined section in later MathWorks product releases, are immediately available in every referencing package.

To configure a package to use a memory section that is defined in another package:

1 Type `cscdesigner` to launch the Custom Storage Class Designer.

2 Select the **Memory Section** tab.

3 Use **Select Package** to select the package in which you want to reference a class or section defined in some other package.

4 In the **Memory section definitions** pane, select the existing definition below which you want to insert the reference.

5 Click **New Reference**.

A new reference with a default name and properties appears below the previously selected definition. The new reference is selected, and a **Reference** tab appears that shows the reference's initial properties.

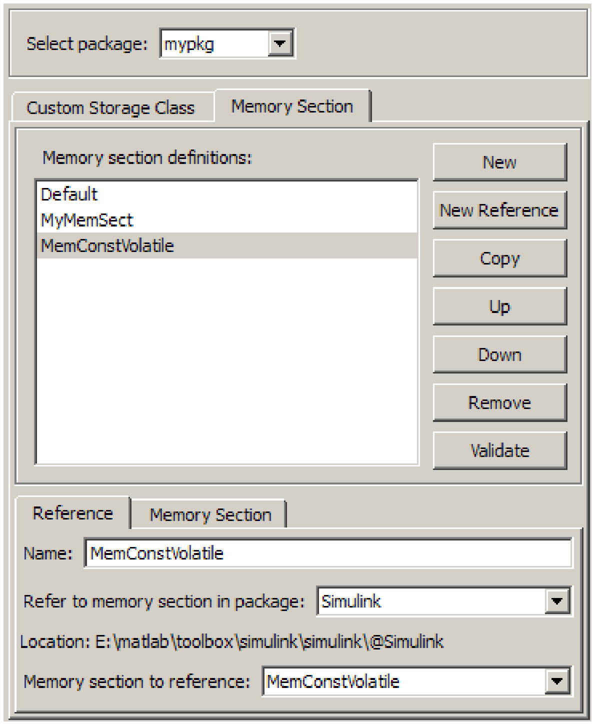
6. Use the **Name** field to enter a name for the new reference. The name must be unique in the importing package, but can duplicate the name in the source package.

7. Set **Refer to memory section in package** to specify the package that contains the memory section you want to reference.

8. Set **Memory section to reference** to specify the memory section to be referenced. Trying to create a circular reference generates an error and leaves the package unchanged.

9. Click **OK** or **Apply** to save the changes to memory. See "Saving Your Definitions" on page 7-18 for information about saving changes permanently.

For example, the next figure shows the memory section `MemConstVolatile` imported from the `Simulink` package into `mypkg`, and given the same name that it has in the source package. Any other name could have been used without affecting the properties of the memory section.



Select package: mypkg

Memory section definitions:

Default
MyMemSect
MemConstVolatile

Name: MemConstVolatile

Refer to memory section in package: Simulink

Location: E:\matlab\toolbox\simulink\simulink\@Simulink

Memory section to reference: MemConstVolatile

You can use Custom Storage Class Designer capabilities to copy, reorder, validate, and otherwise manage memory sections that have been added to a class by reference. However, you cannot change the underlying definitions. You can change a memory section only in the package where it was originally defined.

## Changing Existing Memory Section References

To change an existing memory section reference, select it in the **Memory section definitions** pane. The **Reference** tab appears, showing the current properties of the reference. Make any needed changes, then click **OK** or **Apply** to save the changes to memory. See "Saving Your Definitions" on page 7-18 for information about saving changes permanently.

## Applying CSCs to Parameters and Signals

**In this section...**

### About Applying Custom Storage Classes

You can apply a custom storage class to a parameter or a signal using the GUI or the API.

- To apply a custom storage class to a parameter, you specify the storage class in the `Simulink.Parameter` object that defines the parameter in the base workspace.
- To apply a custom storage class to a signal, you specify the storage class in a `Simulink.Signal` object that is bound to the signal. You can provide this object in two ways:
  - Create the object in the base workspace, then bind it to the signal as described in "Resolving Symbols". When you save the model, you must save the object in a separate file, as with any base workspace object.
  - Use the Signal Properties dialog box to embed the object in the model on the port where the signal originates. When you save the model, Simulink automatically saves the embedded signal object as part of the model file.

Most of the GUI techniques, and most of the API techniques, are the same for parameter and signal objects, and for base workspace and embedded signal objects. Only the initial steps differ, after which you apply the same GUI or API instructions within the context that you established in the initial steps.

The following instructions assume that you have already created any needed packages, custom storage classes, and memory sections, as described in "Creating Packages that Support CSC Definitions" on page 7-8 and "Designing Custom Storage Classes and Memory Sections" on page 7-12.

## Applying a Custom Storage Class to a Parameter

To apply a custom storage class to a parameter, you specify the storage class in the `Simulink.Parameter` object that defines the parameter in the base workspace. The instructions that begin in this section show you how to create that object using the GUI or API. Later instructions show you how to specify a custom storage class and custom attributes.

For information about using parameter objects to specify block parameter values, see "Working with Block Parameters" in the Simulink documentation. For information about parameter storage in generated code, see "Parameter Considerations" in the Real-Time Workshop documentation.

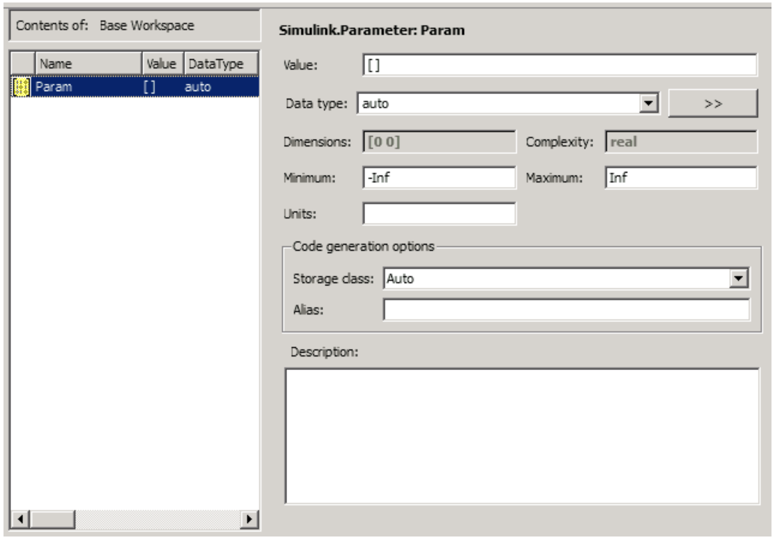
### Providing a Parameter Object Using the GUI

1 In the Model window, choose **View > Model Explorer**.

2 In the **Model Hierarchy** pane, select the `Base Workspace`.

3 Click the **Add Parameter** tool or choose **Add > Simulink Parameter**.

   Simulink creates a `Simulink.Parameter` object with a default name:


Contents of: Base Workspace

| Name | Value | DataType |
|---|---|---|
| Param | [] | auto |

Simulink.Parameter: Param

Value: []

Data type: auto

Dimensions: [0 0]　Complexity: real

Minimum: -Inf　Maximum: Inf

Units:

Code generation options

Storage class: Auto

Alias:

Description:

4 Change the parameter name as needed by editing it in the **Contents** pane. Example: `MyParam`.

5 Set parameter attributes other than **Code generation options** in the **Dialog** pane.

6 Follow the instructions in "Specifying a Custom Storage Class Using the GUI" on page 7-50.

## Providing a Parameter Object Using the API

1 In the MATLAB Command Window, enter:

```
ParamName=ParamClass
```

where *`ParamClass`* is `Simulink.Parameter` or any subclass of it that you have defined.

2 Simulink creates a *`ParamClass`* object with the specified name:

```
MyParam =

Simulink.Parameter (handle)
```

```
          Value: []
        RTWInfo: [1x1 Simulink.ParamRTWInfo]
    Description: ''
       DataType: 'auto'
            Min: -Inf
            Max: Inf
       DocUnits: ''
     Complexity: 'real'
     Dimensions: [0 0]
```

3. Set parameter attributes other than `RTWInfo`, which controls custom storage classes.

4. Follow the instructions in "Specifying a Custom Storage Class Using the API" on page 7-53.

## Applying a Custom Storage Class to a Signal

To apply a custom storage class to a signal, you specify the storage class in a `Simulink.Signal` object. This object can exist in either of two locations:

- In the MATLAB base workspace
- On the port where the signal originates

The object itself is the same in either case; only its location and some of the techniques for managing it differ. The instructions that begin in this section show you how to create a signal object in either location using the GUI or API. Later instructions show you how to specify the custom storage class and custom attributes.

A given signal can be associated with at most one signal object under any circumstances. The signal can refer to the object more that once, but every reference must resolve to exactly the same object. A different signal object that has exactly the same properties will not meet the requirement for uniqueness. A compile-time error occurs if a model associates more than one signal object with any signal.

Assigning a signal to any non-`Auto` storage class automatically makes the signal a test point, overriding the setting of **Signal Properties > Logging**

**and accessibility > Test point**. See “Working with Test Points”for more information.

For information about using signal objects to specify signal attributes, see “Working with Signals” in the Simulink documentation. For information about signal storage in generated code, see “Signal Considerations” in the Real-Time Workshop documentation.

## Applying a CSC Using a Base Workspace Signal Object

The first step is to create the signal object in the base workspace, after which you specify any needed signal attributes and the custom storage class and attributes.

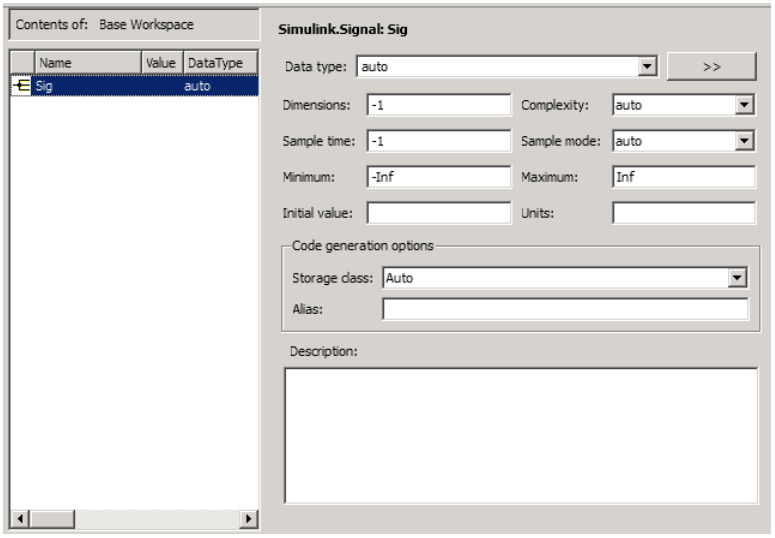
### Providing a Base Workspace Signal Object Using the GUI

1 In the Model window, choose **View > Model Explorer**.

2 In the **Model Hierarchy** pane, select the `Base Workspace`.

3 Click the **Add Signal** tool or choose **Add > Simulink Signal**.

   Simulink creates a `Simulink.Signal` object with a default name:



Contents of: Base Workspace

| Name | Value | DataType |
|---|---|---|
| Sig | | auto |

Simulink.Signal: Sig

Data type: auto

Dimensions: -1
Complexity: auto
Sample time: -1
Sample mode: auto
Minimum: -Inf
Maximum: Inf
Initial value:
Units:

Code generation options
Storage class: Auto
Alias:

Description:

4 Change the signal name as needed by editing it in the **Contents** pane. Example: `MySig`.

5 Set signal attributes other than **Code generation options** in the **Dialog** pane.

6 Give the signal the same name as the signal object, as described in "Naming Signals".

7 Arrange for the signal to resolve to the object, as described in "Resolving Symbols".

8 Follow the instructions in "Specifying a Custom Storage Class Using the GUI" on page 7-50.

## Providing a Base Workspace Signal Object Using the API

1 In the MATLAB Command Window, enter:

```
SignalName=SignalClass
```

where *`SignalClass`* is `Simulink.Signal` or any subclass of it that you have defined.

**2** Simulink creates a *`SignalClass`* object with the specified name:

```
MySig =

Simulink.Signal (handle)
         RTWInfo: [1x1 Simulink.SignalRTWInfo]
     Description: ''
        DataType: 'auto'
             Min: -Inf
             Max: Inf
        DocUnits: ''
      Dimensions: -1
      Complexity: 'auto'
      SampleTime: -1
    SamplingMode: 'auto'
    InitialValue: ''
```

**3** Set parameter attributes other than `RTWInfo`, which controls custom storage classes.

**4** Give the signal the same name as the signal object, as described in “Naming Signals”.

**5** Arrange for the signal to resolve to the object, as described in “Resolving Symbols”.

**6** Follow the instructions in “Specifying a Custom Storage Class Using the API” on page 7-53.

## Applying a CSC Using an Embedded Signal Object

You can use the GUI or the API to apply a CSC using an embedded signal object.

- If you use the GUI, you use the Signal Properties dialog box to specify the attributes you want. The software then creates a `Simulink.Signal` object and assigns it to the output port where the signal originates.
- If you use the API, you instantiate `Simulink.Signal` or a subclass of it, set the attribute values that you want, and assign the object to the output port where the signal originates.

In either case, the effect on code generation is the same as if you had created a base workspace signal object that specified the same name, CSC, and custom attributes as the embedded signal object. See “Applying a CSC Using a Base Workspace Signal Object” on page 7-41 for details.

The advantages of using embedded signal objects are that they do not clutter the base workspace, and they do not need to be saved separately from the model, as base workspace objects do. When you save a model, Simulink saves any embedded signal objects in the model file, and reloads the objects when you later reload the model.

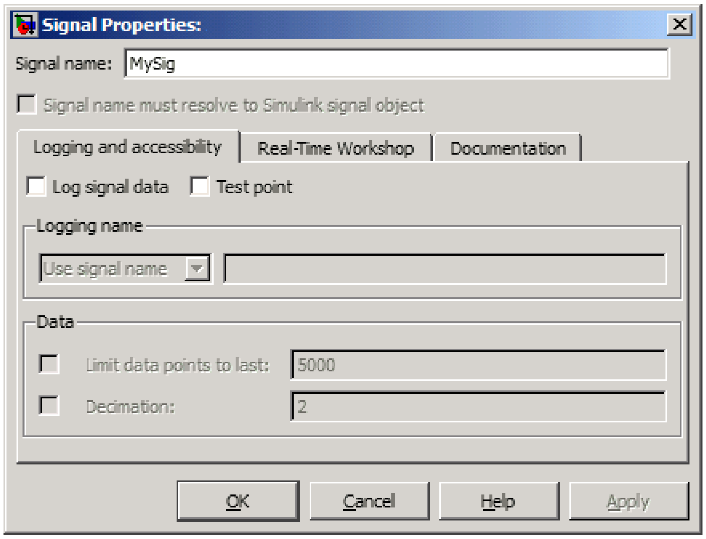
The disadvantage of embedded signal objects is that you can use such an object *only* to specify a custom storage class, custom attributes, and an alias; you must accept the default values for all other signal attributes. You cannot work around this restriction by providing additional information in a base workspace signal object on the same signal, because a signal object can have at most one associated signal object, as described in “Multiple Signal Objects”.

## Providing an Embedded Signal Object using the GUI

1 Give the signal a name, which must be a valid ANSI C identifier. Example: `MySig`.

2 Right-click the signal and choose **Signal Properties** from the context menu.

   The Signal Properties dialog box opens:



Signal Properties:

Signal name: MySig

☐ Signal name must resolve to Simulink signal object

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☐ Log signal data ☐ Test point

Logging name

Use signal name

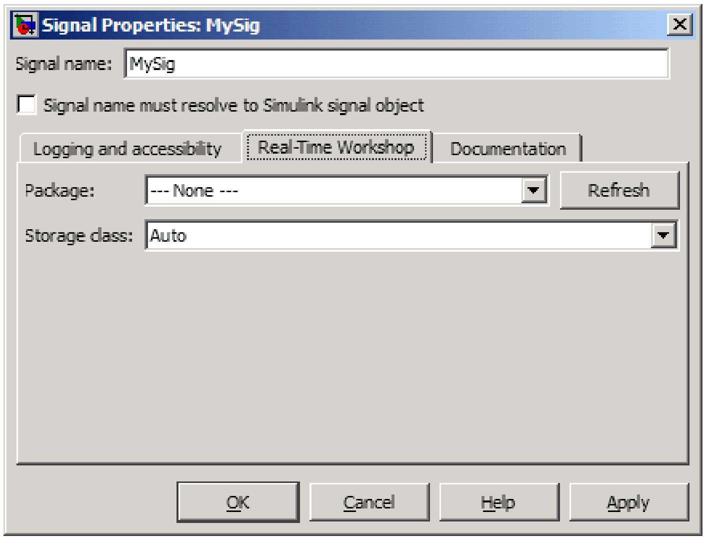
Data

☐ Limit data points to last: 5000

☐ Decimation: 2

3 *Do not* select **Signal name must resolve to Simulink signal object**. Selecting it would require a base workspace signal object, which would conflict with the embedded signal object.

4 Click the **Real-Time Workshop** tab:



Signal Properties: MySig

Signal name: MySig

☐ Signal name must resolve to Simulink signal object

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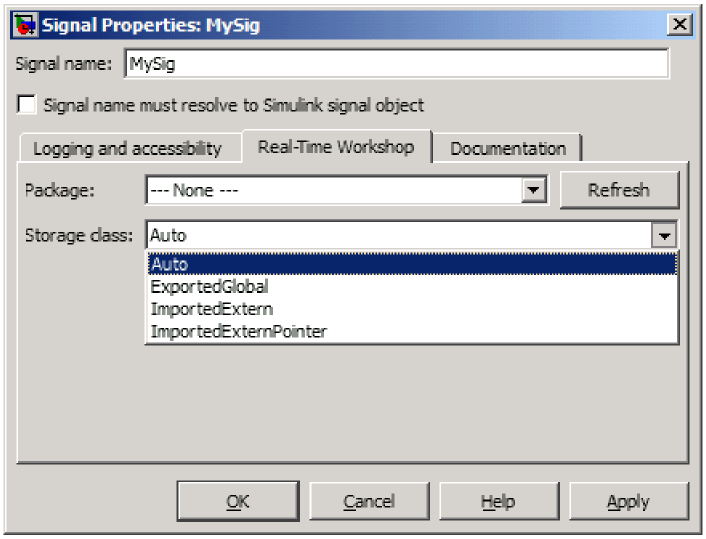
Package: --- None ---

Storage class: Auto

**5** The **Package** is initially `---None---`. When no package is specified, only the non-custom built-in storage classes defined for both GRT and ERT targets are available:


Signal Properties: MySig

Signal name: MySig

☐ Signal name must resolve to Simulink signal object

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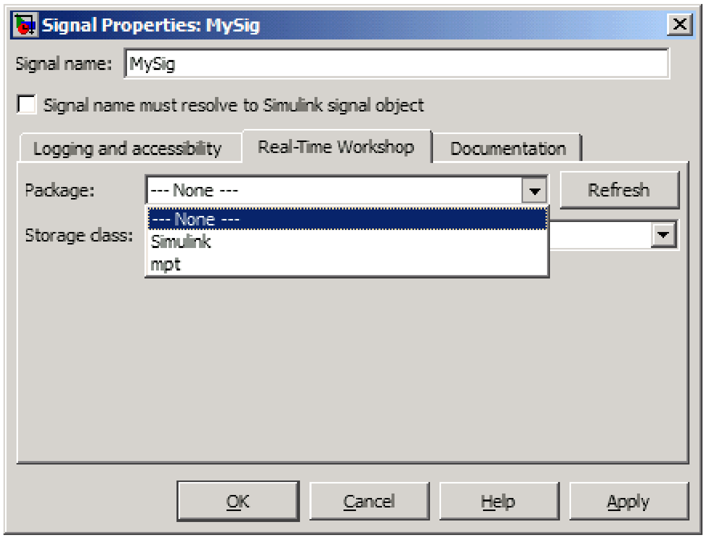
Package: --- None --- [Refresh]

Storage class: Auto

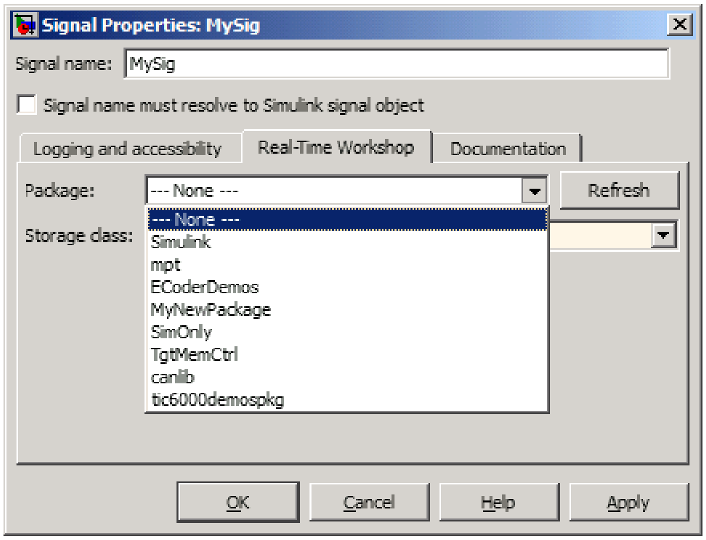
Auto
ExportedGlobal
ImportedExtern
ImportedExternPointer

Applying a storage class when the package is `---None---` sets internal storage class attributes rather than creating an embedded signal object. For more information, see "Signal Considerations" and "Simulink Data Object Considerations" in the Real-Time Workshop documentation.

**6** To apply a custom storage class, you must first specify the package where it is defined. Initially, viewing the **Package** menu displays only the built-in `Simulink` and `mpt` packages:

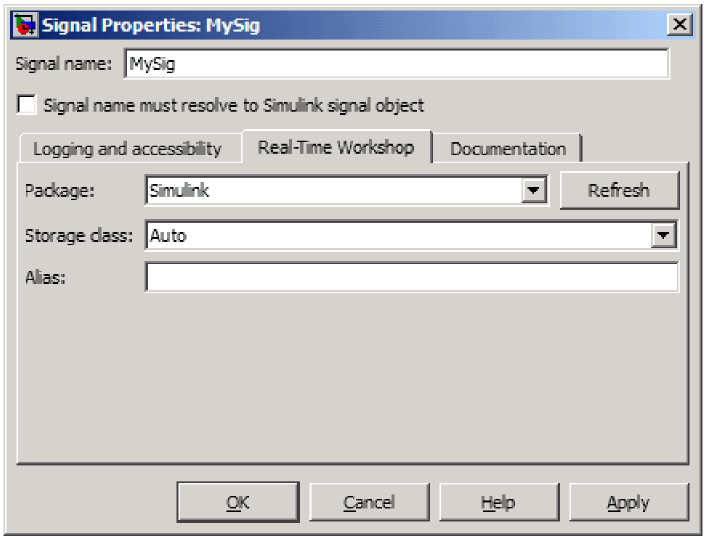


7 Click **Refresh** to load any other available packages, including user-defined packages, available on the MATLAB path. After a brief delay, a timer box tracks the progress of the package search. After the search completes, viewing the **Package** menu displays all available packages:



Once you have used **Refresh** in any Signal Properties dialog, Simulink saves the information for later use, so you do not have to click **Refresh** again during the current MATLAB session.

**8** Select the package that contains the custom storage class you want to apply, e.g. `Simulink`:



Signal name: MySig

[ ] Signal name must resolve to Simulink signal object

Package: Simulink

Storage class: Auto

Alias:

**9** Follow the instructions in "Specifying a Custom Storage Class Using the GUI" on page 7-50.

## Deleting an Embedded Signal Object Using the GUI

To delete an embedded signal object with the GUI, delete the name of the signal to which the object applies, by editing the name in the graphical model or in the Signal Properties dialog box. Simulink automatically deletes the embedded signal object as soon as its signal has no name.

## Providing an Embedded Signal Object using the API

To provide an embedded signal object using the API, you create the object, set its custom storage class and any custom attributes, then assign the object to the output port on which it will be embedded.

1. Name the signal if it does not already have a name. The name must be a valid ANSI C identifier.

2. In the MATLAB Command Window, enter:

   ```
   SignalName=SignalClass
   ```

   where *`SignalClass`* is `Simulink.Signal` or any subclass of it that you have defined. The name of the signal object does not need to match the name of the signal to which the object will be applied.

3. Simulink creates a *`SignalClass`* object with the specified name. Example:

   ```
   MySig =

   Simulink.Signal (handle)
            RTWInfo: [1x1 Simulink.SignalRTWInfo]
        Description: ''
           DataType: 'auto'
                Min: -Inf
                Max: Inf
           DocUnits: ''
         Dimensions: -1
         Complexity: 'auto'
         SampleTime: -1
       SamplingMode: 'auto'
       InitialValue: ''
   ```

4. *Do not* set any attributes. An embedded signal object can specify *only* custom storage class information.

5. Follow the instructions in “Specifying a Custom Storage Class Using the API” on page 7-53. After specifying the custom storage class, be sure to assign the signal object to its output port, as described under “Assigning an Embedded Signal Object to an Output Port” on page 7-57.

### Changing an Embedded Signal Object Using the API

To change an embedded signal object using the API, you obtain a copy of the object from the output port on which it is embedded, change the object as needed, then assign the changed object back to the port.

1 Obtain a copy of the signal object using a handle to the output port. Example:

```
hps=get_param(gcb,'PortHandles')
hp=hps.Outport(1)
MySig=get_param(hp,'SignalObject')
```

2 Change the signal object using the techniques described in "Specifying a Custom Storage Class Using the API" on page 7-53. After making the changes, be sure to copy the signal object to its output port, as described in "Assigning an Embedded Signal Object to an Output Port" on page 7-57.

### Deleting an Embedded Signal Object Using the API

To delete an embedded signal object with the API, obtain a handle to the output port where the signal object is embedded, then set the port's `SignalObject` parameter to `[]`:

```
hps=get_param(gcb,'PortHandles')
hp=hps.Outport(1)
set_param(hp,'SignalObject',[])
```

## Specifying a Custom Storage Class Using the GUI

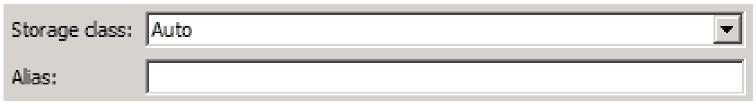
The initial steps for applying a CSC with the GUI differ depending on whether you are applying the CSC to a parameter using a base workspace object, to a signal using a base workspace object, or to a signal using an embedded object. The initial steps for each of these three cases appear in:

- "Providing a Parameter Object Using the GUI" on page 7-38
- "Providing a Base Workspace Signal Object Using the GUI" on page 7-41
- "Providing an Embedded Signal Object using the GUI" on page 7-44

After the initial steps, applying a CSC with the GUI is the same in all three cases. The following instructions show you how to finish applying a CSC with the GUI. The instructions assume that you have completed one of the previous sets of instructions, and that the dialog you used to execute those instructions is still open. If necessary, return to the relevant section and restore the situation that existed at its end, then return to this section.

The instructions given in this section apply to all packages, but the available custom storage classes and custom attributes depend on the package that you select. The examples in this section assume that you are using the `Simulink` package.

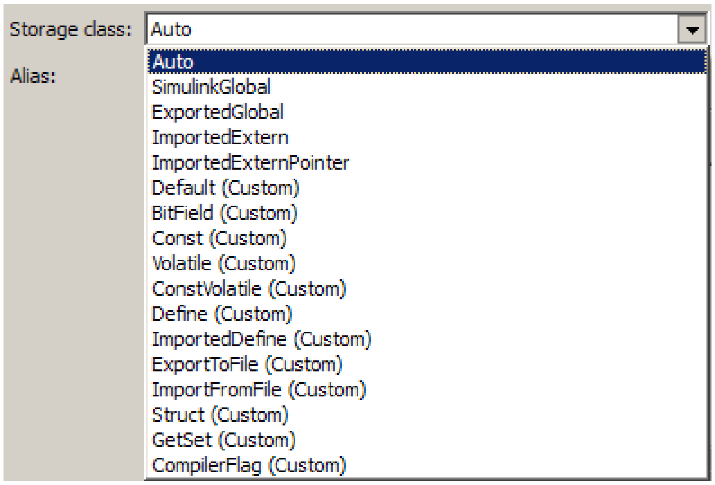
The dialog that you used to begin the process of applying a CSC with the GUI by providing an object contains two fields: one for specifying a custom storage class and one for optionally specifying an alias. These fields are the same in all three of the dialogs that you might use:


Storage class: Auto
Alias:

**Storage class** is `Auto` because that is the default storage class in the `Simulink` package. Other packages may have different defaults. You can specify an **Alias** whenever the **Storage class** is not `Auto`. If **Storage class** is `Auto`, Simulink deletes any alias you try to specify, leaving the field blank. If you specify an alias, it appears in generated code instead of the name of the object.

To specify a custom storage class and its custom attributes:

1 View the **Storage Class** menu, which looks like this for the `Simulink` package:



Storage class: Auto

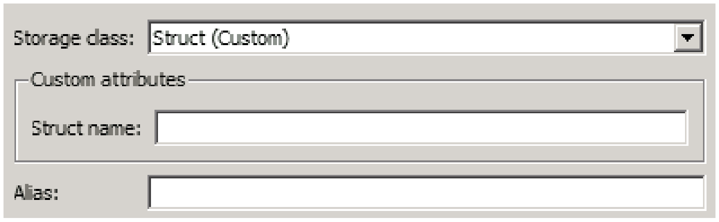
Alias:

Auto
SimulinkGlobal
ExportedGlobal
ImportedExtern
ImportedExternPointer
Default (Custom)
BitField (Custom)
Const (Custom)
Volatile (Custom)
ConstVolatile (Custom)
Define (Custom)
ImportedDefine (Custom)
ExportToFile (Custom)
ImportFromFile (Custom)
Struct (Custom)
GetSet (Custom)
CompilerFlag (Custom)

Each custom storage class has `(custom)` suffixed to its name. The storage classes `SimulinkGlobal`, `ExportedGlobal`, `ImportedExtern`, and `ImportedExternPointer` are the built-in non-custom storage classes described in "Signal Considerations" and "Simulink Data Object Considerations" in the Real-Time Workshop documentation.

2 Choose the desired custom storage class from **Storage class**, for example, `Struct`.

   If the storage class defines any custom attributes, fields for defining them appear:



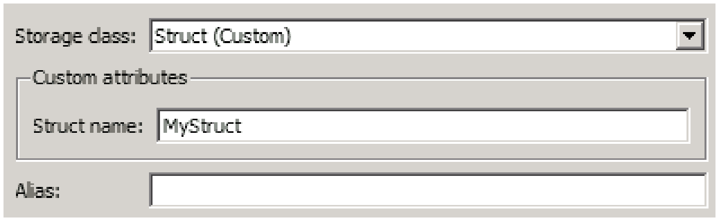
Storage class: Struct (Custom)

Custom attributes

Struct name:

Alias:

3 Provide values for any custom attributes. `Struct` has only one, **Struct name**. For example, set **Struct name** to `MyStruct`:


Storage class: Struct (Custom)

Custom attributes

Struct name: MyStruct

Alias:

**4** Click **Apply**.

In generated code, all data whose storage is controlled by this custom storage class specification will appear in a structure named `MyStruct`. See "Generating Code with Custom Storage Classes" on page 7-58 for an example.

## Specifying a Custom Storage Class Using the API

The initial steps for applying a CSC with the API differ depending on whether you are applying the CSC to a parameter using a base workspace object, to a signal using a base workspace object, or to a signal using an embedded object. The initial steps for each of these three cases appear in:

- "Providing a Parameter Object Using the API" on page 7-39
- "Providing a Base Workspace Signal Object Using the API" on page 7-42
- "Providing an Embedded Signal Object using the API" on page 7-48

After the initial steps, applying a CSC with the API is the same in all three cases, except for an assignment needed only by an embedded signal object. The following instructions show you how to finish applying a CSC with the API. The instructions assume that you have completed one of the previous sets of instructions, and that the resulting objects an attributes are unchanged. If necessary, return to the relevant section and restore the situation that existed at its end, then return to this section.

The instructions given in this section apply to all packages, but the available custom storage classes and custom attributes depend on the package that you select. The examples in this section assume that you are using the `Simulink` package. The examples also assume that the object for which you want to specify a custom storage class is named `MyObj`, which is a parameter or signal object that exists in the base workspace, or a signal object that will be assigned to an output port.

The rest of this section provides information that is specific to custom storage classes in Real-Time Workshop Embedded Coder. See “Simulink Package Custom Storage Classes” on page 7-6 for a list of the custom storage classes that are built into the `Simulink` package for use by Real-Time Workshop Embedded Coder software.

### RTWInfo Properties

Each Simulink parameter object or signal object defines properties called `RTWInfo` properties. Real-Time Workshop uses these properties to control storage class assignment in generated code. The `RTWInfo` properties and their default values are:

```
          StorageClass: 'Auto'
                 Alias: ''
    CustomStorageClass: 'Default'
      CustomAttributes: [1x1 SimulinkCSC.AttribClass_Simulink_Default]
```

For more information about `RTWInfo` properties, see “Signal Considerations” and “Simulink Data Object Considerations” in the Real-Time Workshop documentation.

### Specifying a Custom Storage Class

To specify a custom storage class using `RTWInfo` properties:

1. Set `StorageClass` to `'Custom'`.

2. Set `CustomStorageClass` to the name of the storage class.

For example, to specify the `Struct` custom storage class:

```
MyObj.RTWInfo.StorageClass='Custom'
MyObj.RTWInfo.CustomStorageClass='Struct'
```

Whenever you have specified a custom storage class other than `Auto`, you can specify an alias by setting the `Alias` attribute. If you specify an alias, it appears in generated code instead of the name of the object.

## Specifying Instance-Specific Attributes

A custom storage class can have properties that define attributes that are specific to that CSC. Such properties are called **instance-specific attributes**. For example, if you specify the Struct custom storage class, you must specify the name of the C language structure that will store the data. That name is an instance-specific attribute of the Struct CSC.

Instance-specific attributes are stored in the RTWInfo property CustomAttributes. This property is initially defined as follows:

```
SimulinkCSC.AttribClass_Simulink_Default
1x1 struct array with no fields
```

When you specify a custom storage class, Simulink automatically populates RTWInfo.CustomAttributes with the fields necessary to represent any instance-specific attributes of that CSC. For example, if you set the MySig CSC to Struct, as described in "Specifying a Custom Storage Class" on page 7-54, then enter:

```
MyObj.RTWInfo.CustomAttributes
```

MATLAB displays:

```
SimulinkCSC.AttribClass_Simulink_Struct
    StructName: ''
```

To specify that StructName is MyStruct, enter:

```
MyObj.RTWInfo.CustomAttributes.StructName='MyStruct'
```

MATLAB displays:

```
SimulinkCSC.AttribClass_Simulink_Struct
    StructName: 'MyStruct'
```

**Simulink Package CSC Instance-Specific Properties**

| Class Name | Instance-Specific Property | Purpose |
|---|---|---|
| `BitField` | `CustomAttributes.StructName` | Name of the bitfield `struct` into which the code generator packs the object's Boolean data. |
| `ExportToFile` | `CustomAttributes.HeaderFile` | Name of header (`.h`) file that contains exported variable declarations and export directives for the object. |
| `GetSet` | `CustomAttributes.HeaderFile` | Name of header (`.h`) file to `#include` in the generated code. See "GetSet Custom Storage Class for Data Store Memory" on page 7-66 |
| | `CustomAttributes.GetFunction` | String that specifies the name of a function call to read data. |
| | `CustomAttributes.SetFunction` | String that specifies the name of a function call to write data. |
| `ImportedDefine` | `CustomAttributes.HeaderFile` | The header file that defines the values of code variant preprocessor conditionals. See "Generating Code Variants for Variant Models" on page 3-2 |
| `ImportFromFile` | `CustomAttributes.HeaderFile` | Name of header (`.h`) file containing global variable declarations the code generator imports for the object. |
| `Struct` | `CustomAttributes.StructName` | Name of the `struct` into which the code generator packs the object's data. |

### Assigning an Embedded Signal Object to an Output Port

If you are operating on an embedded signal object with the API, you must copy the object to the port after providing or changing its `RTWInfo` properties. For example, if `MyObj` is a signal object that you want to copy to the output port, enter:

```
hps=get_param(gcb,'PortHandles')
hp=hps.Outport(1)
set_param(hp,'SignalObject','MyObj')
```

Subsequent changes to the source object in the base workspace have no effect on the output port copy, and you can delete the source object if you have no further use for it:

```
clear ('MyObj')
```

## Generating Code with Custom Storage Classes

**In this section...**

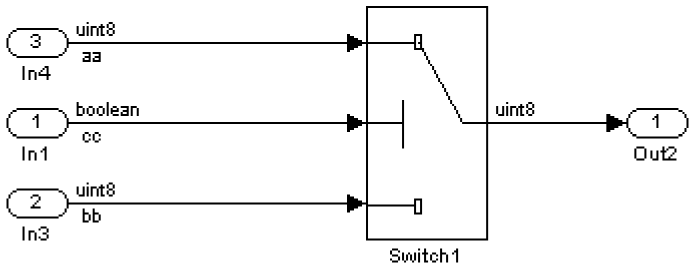
### Code Generation Prerequisites

Before you generate code for a model that uses custom storage classes, set model options as follows:

- If your model assigns custom storage classes to any parameters, select **Inline parameters** on the **Configuration Parameters > Optimization** pane. This requirement also applies to models that assign built-in storage classes to parameters. Otherwise, the code generator ignores CSC specifications for parameters.
- Deselect **Ignore custom storage classes** on the **Configuration Parameters > Real-Time Workshop** pane. Otherwise, the code generator ignores all CSC specifications, and treats all data objects as if their **Storage class** were `Auto`.

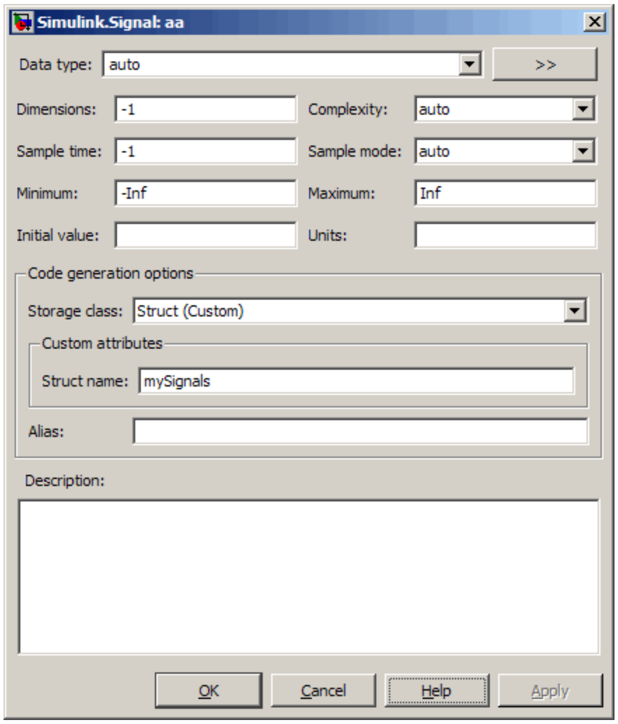
### Code Generation Example

This section presents an example of code generation with CSCs, based on this model:



The model contains three named signals: `aa`, `bb`, and `cc`. Using the predefined `Struct` custom storage class, the example generates code that packs these signals into a `struct` named `mySignals`. The `struct` declaration is then exported to externally written code.

To specify the `struct`, you provide `Simulink.Signal` objects that specify the `Struct` custom storage class, and associate the objects with the signals as described in "Applying CSCs to Parameters and Signals" on page 7-37. All three objects have the same properties. This figure shows the signal object properties for `aa`:


Simulink.Signal: aa

| | | | |
|---|---|---|---|
| Data type: | auto | | |
| Dimensions: | -1 | Complexity: | auto |
| Sample time: | -1 | Sample mode: | auto |
| Minimum: | -Inf | Maximum: | Inf |
| Initial value: | | Units: | |

Code generation options

Storage class: Struct (Custom)

Custom attributes

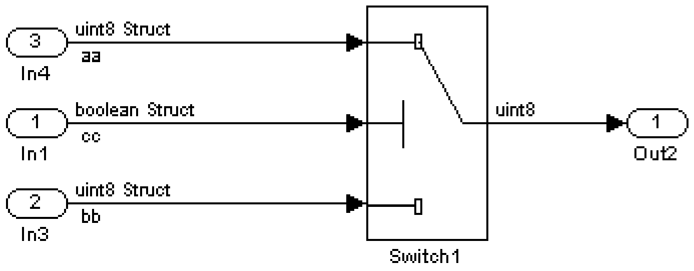
Struct name: mySignals

Alias:

Description:

The association between identically named model signals and signal objects is formed as described in "Resolving Symbols". In this example, the symbols `aa`, `bb`, and `cc` resolve to the signal objects `aa`, `bb`, and `cc`, which have custom storage class `Struct`. In the generated code, storage for the three signals will be allocated within a `struct` named `mySignals`.

You can display the storage class of the signals in the block diagram by selecting **Port/Signal Display > Storage Class** from the Simulink model editor **Format** menu. The figure below shows the block diagram with signal data types and signal storage classes displayed.



With the model configured as described in "Code Generation Prerequisites" on page 7-58, and the signal objects defined and associated with the signals, you can generate code that uses the custom storage classes to generate the desired data structure for the signals. After code generation, the relevant definitions and declarations are located in three files:

- *`model`*`_types.h` defines the following `struct` type for storage of the three signals:

  ```
  typedef struct MySignals_tag {
    boolean_T cc;
    uint8_T bb;
    uint8_T aa;
  } mySignals_type;
  ```

- *`model`*`.c` (or `.cpp`) defines the variable `mySignals`, as specified in the object's instance-specific `StructName` attribute. The variable is referenced in the code generated for the Switch block:

  ```
  /* Definition for Custom Storage Class: Struct */

  mySignals_type mySignals = {
  /* cc */
  FALSE,
  /* bb */
  ```

```
0,
/* aa */
  0
};
...
/*  Switch: '<Root>/Switch1'  */
  if(mySignals.cc) {
    rtb_Switch1 = mySignals.aa;
  } else {
    rtb_Switch1 = mySignals.bb;
  }
```

- *model*.h exports the mySignals Struct variable:

```
/* Declaration for Custom Storage Class: Struct */

extern mySignals_type mySignals;
```

### Grouped Custom Storage Classes

A custom storage class that results in multiple data objects being referenced with a single variable in the generated code, in the previous example, is called a *grouped custom storage class*. In the Simulink package, Bitfield and Struct (shown in the preceding example) are grouped CSCs. Data grouped by a CSC is referred to as *grouped data*.

## Defining Advanced Custom Storage Class Types

**In this section...**

### Overview

Certain data layouts (for example, nested structures) cannot be generated using the standard `Unstructured` and `FlatStructure` custom storage class types. You can create a new custom storage class from scratch if you want to generate other types of data. Note that this requires knowledge of TLC programming and use of a special advanced mode of the Custom Storage Class Designer.

The `GetSet` CSC (see "Creating Packages that Support CSC Definitions" on page 7-8) is an example of an advanced CSC that is provided with the Real-Time Workshop Embedded Coder software.

The following sections explain how to define advanced CSC types.

### Create Your Own Parameter and Signal Classes

The first step is to use the Simulink Data Class Designer to create your own package containing classes derived from `Simulink.Parameter` or `Simulink.Signal`. This procedure is described in "Creating Packages that Support CSC Definitions" on page 7-8.

Add your own object properties and class initialization if desired. For each of your classes, select the **Create your own custom storage classes for this class** option.

## Create a Custom Attributes Class for Your CSC (Optional)

If you have instance-specific properties that are relevant only to your CSC, you should use the Simulink Data Class Designer to create a *custom attributes class* for the package. A custom attributes class is a subclass of `Simulink.CustomStorageClassAttributes`. The name, type, and default value properties you set for the custom attributes class define the user view of instance-specific properties.

For example, the `ExportToFile` custom storage class requires that you set the `RTWInfo.CustomAttributes.HeaderFile` property to specify a `.h` file used for exporting each piece of data. See "Simulink Package Custom Storage Classes" on page 7-6 for further information on instance-specific properties.

## Write TLC Code for Your CSC

The next step is to write TLC code that implements code generation for data of your new custom storage class. A template TLC file is provided for this purpose. To create your TLC code, follow these steps:

1. Create a `tlc` directory inside your package's @directory (if it does not already exist). The naming convention to follow is

   ```
   @PackageName/tlc
   ```

2. Copy `TEMPLATE_v1.tlc` (or another CSC template) from `*matlabroot*/toolbox/rtw/targets/ecoder/csc_templates` into your `tlc` directory to use as a starting point for defining your custom storage class.

3. Write your TLC code, following the comments in the CSC template file. Comments describe how to specify code generation for data of your custom storage class (for example, how data structures are to be declared, defined, and whether they are accessed by value or by reference).

Alternatively, you can copy a custom storage class TLC file from another existing package as a starting point for defining your custom storage class.

## Register Custom Storage Class Definitions

After you have created a package for your new custom storage class and written its associated TLC code, you must register your class definitions with the Custom Storage Class Designer, using its advanced mode.

The advanced mode supports selection of an additional storage class **Type**, designated `Other`. The `Other` type is designed to support special CSC types that cannot be accommodated by the standard `Unstructured` and `FlatStructure` custom storage class types. The `Other` type cannot be assigned to a CSC except when the Custom Storage Class Designer is in advanced mode.

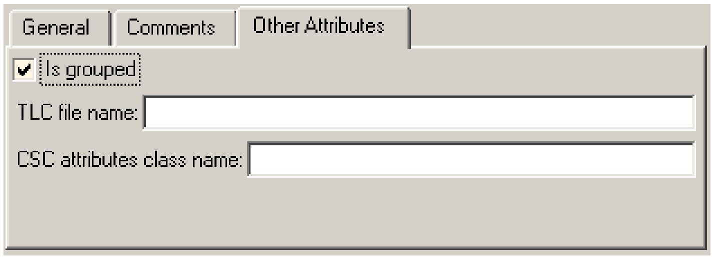
To register your class definitions:

1 Launch the Custom Storage Class Designer in advanced mode by typing the following command at the MATLAB prompt:

```
cscdesigner -advanced
```

2 Select your package and create a new custom storage class.

3 Set the **Type** of the custom storage class to `Other`. Note that when you do this, the **Other Attributes** pane is displayed. This pane is visible only for CSCs whose **Type** is set to `Other`.



☑ Is grouped

TLC file name:

CSC attributes class name:

If you specify a customized package, additional options, as defined by the package, also appear on the **Other Attributes** pane.

4 Set the properties shown on the **Other Attributes** pane. The properties are:

- **Is grouped**: Select this option if you intend to combine multiple data objects of this CSC into a single variable in the generated code. (for example, a struct).
- **TLC file name**: Enter the name of the TLC file corresponding to this custom storage class. The location of the file is assumed to be in the `/tlc` subdirectory for the package, so you should not enter the path to the file.
- **CSC attributes class name**: (optional) If you created a custom attributes class corresponding to this custom storage class, enter the full name of the custom attributes class. (see "Create a Custom Attributes Class for Your CSC (Optional)" on page 7-63).

5 Set the remaining properties on the **General** and **Comments** panes based on the layout of the data that you wish to generate (as defined in your TLC file).

## GetSet Custom Storage Class for Data Store Memory

**In this section...**

### Overview

The `GetSet` custom storage class is designed to generate specialized function calls to read from (get) and write to (set) the memory associated with a Data Store Memory block, when there is a need to read/write a signal many times in a single model. See "Working with Data Stores" for information about data stores and the Data Store Memory block.

The `GetSet` storage class is an advanced CSC: it cannot be represented by the standard `Unstructured` or `FlatStructure` custom storage class types. To access the CSC definition for `GetSet`, you must launch Custom Storage Class designer in advanced mode:

```
cscdesigner -advanced
```

`GetSet` CSC is capable of handling signals other than data stores. `GetSet` is supported for the outputs of most built-in blocks provided by The MathWorks. However, it is not supported for user-written S-functions. A workaround is to drop a Signal Conversion block at the outport of an S-Function (or unsupported built-in) block and assign the `GetSet` storage class to the output of the Signal Conversion block.

The next table summarizes the instance-specific properties of the `GetSet` storage class:

| Property | Description |
|---|---|
| `GetFunction` | String that specifies the name of a function call to read data. |
| `SetFunction` | String that specifies the name of a function call to write data. |
| `HeaderFile` (optional) | String that specifies the name of a header (`.h`) file to add as an `#include` in the generated code.<br><br>**Note** If you omit the `HeaderFile` property for a `GetSet` data object, you must specify a header file by an alternative means, such as the **Header file** field of the **Real-Time Workshop/Custom Code** pane of the Configuration Parameters dialog box. Otherwise, the generated code might not compile or might function improperly. |

For example, if the `GetFunction` of signal `X` is specified as `'get_X'` then the generated code calls `get_X()` wherever the value of `X` is used. Similarly, if the `SetFunction` of signal `X` is specified as `'set_X'` then the generated code calls `set_X(value)` wherever the value of `X` is assigned.

For wide signals, an additional index argument is passed, so the calls to the get and set functions are `get_X(idx)` and `set_X(idx, value)` respectively.

The following restrictions apply to the `GetSet` custom storage class:

- The `GetSet` custom storage class supports only signals of noncomplex data types.
- The `GetSet` custom storage class is designed for use with the state of the Data Store Memory block

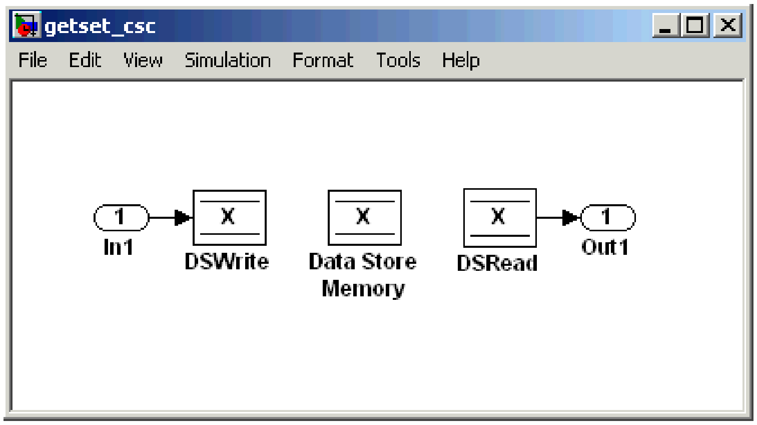
For more details about the definition of the `GetSet` storage class, look at its associated TLC code in the file

```
matlabroot\toolbox\simulink\simulink\@Simulink\tlc\GetSet.tlc
```

## Example of Generated Code with GetSet Custom Storage Class

The model below contains a Data Store Memory block that resolves to Simulink signal object `X`. `X` is configured to use the `GetSet` custom storage class as follows:

```
X = Simulink.Signal;
X.RTWInfo.StorageClass                    = `Custom';
X.RTWInfo.CustomStorageClass              = `GetSet';
X.RTWInfo.CustomAttributes.GetFunction = `get_X';
X.RTWInfo.CustomAttributes.SetFunction = `set_X';
X.RTWInfo.CustomAttributes.HeaderFile  = `user_file.h';
```



The following code is generated for this model:

```
/* Includes for objects with custom storage classes. */
   #include "user_file.h"

   void getset_csc_step(void)
   {
     /* local block i/o variables */
     real_T rtb_DSRead_o;

     /* DataStoreWrite: '<Root>/DSWrite' incorporates:
      *   Inport: '<Root>/In1'
      */
     set_X(getset_csc_U.In1);

     /* DataStoreRead: '<Root>/DSRead' */
     rtb_DSRead_o = get_X();

     /* Outport: '<Root>/Out1' */
     getset_csc_Y.Out1 = rtb_DSRead_o;
   }
```

**Note** The Data Store Memory block creates a local variable to ensure that its value does not change in the middle of a simulation step. This also avoids multiple calls to the data's `GetFunction`.

## Custom Storage Class Implementation

You can skip this section unless you want to ship custom storage class definitions in an uneditable format, or you intend to bypass the Custom Storage Class designer and work directly with files that contain custom storage class definitions.

The file that defines a package's custom storage classes is called a *CSC registration file*. The file is always named `csc_registration` and resides in the *@package* directory that defines the package. A CSC registration file can be a P-file (`csc_registration.p`) or an M-file (`csc_registration.m`). A built-in package defines custom storage classes in both a P-file and a functionally equivalent M-file. A user-defined package initially defines custom storage classes only in an M-file.

P-files take precedence over M-files, so when MATLAB looks for a package's CSC registration file and finds both a P-file and an M-file, MATLAB loads the P-file and ignores the M-file. All capabilities and tools, including the Custom Storage Class Designer, then use the CSC definitions stored in the P-file. P-files cannot be edited, so all CSC Designer editing capabilities are disabled for CSCs stored in a P-file. If no P-file exists, MATLAB loads CSC definitions from the M-file. M-files are editable, so all CSC Designer editing capabilities are enabled for CSCs stored in an M-file.

Because CSC definitions for a built-in package exist in both a P-file and an M-file, they are uneditable. You can make the definitions editable by deleting the P-file, but The MathWorks discourages modifying CSC registration files or any other files under `matlabroot`. The preferred technique is to create user-defined packages, data classes, and custom storage classes, as described in "Subclassing Simulink Data Classes" and this chapter.

The CSC Designer saves CSC definitions for user-defined packages in an M-file, so the definitions are editable. You can make the definitions uneditable by using the `pcode` function to create an equivalent P-file, which will then shadow the M-file. However, you should preserve the M-file if you may need to make further changes, because you cannot modify CSC definitions that exist only in a P-file.

You can also use tools or techniques other than the Custom Storage Class Designer to create and edit M-files that define CSCs. However, The

MathWorks discourages this practice, which is vulnerable to syntax errors and can give unexpected results if a shadowing P-file exists. When MATLAB finds an older P-file that shadows a newer M-file, it displays a warning in the MATLAB Command Window.

## Custom Storage Class Limitations

- The Fcn block does not support parameters with custom storage class in code generation.
- For CSCs in models that use referenced models (see "Referencing a Model"):
  - If data is assigned a grouped CSC, such as `Struct` or `Bitfield`, the CSC's **Data scope** property must be `Imported` and the data declaration must be provided in a user-supplied header file. See "Grouped Custom Storage Classes" on page 7-61 for more information about grouped CSCs.
  - If data is assigned an ungrouped CSC, such as `Const`, and the data's **Data scope** property is `Exported`, its **Header file** property must be unspecified. This results in the data being exported with the standard header file, *`model`*`.h`. Note that for ungrouped data, the **Data scope** and **Header file** properties are either specified by the selected CSC, or as one of the data object's instance-specific properties.

## Custom Storage Classes Prior to R2009a

If you save a model that uses embedded signal objects in a release prior to R2009a, the saved model omits the embedded signal objects. The saved model contains the same information that it would have contained if the embedded signal objects had never existed, and output ports have no `SignalObject` property. See "Applying a CSC Using an Embedded Signal Object" on page 7-43 for information about embedded signal objects.

## Custom Storage Classes Prior to Release 14

**In this section...**

### Introduction

In releases prior to Real-Time Workshop Embedded Coder version 4.0 (MATLAB Release 14), custom storage classes were implemented with special `Simulink.CustomSignal` and `Simulink.CustomParameter` classes. This section describes these older classes.

---

**Note** Models that use the `Simulink.CustomSignal` and `Simulink.CustomParameter` classes continue to operate correctly. The current CSCs support a superset of the functions of the older classes. Therefore, you should consider using the `Simulink.Signal` and `Simulink.Parameter` classes instead (see "Compatibility Issues for Older Custom Storage Classes" on page 7-81).

---

### Simulink.CustomParameter Class

This class is a subclass of `Simulink.Parameter`. Objects of this class have expanded `RTWInfo` properties. The properties of `Simulink.CustomParameter` objects are:

- `RTWInfo.StorageClass`. This property should always be set to the default value, `Custom`.

- `RTWInfo.CustomStorageClass`. This property takes on one of the enumerated values described in the tables below. This property controls the generated storage declaration and code for the object.
- `RTWInfo.CustomAttributes`. This property defines additional attributes that are exclusive to the class, as described in "Instance-Specific Attributes for Older Storage Classes" on page 7-78.
- `Value`. This property is the numeric value of the object, used as an initial (or inlined) parameter value in generated code.

## Simulink.CustomSignal Class

This class is a subclass of `Simulink.Signal`. Objects of this class have expanded `RTWInfo` properties. The properties of `Simulink.CustomSignal` objects are:

- `RTWInfo.StorageClass`. This property should always be set to the default value, `Custom`.
- `RTWInfo.CustomStorageClass`. This property takes on one of the enumerated values described in the tables below. This property controls the generated storage declaration and code for the object.
- `RTWInfo.CustomAttributes`. This optional property defines additional attributes that are exclusive to the storage class, as described in "Instance-Specific Attributes for Older Storage Classes" on page 7-78.

The following tables summarize the predefined custom storage classes for `Simulink.CustomSignal` and `Simulink.CustomParameter` objects. The entry for each class indicates

- Name and purpose of the class.
- Whether the class is valid for parameter or signal objects. For example, you can assign the storage class `Const` to a parameter object. This storage class is not valid for signals, however, since signal data (except for the case of invariant signals) is not constant.
- Whether the class is valid for complex data or nonscalar (wide) data.
- Data types supported by the class.

The first three classes, shown in Const, ConstVolatile, and Volatile Storage Classes (Prior to Release 14) on page 7-76, insert type qualifiers in the data declaration.

**Const, ConstVolatile, and Volatile Storage Classes (Prior to Release 14)**

| Class Name | Purpose | Parameters | Signals | Data Types | Complex | Wide |
|---|---|---|---|---|---|---|
| `Const` | Use `const` type qualifier in declaration | Y | N | any | Y | Y |
| `ConstVolatile` | Use `const volatile` type qualifier in declaration | Y | N | any | Y | Y |
| `Volatile` | Use `volatile` type qualifier in declaration | Y | Y | any | Y | Y |

The second set of three classes, shown in ExportToFile, ImportFromFile, and Internal Storage Classes (Prior to Release 14) on page 7-76, handles issues of data scope and file partitioning.

**ExportToFile, ImportFromFile, and Internal Storage Classes (Prior to Release 14)**

| Class Name | Purpose | Parameters | Signals | Data Types | Complex | Wide |
|---|---|---|---|---|---|---|
| `ExportToFile` | Generate and include files, with user-specified name, containing global variable declarations and definitions | Y | Y | any | Y | Y |

**ExportToFile, ImportFromFile, and Internal Storage Classes (Prior to Release 14) (Continued)**

| Class Name | Purpose | Parameters | Signals | Data Types | Complex | Wide |
|---|---|---|---|---|---|---|
| `ImportFromFile` | Include predefined header files containing global variable declarations | Y | Y | any | Y | Y |
| `Internal` | Declare and define global variables whose scope is limited to Real-Time Workshop generated code | Y | Y | any | Y | Y |

The final three classes, shown in BitField, Define, and Struct Storage Classes (Prior to Release 14) on page 7-77, specify the data structure or construct used to represent the data.

**BitField, Define, and Struct Storage Classes (Prior to Release 14)**

| Class Name | Purpose | Parameters | Signals | Data types | Complex | Wide |
|---|---|---|---|---|---|---|
| `BitField` | Embed Boolean data in a named bit field | Y | Y | Boolean | N | N |
| `Define` | Represent parameters with a `#define` macro | Y | N | any | N | N |

**BitField, Define, and Struct Storage Classes (Prior to Release 14) (Continued)**

| Class Name | Purpose | Parameters | Signals | Data types | Complex | Wide |
|---|---|---|---|---|---|---|
| `Struct` | Embed data in a named struct to encapsulate sets of data | Y | Y | any | N | Y |

## Instance-Specific Attributes for Older Storage Classes

Some custom storage classes have attributes that are exclusive to the class. These attributes are made visible as members of the `RTWInfo.CustomAttributes` field. For example, the `BitField` class has a `BitFieldName` attribute (`RTWInfo.CustomAttributes.BitFieldName`).

Additional Properties of Custom Storage Classes (Prior to Release 14) on page 7-78 summarizes the storage classes with additional attributes, and the meaning of those attributes. Attributes marked optional have default values and may be left unassigned.

**Additional Properties of Custom Storage Classes (Prior to Release 14)**

| Storage Class Name | Additional Properties | Description | Optional (has default) |
|---|---|---|---|
| `ExportToFile` | `FileName` | String. Defines the name of the generated header file within which the global variable declaration should reside. If unspecified, the declaration is placed in *`model`*`_export.h` by default. | Y |
| `ImportFromFile` | `FileName` | String. Defines the name of the generated header file which to be used in `#include` directive. | N |

**Additional Properties of Custom Storage Classes (Prior to Release 14) (Continued)**

| Storage Class Name | Additional Properties | Description | Optional (has default) |
|---|---|---|---|
| `ImportFromFile` | `IncludeDelimeter` | Enumerated. Defines delimiter used for filename in the `#include` directive. Delimiter is either double quotes (for example, `#include "vars.h"`) or angle brackets (for example, `#include <vars.h>`). The default is quotes. | Y |
| `BitField` | `BitFieldName` | String. Defines name of bit field in which data is embedded; if unassigned, the name defaults to `rt_BitField`. | Y |
| `Struct` | `StructName` | String. Defines name of the struct in which data is embedded; if unassigned, the name defaults to `rt_Struct`. | Y |

## Assigning a Custom Storage Class to Data

You can create custom parameter or signal objects from the MATLAB command line. For example, the following commands create a custom parameter object `p` and a custom signal object `s`:

```
p = Simulink.CustomParameter
s = Simulink.CustomSignal
```

After creating the object, set the `RTWInfo.CustomStorageClass` and `RTWInfo.CustomAttributes` fields. For example, the following commands sets these fields for the custom parameter object `p`:

```
p.RTWInfo.CustomStorageClass = 'ExportToFile'
p.RTWInfo.CustomAttributes.FileName = 'testfile.h'
```

Finally, make sure that the `RTWInfo.StorageClass` property is set to `Custom`. If you inadvertently set this property to some other value, the custom storage properties are ignored.

## Code Generation with Older Custom Storage Classes

The procedure for generating code with data objects that have a custom storage class is similar to the procedure for code generation using Simulink data objects that have built-in storage classes. If you are unfamiliar with this procedure, see the discussion of Simulink data objects in the "Defining Data Representation and Storage for Code Generation" section of the Real-Time Workshop documentation.

To generate code with custom storage classes, you must

1. Create one or more data objects of class `Simulink.CustomParameter` or `Simulink.CustomSignal`.

2. Set the custom storage class property of the objects, as well as the class-specific attributes (if any) of the objects.

3. Reference these objects as block parameters, signals, block states, or Data Store memory.

When generating code from a model employing custom storage classes, make sure that the **Ignore custom storage classes** option is *not* selected. This is the default for the Real-Time Workshop Embedded Coder software.

When **Ignore custom storage classes** is selected:

- Objects with custom storage classes are treated as if their storage class attribute is set to `Auto`.
- The storage class of signals that have custom storage classes is not displayed on the signal line, even if the **Storage class** option of the Simulink model editor **Format** menu is selected.

**Ignore custom storage classes** lets you switch to a target that does not support CSCs, such as the generic real-time target (GRT), without having to reconfigure your parameter and signal objects.

When using the Real-Time Workshop Embedded Coder software, you can control the **Ignore custom storage classes** option with the check box in the **Real-Time Workshop** pane of the Configuration Parameters dialog box.

If you are using a target that does not have a check box for this option (such as a custom target) you can enter the option directly into the **TLC options** field in the **Real-Time Workshop** pane of the Configuration Parameters dialog box. The following example turns the option on:

```
-aIgnoreCustomStorageClasses=1
```

## Compatibility Issues for Older Custom Storage Classes

In Release 14, the full functionality of the `Simulink.CustomSignal` and `Simulink.CustomParameter` classes was added to the `Simulink.Signal` and `Simulink.Parameter` classes. You should consider replacing the use of `Simulink.CustomSignal` and `Simulink.CustomParameter` objects by using equivalent `Simulink.Signal` and `Simulink.Parameter` objects.

If you prefer, you can continue to use the `Simulink.CustomSignal` and `Simulink.CustomParameter` classes in the current release. Note that the following changes have been implemented in these classes:

- The `Internal` storage class has been removed from the enumerated values of the `RTWInfo.CustomStorageClass` property. `Internal` storage class is no longer supported.
- For the `ExportToFile` and `ImportFromFile` storage classes, the `RTWInfo.CustomAttributes.FileName` and `RTWInfo.CustomAttributes.IncludeDelimeter` properties have been obsoleted and combined into a single property, `RTWInfo.CustomAttributes.HeaderFile`. When specifying a header file, include both the filename and the required delimiter as you want them to appear in generated code, as in the following example:

  ```
  myobj.RTWInfo.CustomAttributes.HeaderFile = '<myheader.h>';
  ```

- Prior to Release 14, user-defined CSCs were created by designing custom packages that included the CSC definitions. This technique for creating

CSCs is obsolete; see “Creating Packages that Support CSC Definitions” on page 7-8 for a description of the current procedure, which is much simpler.

If you designed your own custom packages containing CSCs prior to Release 14 you should convert them to Release 14 CSCs. The conversion procedure is described in the next section, “Converting Older Packages to Use CSC Registration Files” on page 7-82.

## Converting Older Packages to Use CSC Registration Files

A Simulink data class package can be associated with one or more CSC definitions. In Release 14, the linkage between a set of CSC definitions and a package is formed when a CSC registration file (`csc_registration.m`) is located in the package directory.

Prior to Release 14, user-defined CSCs were created by designing custom packages that included the CSC definitions as part of the package.

The Simulink Data Class Designer supports conversion of older packages to the use of CSC registration files. When such a package is selected in Data Class Designer, a special conversion button is displayed on the **Custom Storage Classes** pane. This button lets you invoke a conversion procedure; you can then write out all files and directories required to define the package, including a CSC registration file. To convert a package:

1. You should make a complete backup copy of the package directory before converting the package. After backing up the directory, remove the @ prefix from the backup directory name and make sure that the backup directory is not on the MATLAB path.

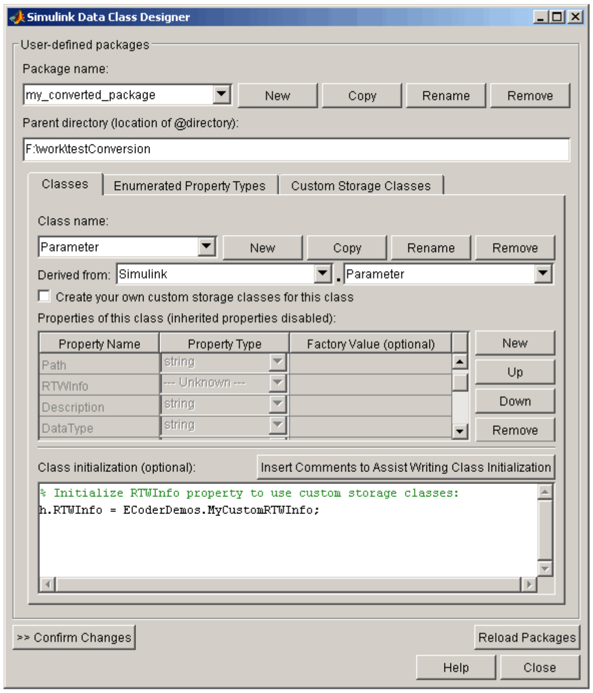
2. Open the Simulink Data Class Designer by choosing **Tools > Data Class Designer** in the model window, or typing the following at the MATLAB command prompt:

   ```
   sldataclassdesigner
   ```

3. The Data Class Designer loads all packages that exist on the MATLAB path. Select the package to be converted from the **Package name** menu. Then, click **OK**.

**4** If you want to store the converted package in a different directory than the original package, enter the desired path in the **Parent directory** field. This step is optional.

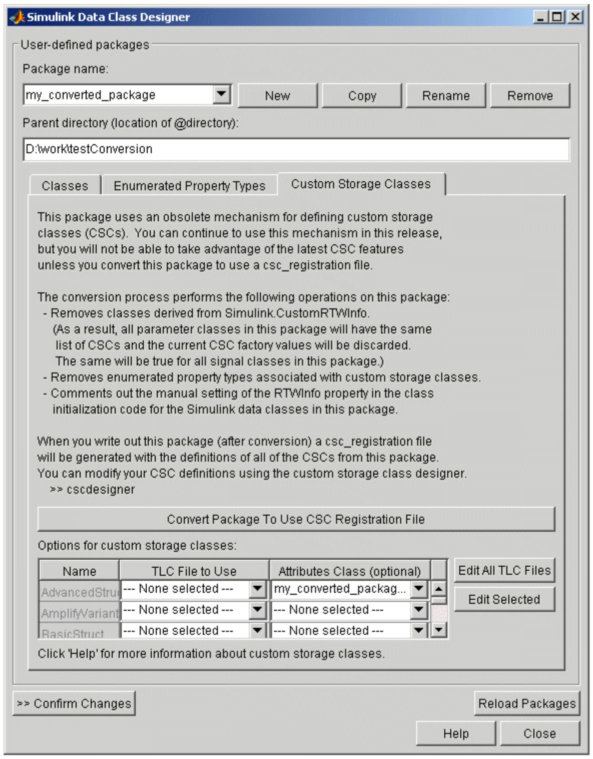
The figure below shows the package `my_converted_package`. The package definition is stored in `d:\work\testConversion`.


Simulink Data Class Designer
User-defined packages
Package name:
my_converted_package
New
Copy
Rename
Remove
Parent directory (location of @directory):
F:\work\testConversion
Classes
Enumerated Property Types
Custom Storage Classes
Class name:
Parameter
Derived from:
Simulink
Parameter
Create your own custom storage classes for this class
Properties of this class (inherited properties disabled):
Up
Down
Class initialization (optional):
Insert Comments to Assist Writing Class Initialization
>> Confirm Changes
Reload Packages
Help
Close

| Property Name | Property Type | Factory Value (optional) |
|---|---|---|
| Path | string | |
| RTWInfo | --- Unknown --- | |
| Description | string | |
| DataType | string | |

```
% Initialize RTWInfo property to use custom storage classes:
h.RTWInfo = ECoderDemos.MyCustomRTWInfo;
```

**5** Click on the **Custom Storage Classes** pane. The pane displays a message indicating that the package contains obsolete CSC definitions, as shown in this figure.



Package name: my_converted_package

Parent directory (location of @directory): D:\work\testConversion

This package uses an obsolete mechanism for defining custom storage classes (CSCs). You can continue to use this mechanism in this release, but you will not be able to take advantage of the latest CSC features unless you convert this package to use a csc_registration file.

The conversion process performs the following operations on this package:
- Removes classes derived from Simulink.CustomRTWInfo.
  (As a result, all parameter classes in this package will have the same list of CSCs and the current CSC factory values will be discarded. The same will be true for all signal classes in this package.)
- Removes enumerated property types associated with custom storage classes.
- Comments out the manual setting of the RTWInfo property in the class initialization code for the Simulink data classes in this package.

When you write out this package (after conversion) a csc_registration file will be generated with the definitions of all of the CSCs from this package. You can modify your CSC definitions using the custom storage class designer.
```
>> cscdesigner
```

Convert Package To Use CSC Registration File

Options for custom storage classes:

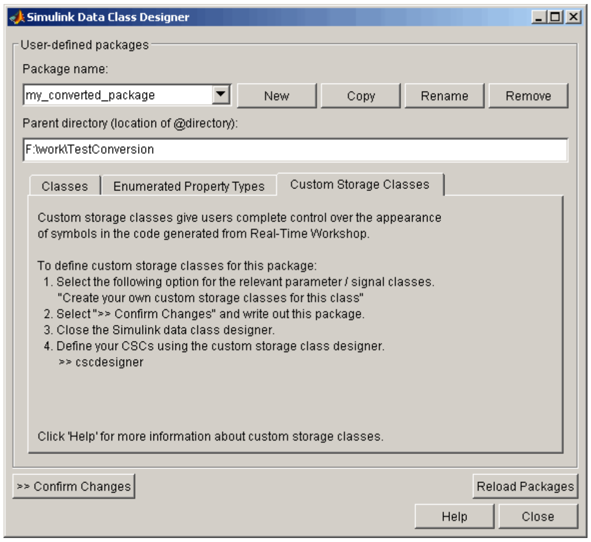
| Name | TLC File to Use | Attributes Class (optional) |
|---|---|---|
| AdvancedStru | --- None selected --- | my_converted_packag... |
| AmplifyVariant | --- None selected --- | --- None selected --- |
| BasicStruct | --- None selected --- | --- None selected --- |

Click 'Help' for more information about custom storage classes.

Below the message text, the pane also contains a button captioned **Convert Package to Use CSC Registration File**. This button invokes a script that converts the package to use a CSC registration file.

Note that this button does not actually create the CSC registration file. That happens when the package files are written out, as described below.

**6** Click **Convert Package to Use CSC Registration File**. After conversion, the appearance of the pane changes, as shown below.



Custom storage classes give users complete control over the appearance
of symbols in the code generated from Real-Time Workshop.

To define custom storage classes for this package:
1. Select the following option for the relevant parameter / signal classes.
"Create your own custom storage classes for this class"
2. Select ">> Confirm Changes" and write out this package.
3. Close the Simulink data class designer.
4. Define your CSCs using the custom storage class designer.
>> cscdesigner

Click 'Help' for more information about custom storage classes.

**7** Click **Confirm Changes**. In the **Confirm Changes** pane, select the package you converted. Add the parent directory to the MATLAB path if necessary. Then, click **Write Selected**.

**8** Click **Close**.

**9** You can now view and edit the CSCs belonging to your package in the Custom Storage Class Designer. To do so, type the following command at the MATLAB prompt:

```
cscdesigner
```

---

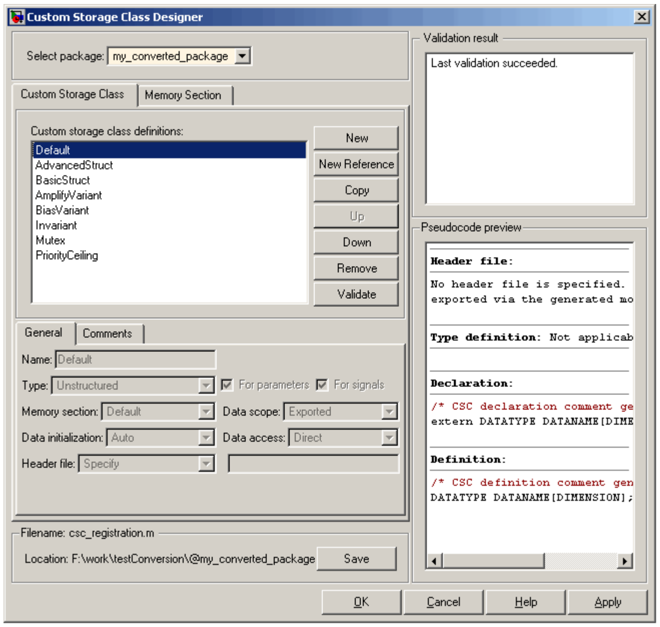
**Note** You must launch the CSC Designer with the `-advanced` motion to edit the attributes of old CSCs because they are defined with user-defined TLC files.

---

The Custom Storage Class Designer loads all packages that have a CSC registration file.

**10** Select your converted package from the **Select package** menu.

The figure below shows the Custom Storage Class Designer displaying the CSCs defined in the package `my_converted_package`. See “Designing Custom Storage Classes and Memory Sections” on page 7-12 for a description of the operation of the Custom Storage Class Designer.


Custom Storage Class Designer

Select package: my_converted_package

Custom storage class definitions:

Default
AdvancedStruct
BasicStruct
AmplifyVariant
BiasVariant
Invariant
Mutex
PriorityCeiling

Name: Default

Type: Unstructured ☑ For parameters ☑ For signals

Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

Filename: csc_registration.m

Location: F:\work\testConversion\@my_converted_package

Validation result

Last validation succeeded.

Pseudocode preview

```
Header file:
No header file is specified.
exported via the generated mo

Type definition: Not applicab

Declaration:
/* CSC declaration comment ge
extern DATATYPE DATANAME[DIME

Definition:
/* CSC definition comment gen
DATATYPE DATANAME[DIMENSION];
```

---

**Note** All user-defined CSCs created prior to Release 14 are defined with their own TLC code. As a result, after conversion, the **Type** is set to `Other` (as opposed to `Unstructured` or `FlatStructure`). See “Defining Advanced Custom Storage Class Types” on page 7-62 for more information.

---

**11** Restart your MATLAB session to ensure that your converted package is accessible.

# Inserting Comments and Pragmas in Generated Code

## Introduction to Memory Sections

**In this section...**

### Overview

The Real-Time Workshop Embedded Coder software provides a memory section capability that allows you to insert comments and pragmas into the generated code for

- Data in custom storage classes
- Model-level functions
- Model-level internal data
- Subsystem functions
- Subsystem internal data

Pragmas inserted into generated code can surround

- A contiguous block of function or data definitions
- Each function or data definition separately

When pragmas surround each function or data definition separately, the text of each pragma can contain the name of the definition to which it applies.

### Memory Sections Demo

To see a demo of memory sections, type `rtwdemo_memsec` in the MATLAB Command Window.

### Additional Information

See the following for additional information relating to memory sections:

- Simulink data types, packages, data classes, and data objects:
  - "Working with Data" in the Simulink documentation
- Real-Time Workshop data structures and storage classes:
  - "Defining Data Representation and Storage for Code Generation" in the Real-Time Workshop documentation
- Real-Time Workshop Embedded Coder custom storage classes:
  - Chapter 7, "Creating and Using Custom Storage Classes" in the Real-Time Workshop Embedded Coder documentation
- Fine-tuned optimization of generated code for functions or data:
  - The *Real-Time Workshop Target Language Compiler* documentation

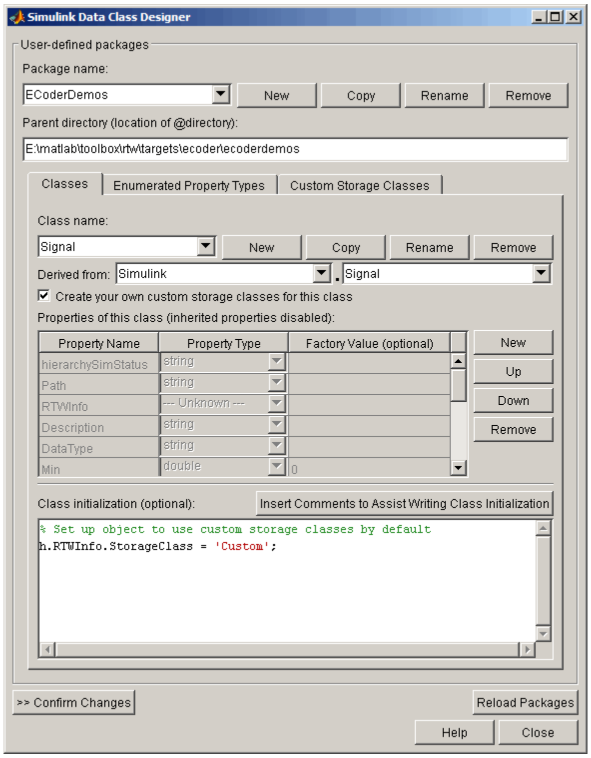
## Requirements for Defining Memory Sections

Before you can define memory sections, you must do the following:

1 Set the Simulink model's code generation target to an embedded target such as `ert.tlc`.

2 If you need to create packages, specify package properties, or create classes, including custom storage classes, choose **Tools > Data Class Designer** in the model window.

A notification box appears that states **Please Wait ... Finding Packages**. After a brief pause, the Simulink Data Class Designer appears. The Data Class Designer initially looks like this:



Package name: ECoderDemos

Parent directory (location of @directory): E:\matlab\toolbox\rtw\targets\ecoder\ecoderdemos

Class name: Signal

Derived from: Simulink . Signal

☑ Create your own custom storage classes for this class

Properties of this class (inherited properties disabled):

| Property Name | Property Type | Factory Value (optional) |
|---|---|---|
| hierarchySimStatus | string | |
| Path | string | |
| RTWInfo | --- Unknown --- | |
| Description | string | |
| DataType | string | |
| Min | double | 0 |

Class initialization (optional):

```
% Set up object to use custom storage classes by default
h.RTWInfo.StorageClass = 'Custom';
```

Complete instructions for using the Data Class Designer appear in "Subclassing Simulink Data Classes" in the Simulink documentation. See also the instructions that appear when you click the **Custom Storage Classes** tab.

**3** If you need to specify custom storage class properties,

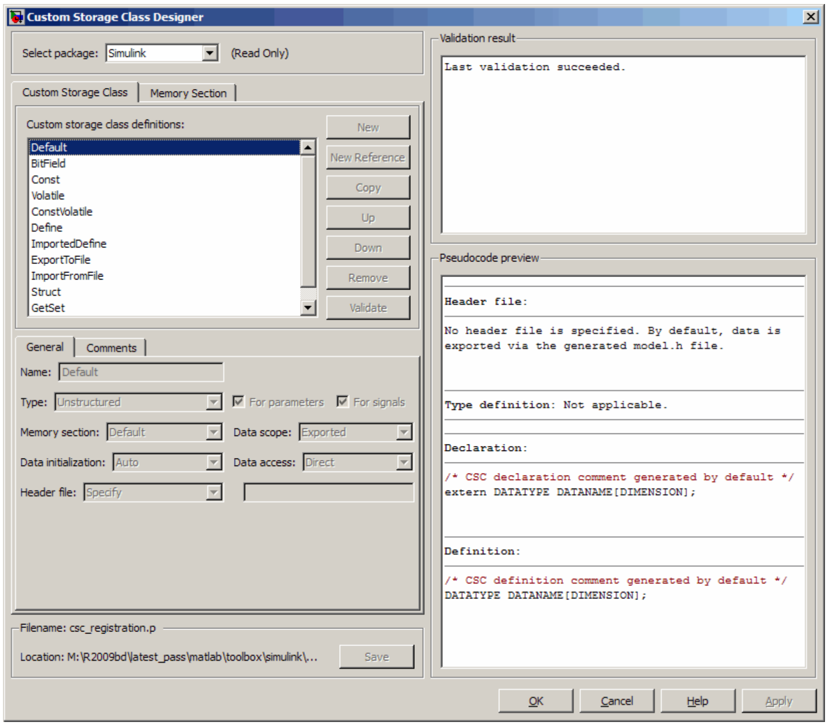
   **a** Choose **View > Model Explorer** in the model window.

      The Model Explorer appears.

   **b** Choose **Tools > Custom Storage Class Designer** in the Model Explorer window.

      A notification box appears that states **Please Wait ... Finding Packages**. After a brief pause, the notification box closes and the Custom Storage Class Designer appears.

   **c** Select the **Custom Storage Class** tab. The **Custom Storage Class** pane initially looks like this:



Select package: Simulink (Read Only)

Custom storage class definitions:
Default
BitField
Const
Volatile
ConstVolatile
Define
ImportedDefine
ExportToFile
ImportFromFile
Struct
GetSet

Name: Default
Type: Unstructured ☑ For parameters ☑ For signals
Memory section: Default Data scope: Exported
Data initialization: Auto Data access: Direct
Header file: Specify

Filename: csc_registration.p
Location: M:\R2009bd\latest_pass\matlab\toolbox\simulink\...

Validation result

```
Last validation succeeded.
```

Pseudocode preview

```
Header file:

No header file is specified. By default, data is
exported via the generated model.h file.

Type definition: Not applicable.

Declaration:

/* CSC declaration comment generated by default */
extern DATATYPE DATANAME[DIMENSION];

Definition:

/* CSC definition comment generated by default */
DATATYPE DATANAME[DIMENSION];
```

**d** Use the **Custom Storage Class** pane as needed to select a writable package and specify custom storage class properties. Instructions for using this pane appear in "Designing Custom Storage Classes and Memory Sections" on page 7-12.

## Defining Memory Sections

**In this section...**

### Editing Memory Section Properties

After you have satisfied the requirements in “Requirements for Defining Memory Sections” on page 8-4, you can define memory sections and specify their properties. To create new memory sections or specify memory section properties,

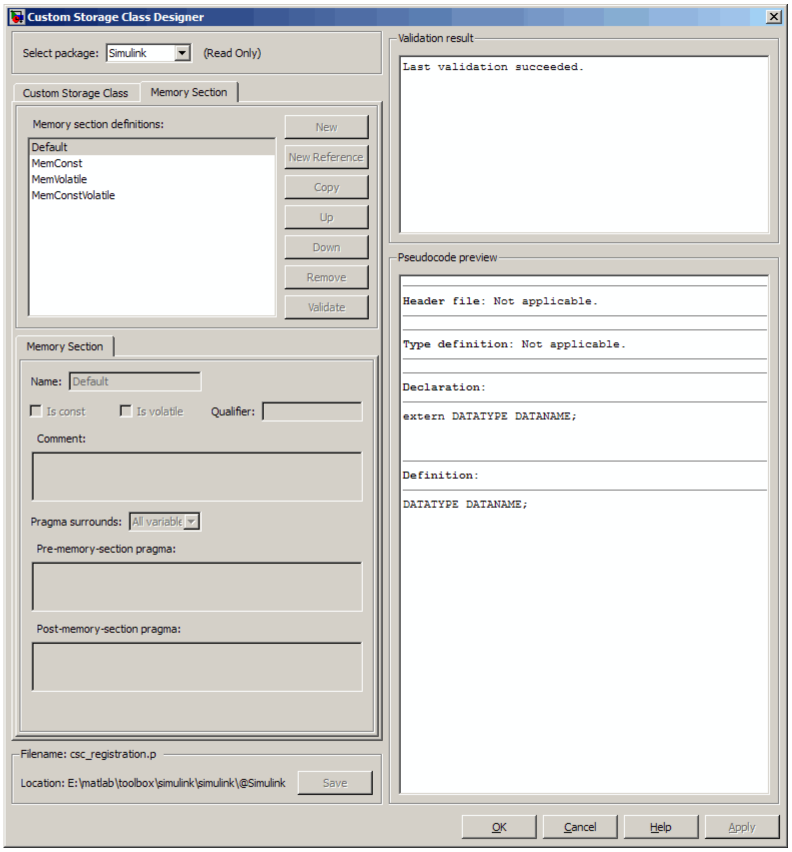
1. Choose **View > Model Explorer** in the model window.

   The Model Explorer appears.

2. Choose **Tools > Custom Storage Class Designer** in the Model Explorer window.

   A notification box appears that states **Please Wait ... Finding Packages**. After a brief pause, the notification box closes and the Custom Storage Class Designer appears.

3. Click the **Memory Section** tab of the Custom Storage Class Designer. The **Memory Section** pane initially looks like this:



Select package: Simulink (Read Only)

Memory section definitions:

- Default
- MemConst
- MemVolatile
- MemConstVolatile

Name: Default

Pragma surrounds: All variable

Filename: csc_registration.p

Location: E:\matlab\toolbox\simulink\simulink\@Simulink

Validation result

```
Last validation succeeded.
```

Pseudocode preview

```
Header file: Not applicable.

Type definition: Not applicable.

Declaration:

extern DATATYPE DATANAME;

Definition:

DATATYPE DATANAME;
```

**4** If you intend to create or change memory section definitions, use the **Select package** field to select a writable package.

The rest of this section assumes that you have selected a writable package, and describes the use of the **Memory section** subpane on the lower left. For descriptions of the other subpanes, instructions for validating memory section definitions, and other information, see “Creating and Editing Memory Section Definitions” on page 7-31.

## Specifying the Memory Section Name

To specify the name of a memory section, use the **Name** field. A memory section name must be a legal MATLABMATLAB identifier.

## Specifying a Qualifier for Custom Storage Class Data Definitions

To specify a qualifier for custom storage class data definitions in a memory section, enter the components of the qualifier below the **Name** field.

- To specify `const`, check **Is const**.
- To specify `volatile`, check **Is volatile**.
- To specify anything else (e.g., `static`), enter the text in the **Qualifier** field.

The qualifier will appear in generated code with its components in the same left-to-right order in which their definitions appear in the dialog box. A preview appears in the **Pseudocode preview** subpane on the lower right.

**Note** Specifying a qualifier affects only custom storage class data definitions. The code generator omits the qualifier from any other category of definition.

## Specifying Comment and Pragma Text

To specify a comment, prepragma, or postpragma for a memory section, enter the text in the appropriate edit boxes on the left side of the Custom Storage Class Designer. These boxes accept multiple lines separated by ordinary Returns.

## Surrounding Individual Definitions with Pragmas

If the **Pragma surrounds** field for a memory section specifies `Each variable`, the code generator will surround each definition in a contiguous block of definitions with the comment, prepragma, and postpragma defined for the section. This behavior occurs with all categories of definitions.

If the **Pragma surrounds** field for a memory section specifies `All variables`, the code generator will insert the comment and prepragma for the section before the first definition in a contiguous block of custom storage class data definitions, and the postpragma after the last definition in the block.

---

**Note** Specifying `All variables` affects only custom storage class data definitions. For any other category of definition, the code generator surrounds each definition separately regardless of the value of **Pragma surrounds**.

---

## Including Identifier Names in Pragmas

When pragmas surround each separate definition in a contiguous block, you can include the string `%<identifier>` in a pragma. The string must appear without surrounding quotes.

- When `%<identifier>` appears in a prepragma, the code generator will substitute the identifier from the subsequent function or data definition.
- When `%<identifier>` appears in a postpragma, the code generator will substitute the identifier from the previous function or data definition.

You can use `%<identifier>` with pragmas *only* when pragmas to surround each variable. The `Validate` phase will report an error if you violate this rule.

---

**Note** Although `%<identifier>` looks like a TLC variable, it is not: it is just a keyword that directs the code generator to substitute the applicable data definition identifier when it outputs a pragma. TLC variables cannot appear in pragma specifications in the **Memory Section** pane.

---

## Configuring Memory Sections

You can configure a model such that the generated code includes comments and pragmas for

- Data defined in custom storage classes
- Internal data not defined in custom storage classes
- Model-level functions
- Atomic subsystem functions with or without separate data

| To... | Select... |
|---|---|
| Specify the package that contains memory sections that you want to apply | The name of a package for **Package**. Click **Refresh package list** to refresh the list of available packages in your configuration. |
| Apply memory sections to initialize/start and terminate functions | A value for **Initialize/Terminate**. |
| Apply memory sections to step, run-time initialization, derivative, enable, and disable functions | A value for **Execution**. |
| Apply memory sections to constant parameters, constant, block I/O, or zero representation | A value for **Constants**. |
| Apply memory sections to root inputs or outputs | A value for **Inputs/Outputs**. |
| Apply memory sections to block I/O, Dwork vectors, run-time models, zero-crossings | A value for **Internal data**. |
| Apply memory sections to parameters | A value for **Parameters**. |

The interface checks whether the specified package is on the MATLAB path and that the selected memory sections are in the package. The results of this validation appear in the field **Validation results**.

## Applying Memory Sections

**In this section...**

### Assigning Memory Sections to Custom Storage Classes

To assign a memory section to a custom storage class,

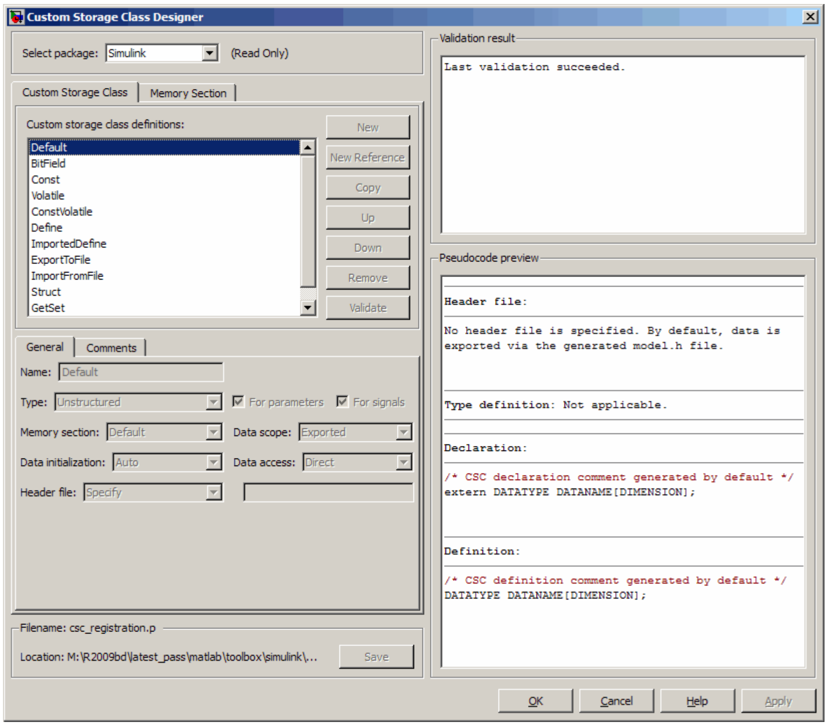
1 Choose **View > Model Explorer** in the model window.

   The Model Explorer appears.

2 Choose **Tools > Custom Storage Class Designer** in the Model Explorer window.

   A notification box appears that states **Please Wait ... Finding Packages**. After a brief pause, the notification box closes and the Custom Storage Class Designer appears.

3 Select the **Custom Storage Class** tab. The **Custom Storage Class** pane initially looks like this:



Select package: Simulink (Read Only)

Custom storage class definitions:

- Default
- BitField
- Const
- Volatile
- ConstVolatile
- Define
- ImportedDefine
- ExportToFile
- ImportFromFile
- Struct
- GetSet

Name: Default

Type: Unstructured ✓ For parameters ✓ For signals

Memory section: Default Data scope: Exported

Data initialization: Auto Data access: Direct

Header file: Specify

Filename: csc_registration.p

Location: M:\R2009bd\latest_pass\matlab\toolbox\simulink\...

Validation result

```
Last validation succeeded.
```

Pseudocode preview

```
Header file:

No header file is specified. By default, data is
exported via the generated model.h file.

Type definition: Not applicable.

Declaration:

/* CSC declaration comment generated by default */
extern DATATYPE DATANAME[DIMENSION];

Definition:

/* CSC definition comment generated by default */
DATATYPE DATANAME[DIMENSION];
```

**4** Use the **Select package** field to select a writable package. The rest of this section assumes that you have selected a writable package.

**5** Select the desired custom storage class in the **Custom storage class definitions** pane.

**6** Select the desired memory section from the **Memory section** pull-down.

**7** Click **Apply** to apply changes to the open copy of the model; **Save** to apply changes and save them to disk; or **OK** to apply changes, save changes, and close the Custom Storage Class Designer.

Generated code for all data definitions in the specified custom storage class will be enclosed in the pragmas of the specified memory section. The pragmas can surround contiguous blocks of definitions or each definition separately, as described in “Surrounding Individual Definitions with Pragmas” on page 8-9.

For more information, see “Creating Packages that Support CSC Definitions” on page 7-8.

## Applying Memory Sections to Model-Level Functions and Internal Data

When using the Real-Time Workshop Embedded Coder software, you can apply memory sections to the following categories of model-level functions:

| Function Category | Function Subcategory |
|---|---|
| Initialize/Terminate functions | Initialize/Start |
| | Terminate |
| Execution functions | Step functions |
| | Run-time initialization |
| | Derivative |
| | Enable |
| | Disable |

When using the Real-Time Workshop Embedded Coder software, you can apply memory sections to the following categories of internal data:

| Data Category | Data Definition | Data Purpose |
|---|---|---|
| Constants | `model_cP` | Constant parameters |
| | `model_cB` | Constant block I/O |
| | `model_Z` | Zero representation |
| Input/Output | `model_U` | Root inputs |
| | `model_Y` | Root outputs |

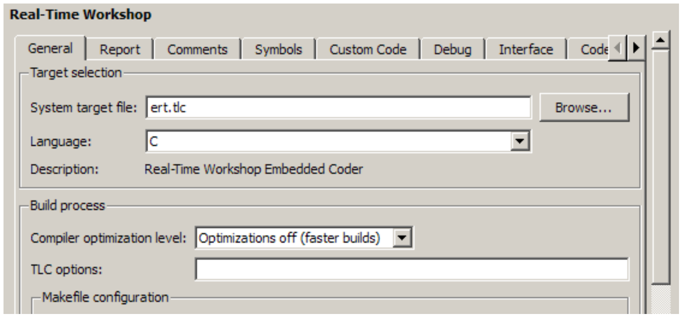
| Data Category | Data Definition | Data Purpose |
|---|---|---|
| Internal data | *model*_B | Block I/O |
| | *model*_D | D-work vectors |
| | *model*_M | Run-time model |
| | *model*_Zero | Zero-crossings |
| Parameters | *model*_P | Parameters |

Memory section specifications for model-level functions and internal data apply to the top level of the model and to all subsystems *except* atomic subsystems that contain overriding memory section specifications, as described in "Applying Memory Sections to Atomic Subsystems" on page 8-16.

To specify memory sections for model-level functions or internal data,

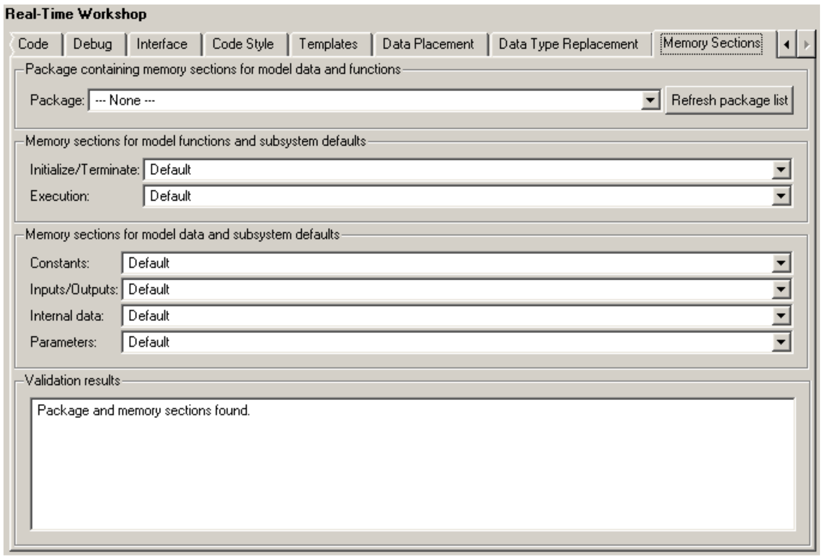
1 Open the Model Explorer and select **Configuration (Active)** > **Real-Time Workshop** > **General**. (Alternatively, choose **Simulation > Configuration Parameters** in the model window.)

2 Ensure that the **System target file** is an ERT target, such as `ert.tlc` .



System target file: ert.tlc
Language: C
Description: Real-Time Workshop Embedded Coder
Compiler optimization level: Optimizations off (faster builds)
TLC options:

3 Select the **Memory Sections** tab. The **Memory Sections** pane looks like this:



Real-Time Workshop

Code | Debug | Interface | Code Style | Templates | Data Placement | Data Type Replacement | Memory Sections

Package containing memory sections for model data and functions

Package: --- None --- | Refresh package list

Memory sections for model functions and subsystem defaults

Initialize/Terminate: Default

Execution: Default

Memory sections for model data and subsystem defaults

Constants: Default

Inputs/Outputs: Default

Internal data: Default

Parameters: Default

Validation results

Package and memory sections found.

4 Initially, the **Package** field specifies `---None---` and the pull-down lists only built-in packages. If you have defined any packages of your own, click **Refresh package list**. This action adds all user-defined packages on your search path to the package list.

5 In the **Package** pull-down, select the package that contains the memory sections that you want to apply.

6 In the pull-down for each category of internal data and model-level function, specify the memory section (if any) that you want to apply to that category. Accepting or specifying `Default` omits specifying any memory section for that category.

7 Click **Apply** to save any changes to the package and memory section selections.

## Applying Memory Sections to Atomic Subsystems

For any atomic subsystem whose generated code format is `Function` or `Reusable Function`, you can specify memory sections for functions and internal data that exist in that code format. Such specifications override any model-level memory section specifications. Such overrides apply only to the atomic subsystem itself, not to any subsystems within it. Subsystems of an atomic subsystem inherit memory section specifications from the containing model, *not* from the containing atomic subsystem.

To specify memory sections for an atomic subsystem,

1. Right-click the subsystem in the model window.

2. Choose **Subsystem Parameters** from the context menu. The Function Block Parameters: *`Subsystem`* dialog box appears.

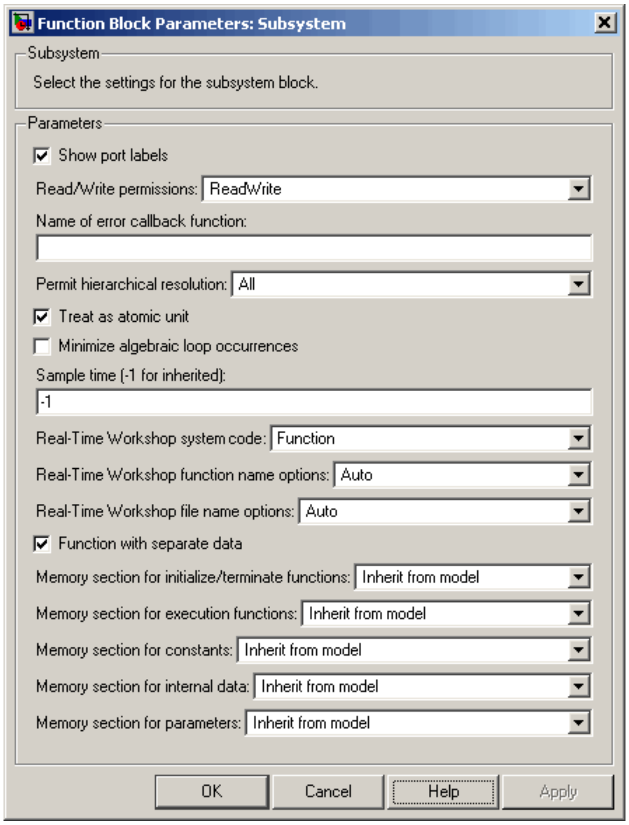
3. Ensure that **Treat as atomic unit** is checked. Otherwise, you cannot specify memory sections for the subsystem.

   For an atomic system, you can use the **Real-Time Workshop system code** field to control the format of the generated code.

4. Ensure that **Real-Time Workshop system code** is `Function` or `Reusable function`. Otherwise, you cannot specify memory sections for the subsystem.

5. If the code format is `Function` and you want separate data, check **Function with separate data**.

   The **Real-Time Workshop** pane now shows all applicable memory section options. The available options depend on the values of **Real-Time Workshop system code** and the **Function with separate data** check box. When the former is `Function` and the latter is checked, the pane looks like this:


Function Block Parameters: Subsystem

Subsystem

Select the settings for the subsystem block.

Parameters

☑ Show port labels

Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

☑ Treat as atomic unit

☐ Minimize algebraic loop occurrences

Sample time (-1 for inherited): -1

Real-Time Workshop system code: Function

Real-Time Workshop function name options: Auto

Real-Time Workshop file name options: Auto

☑ Function with separate data

Memory section for initialize/terminate functions: Inherit from model

Memory section for execution functions: Inherit from model

Memory section for constants: Inherit from model

Memory section for internal data: Inherit from model

Memory section for parameters: Inherit from model

6 In the pull-down for each available definition category, specify the memory section (if any) that you want to apply to that category.

- Selecting `Inherit from model` inherits the corresponding selection (if any) from the model level (not any parent subsystem).
- Selecting `Default` specifies that the category has no associated memory section, overriding any model-level specification for that category.

7 Click **Apply** to save changes, or **OK** to save changes and close the dialog box.

---

**Caution** If you use **Build Subsystem** to generate code for an atomic subsystem that specifies memory sections, the code generator ignores the subsystem-level specifications and uses the model-level specifications instead. The generated code is the same as if the atomic subsystem specified `Inherit from model` for every category of definition. For information about **Build Subsystem**, see “Generating Code and Executables from Subsystems”.

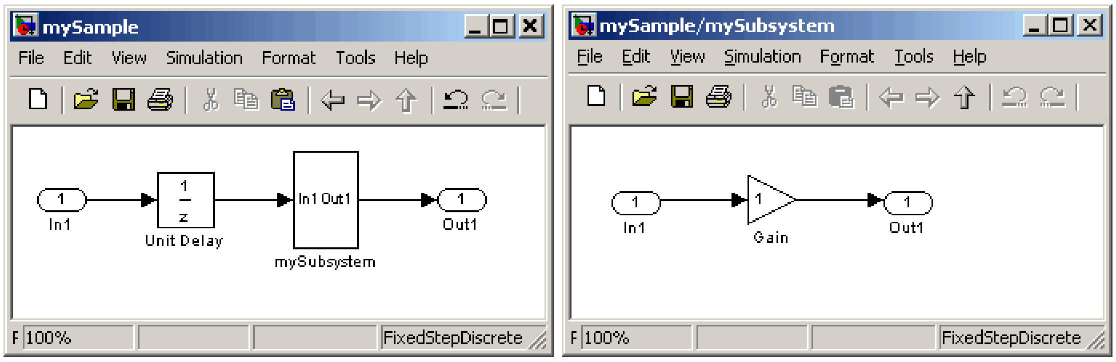
---

It is not possible to specify the memory section for a subsystem in a library. However, you can specify the memory section for the subsystem after you have copied it into a Simulink model. This is because in the library it is unknown what code generation target will be used. You can copy a library block into many different models with different code generation targets and different memory sections available.

## Examples of Generated Code with Memory Sections

### Sample ERT-Based Model with Subsystem

The next figure shows an ERT-based Simulink model that defines one subsystem, and the contents of that subsystem.



Assume that the subsystem is atomic, the **Real-Time Workshop system code** is `Reusable function`, memory sections have been created and assigned as shown in the next two tables, and all data memory sections specify **Pragma surrounds** to be `Each variable`.

#### Model-Level Memory Section Assignments and Definitions

| Section Assignment | Section Name | Field Name | Field Value |
|---|---|---|---|
| Input/Output | `MemSect1` | Prepragma | `#pragma IO_begin` |
| | | Postpragma | `#pragma IO-end` |
| Internal data | `MemSect2` | Prepragma | `#pragma InData-begin(%<identifier>)` |
| | | Postpragma | `#pragma InData-end` |
| Parameters | `MemSect3` | Prepragma | `#pragma Parameters-begin` |
| | | Postpragma | `#pragma Parameters-end` |

**Model-Level Memory Section Assignments and Definitions (Continued)**

| Section Assignment | Section Name | Field Name | Field Value |
|---|---|---|---|
| Initialize/ Terminate | `MemSect4` | Prepragma | `#pragma InitTerminate-begin` |
| | | Postpragma | `#pragma InitTerminate-end` |
| Execution functions | `MemSect5` | Prepragma | `#pragma ExecFunc-begin(%<identifier>)` |
| | | Postpragma | `#pragma ExecFunc-begin(%<identifier>)` |

**Subsystem-Level Memory Section Assignments and Definitions**

| Section Assignment | Section Name | Field Name | Field Value |
|---|---|---|---|
| Execution functions | `MemSect6` | Prepragma | `#pragma DATA_SEC(%<identifier>, "FAST_RAM")` |
| | | Postpragma | |

Given the preceding specifications and definitions, the code generator would create the following code, with minor variations depending on the current version of the Target Language Compiler.

## Model-Level Data Structures

```
#pragma IO-begin
ExternalInputs_mySample mySample_U;
#pragma IO-end

#pragma IO-begin
ExternalOutputs_mySample mySample_Y;
#pragma IO-end

#pragma InData-begin(mySample_B)
BlockIO_mySample mySample_B;
#pragma InData-end

#pragma InData-begin(mySample_DWork)
D_Work_mySample mySample_DWork;
#pragma InData-end

#pragma InData-begin(mySample_M_)
RT_MODEL_mySample mySample_M_;
#pragma InData-end

#pragma InData-begin(mySample_M)
RT_MODEL_mySample *mySample_M = &mySample_M_;
#pragma InData-end

#pragma Parameters-begin
Parameters_mySample mySample_P = {
  0.0 , {2.3}
};
#pragma Parameters-end
```

### Model-Level Functions

```
#pragma ExecFunc-begin(mySample_step)
void mySample_step(void)
{
  real_T rtb_UnitDelay;
  rtb_UnitDelay = mySample_DWork.UnitDelay_DSTATE;
  mySubsystem(rtb_UnitDelay, &mySample_B.mySubsystem;,
   (rtP_mySubsystem *) &mySample_P.mySubsystem);
  mySample_Y.Out1_o = mySample_B.mySubsystem.Gain;
  mySample_DWork.UnitDelay_DSTATE = mySample_U.In1;
}
#pragma ExecFunc-end(mySample_step)

#pragma InitTerminate-begin
void mySample_initialize(void)
{
  rtmSetErrorStatus(mySample_M, (const char_T *)0);
  {
    ((real_T*)&mySample_B.mySubsystem.Gain)[0] = 0.0;
  }
  mySample_DWork.UnitDelay_DSTATE = 0.0;
  mySample_U.In1 = 0.0;
  mySample_Y.Out1_o = 0.0;
  mySample_DWork.UnitDelay_DSTATE = mySample_P.UnitDelay_X0;
}
#pragma InitTerminate-end
```

## Subsystem Function

Because the subsystem specifies a memory section for execution functions that overrides that of the parent model, subsystem code looks like this:

```
/* File: mySubsystem.c */

#pragma DATA_SEC(mySubsystem,  FAST_RAM )
void mySubsystem(real_T rtu_In1,
rtB_mySubsystem *localB,
rtP_mySubsystem *localP)
{
  localB->Gain = rtu_In1 * localP->Gain_Gain;
}
```

If the subsystem had not defined its own memory section for execution functions, but inherited that of the parent model, the subsystem code would have looked like this:

```
/* File: mySubsystem.c */
```

```
#pragma ExecFunc-begin(mySubsystem)
void mySubsystem(real_T rtu_In1,
rtB_mySubsystem *localB,
rtP_mySubsystem *localP)
{
  localB->Gain = rtu_In1 * localP->Gain_Gain;
}
#pragma ExecFunc-end(mySubsystem)
```

## Memory Section Limitation

Memory sections cannot be applied to shared utility functions, such as lookup table functions, data type conversion functions, and fixed-point functions. For information about shared utilities, see “Setting Up Runtime Logging to MAT-Files”, “Supporting Shared Utility Directories in the Build Process”, and “Supporting the Shared Utilities Directory”.

# Optimizing Buses for Code Generation

## Introduction

When you use buses in a model for which you intend to generate code:

- Setting appropriate diagnostic configuration parameters can add to the ease of development.
- The bus implementation techniques used can affect the speed, size, and clarity of that code.
- Some bus implementation techniques that can be useful are not immediately obvious.

This chapter contains guidelines that you can use to improve the results when you work with buses. The guidelines describe techniques for:

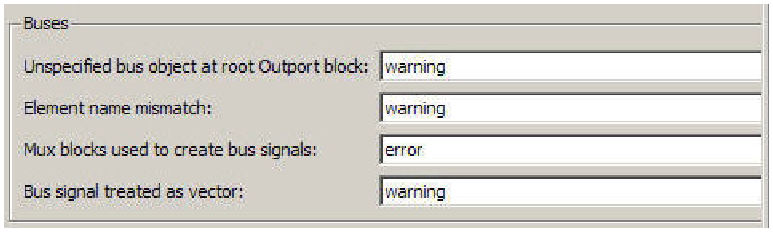
- Simplifying the layout of the model
- Increasing the efficiency of generated code
- Defining data structures for function/subsystem interfaces
- Defining data structures that match existing data structures in external C code

Some tradeoffs inevitably exist among speed, size, and clarity. For example, the code for nonvirtual buses is easier to read because the buses appear in the code as structures, but the code for virtual buses is faster because virtual buses do not require copying signal data. The applicability of some guidelines can therefore depend on where you are in the application development process.

This chapter focuses on optimizations that are appropriate for final production code. Before you read this chapter, be sure that you have read “Using Composite Signals”. This chapter assumes that you understand all the concepts and procedures described in that one, including the blocks used for creating and manipulating buses.

## Setting Bus Diagnostics

Simulink provides diagnostics that you can use to optimize bus usage. The MathWorks recommends setting the following values on the **Configuration parameters > Diagnostics > Connectivity** pane:



Buses

| | |
|---|---|
| Unspecified bus object at root Outport block: | warning |
| Element name mismatch: | warning |
| Mux blocks used to create bus signals: | error |
| Bus signal treated as vector: | warning |

The last diagnostic, **Bus signal treated as vector**, is enabled only when **Mux blocks used to create bus signals** is set to `error`. Setting **Mux blocks used to create bus signals** to `none` disables both diagnostics. Temporarily disabling the two mux and bus diagnostics allows you to debug other bus problems before addressing mux and bus mixtures. You can then enable the last two diagnostics and use them to eliminate any such mixtures. When you build existing models, the diagnostic settings should be as shown at all times. See “Avoiding Mux/Bus Mixtures”for more information.

## Optimizing Virtual and Nonvirtual Buses

**In this section...**

### Use Virtual Buses Wherever Possible

Virtual buses are graphical conveniences that do not affect generated code. As a result, the code generation engine is able to fully optimize the signals in the bus. You should therefore use virtual rather than nonvirtual buses wherever possible. You can convert between virtual and nonvirtual buses as needed using Signal Conversion blocks. In many cases, Simulink automatically converts a virtual bus to a nonvirtual bus when required. For example, a virtual bus input to a Model block becomes a nonvirtual bus with no need for explicit conversion. See for more information.

#### When are Virtual and Nonvirtual Buses Required?

In some cases, Simulink requires the use of nonvirtual buses:

- For non-auto storage classes
- Inports and Outports of Model blocks
- To generate a specific structure from the bus
- Root level Inport or Outport blocks when the bus has mixed data types

In one case, Simulink requires the use of virtual buses:

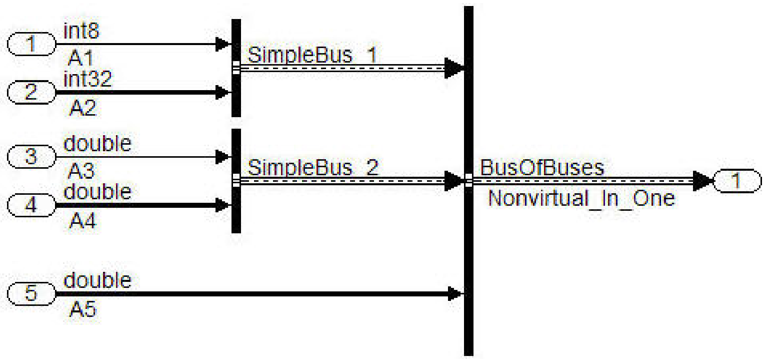
- Only virtual buses can be used for bundling function call signals.

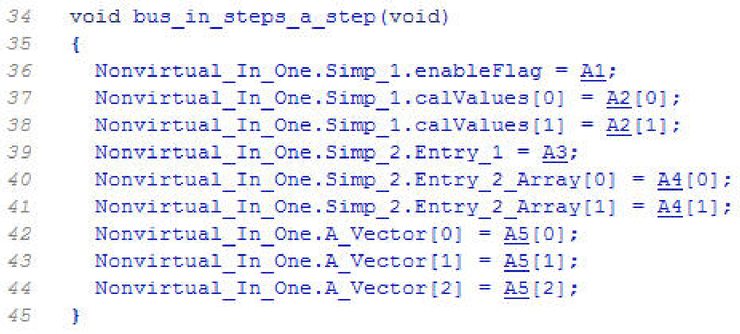
## Avoid Nonlocal Nested Buses in Nonvirtual Buses

Buses can contain subordinate buses. The storage class of any subordinate bus should be `auto`, which results in a local signal. Setting a subordinate bus to a non-`auto` storage class has two undesirable results:

- Allocation of redundant memory (memory for the subordinate bus object and memory for the final bus object)
- Additional copy operations (first copying to the subordinate bus and then copying from the subordinate bus to the final bus)

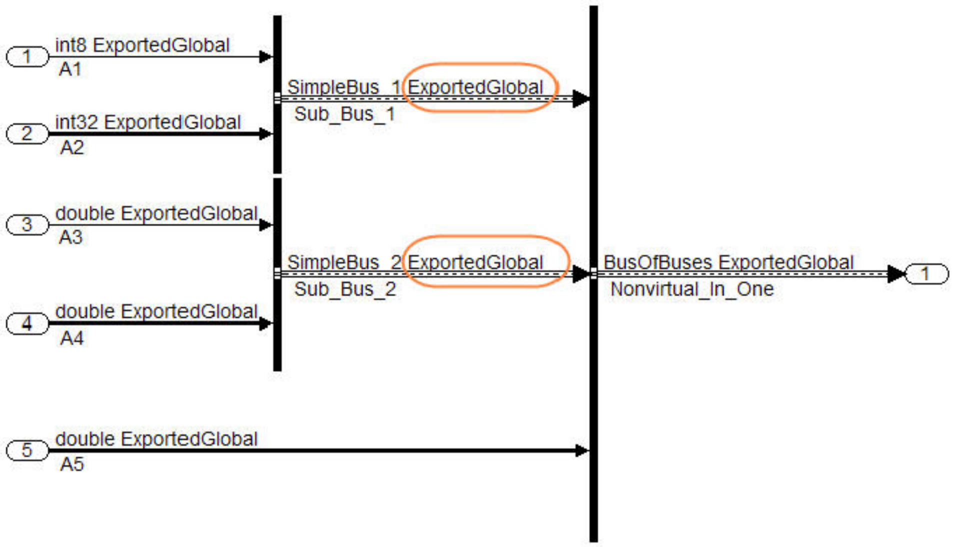
In the following example, the final bus is created from local scoped subordinate elements. The resulting assignment operations are relatively efficient:





```
void bus_in_steps_a_step(void)
{
  Nonvirtual_In_One.Simp_1.enableFlag = A1;
  Nonvirtual_In_One.Simp_1.calValues[0] = A2[0];
  Nonvirtual_In_One.Simp_1.calValues[1] = A2[1];
  Nonvirtual_In_One.Simp_2.Entry_1 = A3;
  Nonvirtual_In_One.Simp_2.Entry_2_Array[0] = A4[0];
  Nonvirtual_In_One.Simp_2.Entry_2_Array[1] = A4[1];
  Nonvirtual_In_One.A_Vector[0] = A5[0];
  Nonvirtual_In_One.A_Vector[1] = A5[1];
  Nonvirtual_In_One.A_Vector[2] = A5[2];
}
```

By contrast in the next example the subordinate elements `sub_bus_1` and `sub_bus_2` are global in scope. First the assignment to the subordinate bus occurs (lines 54 – 59) then the copy of the subordinate bus to the main bus (lines 60 – 61). In most cases, this is not an efficient implementation:



```
52   void bus_in_steps_b_step(void)
53   {
54     Sub_bus_1.enableFlag = A1;
55     Sub_bus_2.Entry_1 = A3;
56     Sub_bus_1.calValues[0] = A2[0];
57     Sub_bus_2.Entry_2_Array[0] = A4[0];
58     Sub_bus_1.calValues[1] = A2[1];
59     Sub_bus_2.Entry_2_Array[1] = A4[1];
60     Nonvirtual_In_Steps.Simp_1 = Sub_bus_1;
61     Nonvirtual_In_Steps.Simp_2 = Sub_bus_2;
62     Nonvirtual_In_Steps.A_Vector[0] = A5[0];
63     Nonvirtual_In_Steps.A_Vector[1] = A5[1];
64     Nonvirtual_In_Steps.A_Vector[2] = A5[2];
65   }
```

## Using Single-Rate and Multi-Rate Buses

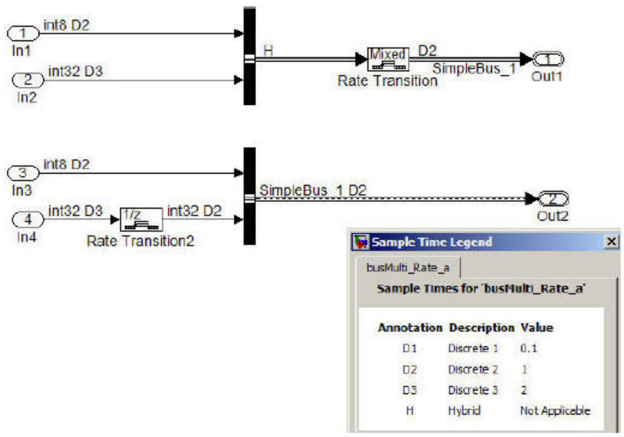
**In this section...**

### Introduction

Nonvirtual buses do not support multiple rates. Virtual buses support multiple rates as long as the bus does not cross any root level inport or outport. The best techniques for optimizing a bus that contains signals that initially have different rates can depend on the type of the bus and the number of signals.

### Techniques for Combining Multiple Rates

The simplest bus contains only two signals. The next figure shows two examples of two-element buses. The first example shows a virtual bus created from two signals that have different rates. The second example shows a nonvirtual bus created from the same two signals. The Sample Time Legend shows the different signal rates:



Sample Times for 'busMulti_Rate_a'

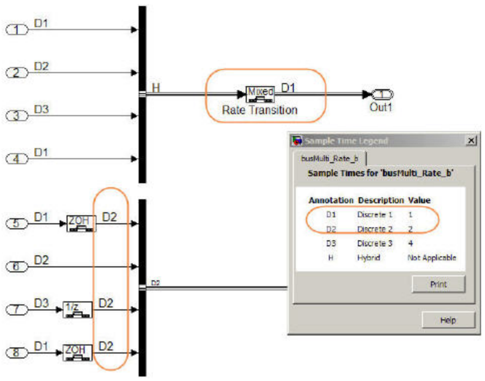
| Annotation | Description | Value |
|---|---|---|
| D1 | Discrete 1 | 0.1 |
| D2 | Discrete 2 | 1 |
| D3 | Discrete 3 | 2 |
| H | Hybrid | Not Applicable |

The signals with different rates in the first example can be combined into a virtual bus, because virtual buses support multiple rates. However, a multirate virtual bus cannot connect to a root-level output port. The bus therefore passes through a Rate Transition block that converts it to a single-rate bus, then connects to the Outport. This technique is preferable only for virtual buses that contain no more than two signals. See “Larger Buses and Multiple Rates” on page 9-9.

The signals with different rates in the second example cannot initially be combined into a nonvirtual bus, because nonvirtual buses do not support multiple rates. One of the signals therefore passes through a Rate Transition block, which converts it to have the same rate as the other signal, then connects to the Bus Creator block. The signals can then combine into a single-rate nonvirtual bus, which can connect to the root-level outport without further conversion.

## Larger Buses and Multiple Rates

When you create a multirate virtual bus that contains more than two signals, you can convert the bus to single-rate by applying a Rate Transition block to the output of the Bus Creator block. However, The MathWorks recommends using a Rate Transition block on each input signal to give full control over the output rate. As the next figure shows, when a single Rate Transition block is used the block sets all the signals to the fastest rate (D1):



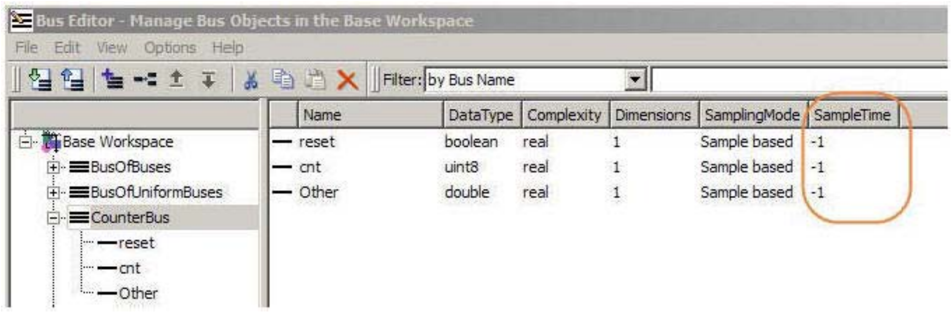
Sample Times for 'busMulti_Rate_b'

| Annotation | Description | Value |
|---|---|---|
| D1 | Discrete 1 | 1 |
| D2 | Discrete 2 | 2 |
| D3 | Discrete 3 | 4 |
| H | Hybrid | Not Applicable |

Note that the preferred techniques for a virtual bus with more than two signals, and the required technique for a nonvirtual bus with any number of signals, are the same. Note also that, in the preceding figure, the blocks that perform rate transition are not actual Rate Transition blocks, but other blocks that can change the signal rate as part of some other operation. The identity of the blocks that perform rate transition makes no difference. All that matters is that the signal rates match when required.

## Specifying Sample Time Rates

The sample time for buses should be specified through the signals that define the bus. If the sample times do not match, use Rate Transition (or equivalent) blocks to create a uniform rate, as shown in the previous figures. The signal rates should *not* be set by specifying **Sample Time** values in a Bus Creator block's bus object. Instead, set the sample time for each signal before inputting it to the Bus Creator, and set each **Sample Time** in the corresponding bus object to -1 (inherited), as shown in the next figure:



| Name | DataType | Complexity | Dimensions | SamplingMode | SampleTime |
|---|---|---|---|---|---|
| reset | boolean | real | 1 | Sample based | -1 |
| cnt | uint8 | real | 1 | Sample based | -1 |
| Other | double | real | 1 | Sample based | -1 |

# Setting Bus Signal Initial Values

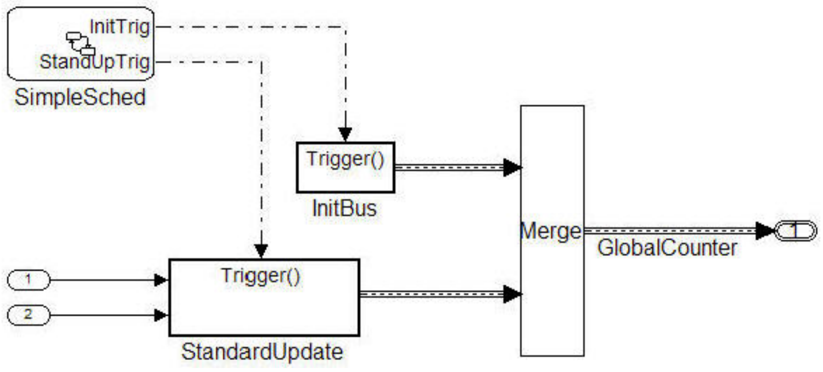
**In this section...**

## Introduction

Unlike scalar and vector signals, buses provide no direct way to initialize signals. This section describes techniques for initializing bus signals in Simulink, Stateflow, and Embedded MATLAB.

## Initializing Bus Signals in Simulink

In Simulink, you can set initial values on a bus by using a set of conditionally executed subsystems, such as Function-Call subsystems, and a Merge block, as shown in this example:

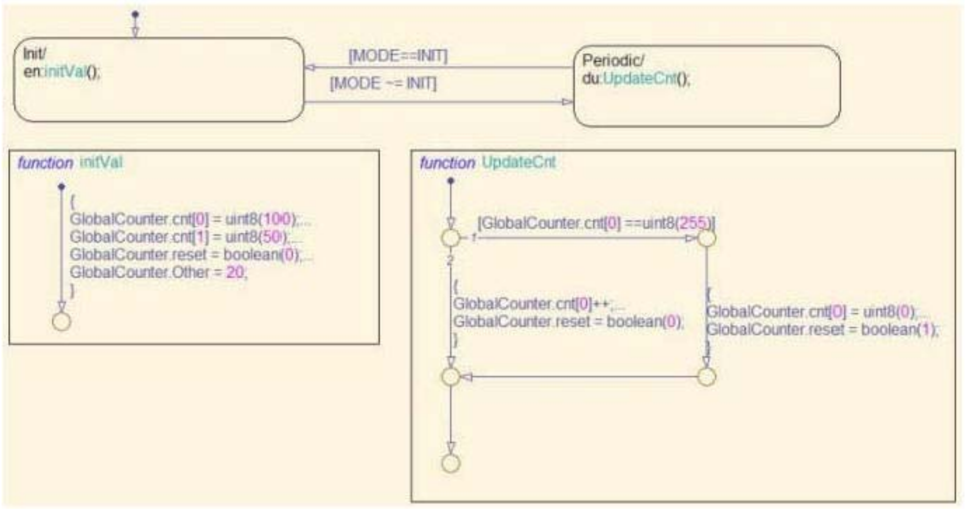


Both subsystems (`InitBus` and `StandardUpdate`) create a bus signal of type `CounterBus`. However, the assignment to the variable `GlobalCounter` is controlled by the Merge block. See "Function-Call Subsystems" for more information.

This technique is limited because the `StandardUpdate` subsystem does not use the initial values from the `InitBus` subsystem. If the calculations depend on past information from the bus, consider using Stateflow or Embedded MATLAB to initialize bus signals.

## Bus Initialization in Stateflow and Embedded MATLAB

Stateflow and Embedded MATLAB allow for conditional execution internally. In the following example, the `init` and `update` code are Functions in the Stateflow diagram. This technique simplifies the presentation in the generated code:



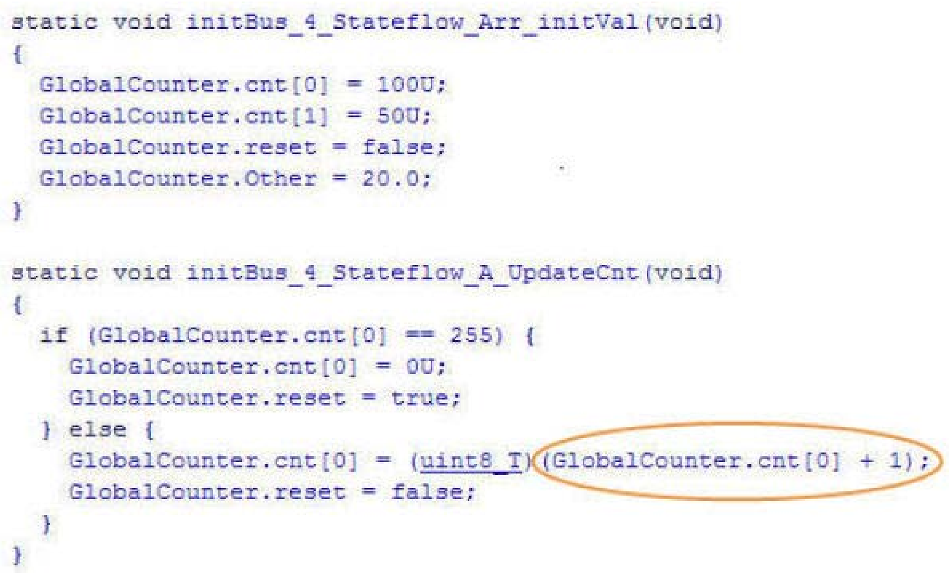
```
{
GlobalCounter.cnt[0] = uint8(100);...
GlobalCounter.cnt[1] = uint8(50);...
GlobalCounter.reset = boolean(0);...
GlobalCounter.Other = 20;
}
```

```
[GlobalCounter.cnt[0] ==uint8(255)]
```

```
{
GlobalCounter.cnt[0]++;...
GlobalCounter.reset = boolean(0);
}
```

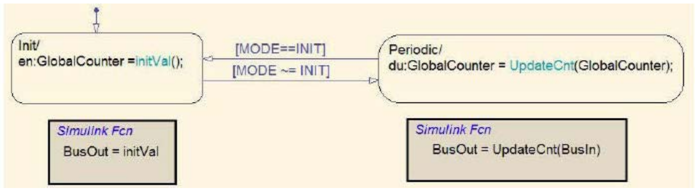
```
{
GlobalCounter.cnt[0] = uint8(0);...
GlobalCounter.reset = boolean(1);
}
```

In the generated code, you can see that the `UpdateCnt`function uses the past value of `GlobalCounter.cnt`:



```
static void initBus_4_Stateflow_Arr_initVal(void)
{
  GlobalCounter.cnt[0] = 100U;
  GlobalCounter.cnt[1] = 50U;
  GlobalCounter.reset = false;
  GlobalCounter.Other = 20.0;
}

static void initBus_4_Stateflow_A_UpdateCnt(void)
{
  if (GlobalCounter.cnt[0] == 255) {
    GlobalCounter.cnt[0] = 0U;
    GlobalCounter.reset = true;
  } else {
    GlobalCounter.cnt[0] = (uint8_T)(GlobalCounter.cnt[0] + 1);
    GlobalCounter.reset = false;
  }
}
```

The previous example used Stateflow Graphical functions to initialize and update the buses. Alternatively, you can use Embedded MATLAB functions or Simulink subsystems embedded in a Stateflow diagram. The next figure illustrates this technique:


Init/
en:GlobalCounter =initVal();
[MODE==INIT]
[MODE ~= INIT]
Periodic/
du:GlobalCounter = UpdateCnt(GlobalCounter);
Simulink Fcn
BusOut = initVal
Simulink Fcn
BusOut = UpdateCnt(BusIn)

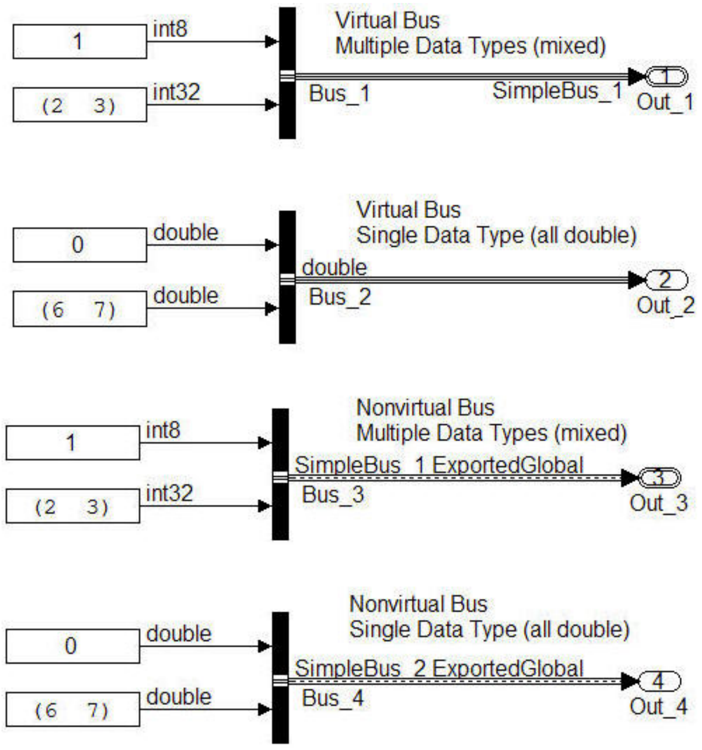
The Simulink subsystems are the same as those used in the earlier Simulink-only example.

## Creating a Bus of Constants

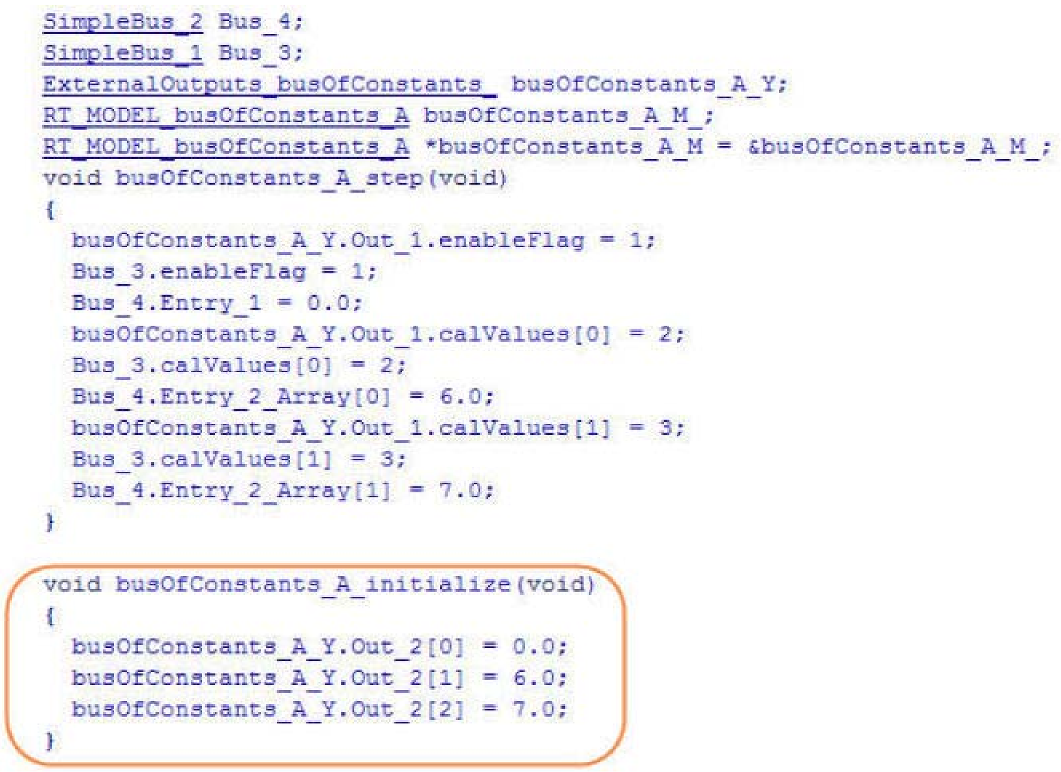
The code for specifying a bus of constant values will appear in either the `Init` or the `Step` function of the model. The code location depends on the configuration of the bus. In most cases the code appears in the `Step` function. However if the following conditions hold the code will be placed in the `Init` function:

- The bus is a virtual bus
- All signals have the same data type
- The signals in the bus are all constants

In the next figure, only the bus named `Bus_2` meets all the requirements:



The code for `Bus_2` therefore appears in the `Init` function. The code for the other buses appears in the `Step` function:



```
SimpleBus_2 Bus_4;
SimpleBus_1 Bus_3;
ExternalOutputs_busOfConstants_ busOfConstants_A_Y;
RT_MODEL_busOfConstants_A busOfConstants_A_M_;
RT_MODEL_busOfConstants_A *busOfConstants_A_M = &busOfConstants_A_M_;
void busOfConstants_A_step(void)
{
  busOfConstants_A_Y.Out_1.enableFlag = 1;
  Bus_3.enableFlag = 1;
  Bus_4.Entry_1 = 0.0;
  busOfConstants_A_Y.Out_1.calValues[0] = 2;
  Bus_3.calValues[0] = 2;
  Bus_4.Entry_2_Array[0] = 6.0;
  busOfConstants_A_Y.Out_1.calValues[1] = 3;
  Bus_3.calValues[1] = 3;
  Bus_4.Entry_2_Array[1] = 7.0;
}

void busOfConstants_A_initialize(void)
{
  busOfConstants_A_Y.Out_2[0] = 0.0;
  busOfConstants_A_Y.Out_2[1] = 6.0;
  busOfConstants_A_Y.Out_2[2] = 7.0;
}
```

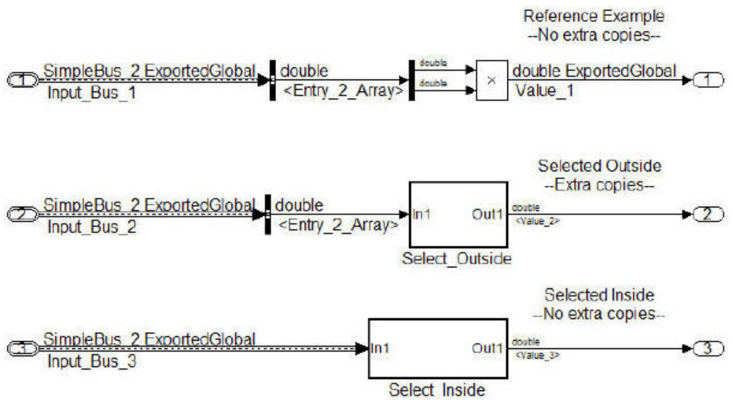
To avoid repeatedly updating a bus of constants, place the bus code into a function-call subsystem, as described in “Initializing Bus Signals in Simulink” on page 9-11. When you use this technique, make sure the function-call subsystem is called at the start of execution. See “Function-Call Subsystems” for more information.

## Buses and Atomic Subsystems

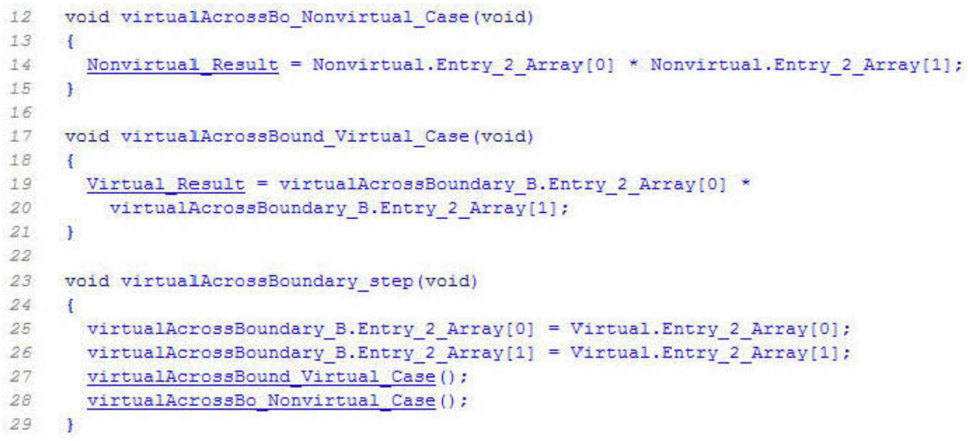
**In this section...**

### Extract Nonvirtual Bus Signals Inside of Atomic Subsystems

Selecting signals from of a nonvirtual bus can result in unnecessary data copies when those signals cross an atomic boundary. In the following example the same code, a simple multiplication of two elements in a vector, is executed three times:



In the second instance when the bus signals are selected outside of the atomic subsystem an unnecessary copy of the bus data is created:

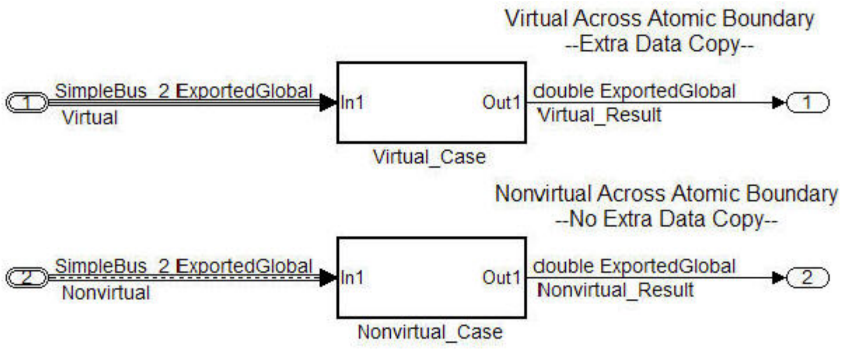


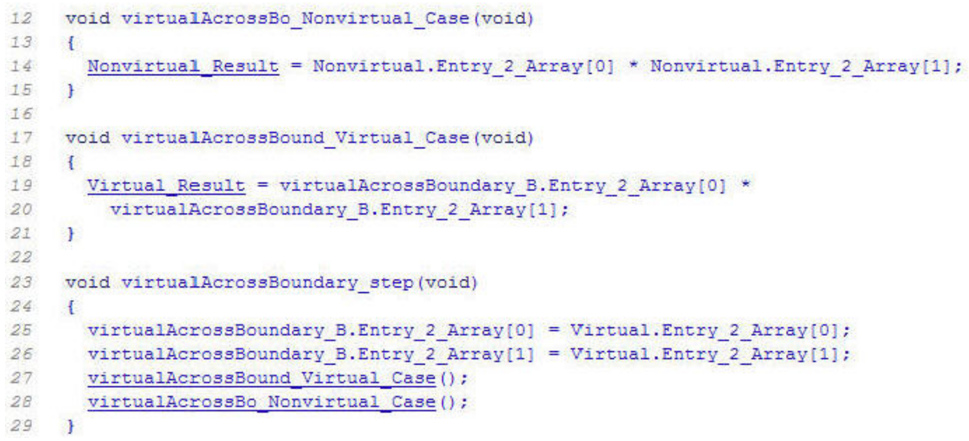
```
void virtualAcrossBo_Nonvirtual_Case(void)
{
  Nonvirtual_Result = Nonvirtual.Entry_2_Array[0] * Nonvirtual.Entry_2_Array[1];
}

void virtualAcrossBound_Virtual_Case(void)
{
  Virtual_Result = virtualAcrossBoundary_B.Entry_2_Array[0] *
    virtualAcrossBoundary_B.Entry_2_Array[1];
}

void virtualAcrossBoundary_step(void)
{
  virtualAcrossBoundary_B.Entry_2_Array[0] = Virtual.Entry_2_Array[0];
  virtualAcrossBoundary_B.Entry_2_Array[1] = Virtual.Entry_2_Array[1];
  virtualAcrossBound_Virtual_Case();
  virtualAcrossBo_Nonvirtual_Case();
}
```

Although this example shows only signals with global scope, both global and local signals show the same behavior: the selection of the signals outside of the model results in an unnecessary copy, while the internal selection does not.

## Virtual Bus Signals Crossing Atomic Boundaries

Virtual buses that cross atomic boundaries can result in the creation of unnecessary data copies. The following example shows the data copy that occurs when a virtual bus crosses an atomic boundary:



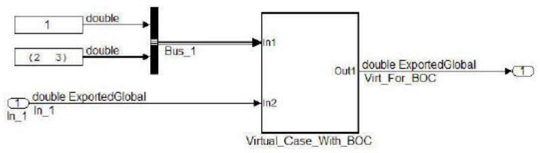


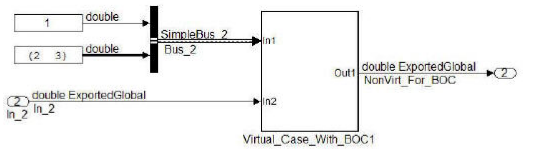
```
12  void virtualAcrossBo_Nonvirtual_Case(void)
13  {
14    Nonvirtual_Result = Nonvirtual.Entry_2_Array[0] * Nonvirtual.Entry_2_Array[1];
15  }
16
17  void virtualAcrossBound_Virtual_Case(void)
18  {
19    Virtual_Result = virtualAcrossBoundary_B.Entry_2_Array[0] *
20      virtualAcrossBoundary_B.Entry_2_Array[1];
21  }
22
23  void virtualAcrossBoundary_step(void)
24  {
25    virtualAcrossBoundary_B.Entry_2_Array[0] = Virtual.Entry_2_Array[0];
26    virtualAcrossBoundary_B.Entry_2_Array[1] = Virtual.Entry_2_Array[1];
27    virtualAcrossBound_Virtual_Case();
28    virtualAcrossBo_Nonvirtual_Case();
29  }
```

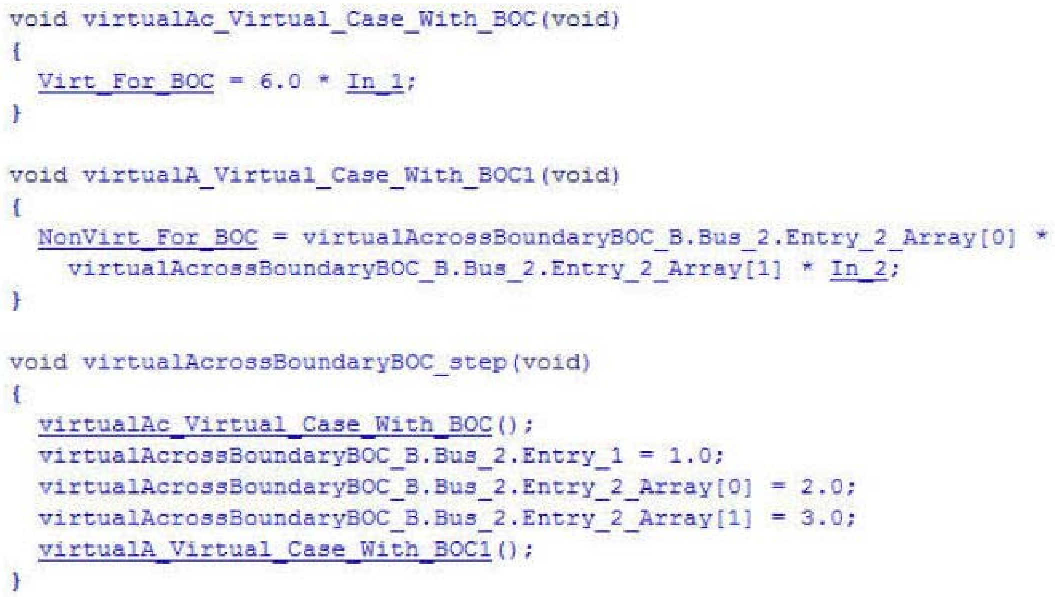
Lines 25–26 show the signals being selected out of the bus before they are used in the function on lines 19–20. By comparison the nonvirtual bus does not require the use of temporary variables.

## Atomic Subsystems and Buses of Constants

If the bus passed into an atomic subsystem consists exclusively of constants, using a virtual bus is more efficient, because Simulink is able to inline the constant values into the code:







```
void virtualAc_Virtual_Case_With_BOC(void)
{
  Virt_For_BOC = 6.0 * In_1;
}

void virtualA_Virtual_Case_With_BOC1(void)
{
  NonVirt_For_BOC = virtualAcrossBoundaryBOC_B.Bus_2.Entry_2_Array[0] *
    virtualAcrossBoundaryBOC_B.Bus_2.Entry_2_Array[1] * In_2;
}

void virtualAcrossBoundaryBOC_step(void)
{
  virtualAc_Virtual_Case_With_BOC();
  virtualAcrossBoundaryBOC_B.Bus_2.Entry_1 = 1.0;
  virtualAcrossBoundaryBOC_B.Bus_2.Entry_2_Array[0] = 2.0;
  virtualAcrossBoundaryBOC_B.Bus_2.Entry_2_Array[1] = 3.0;
  virtualA_Virtual_Case_With_BOC1();
}
```

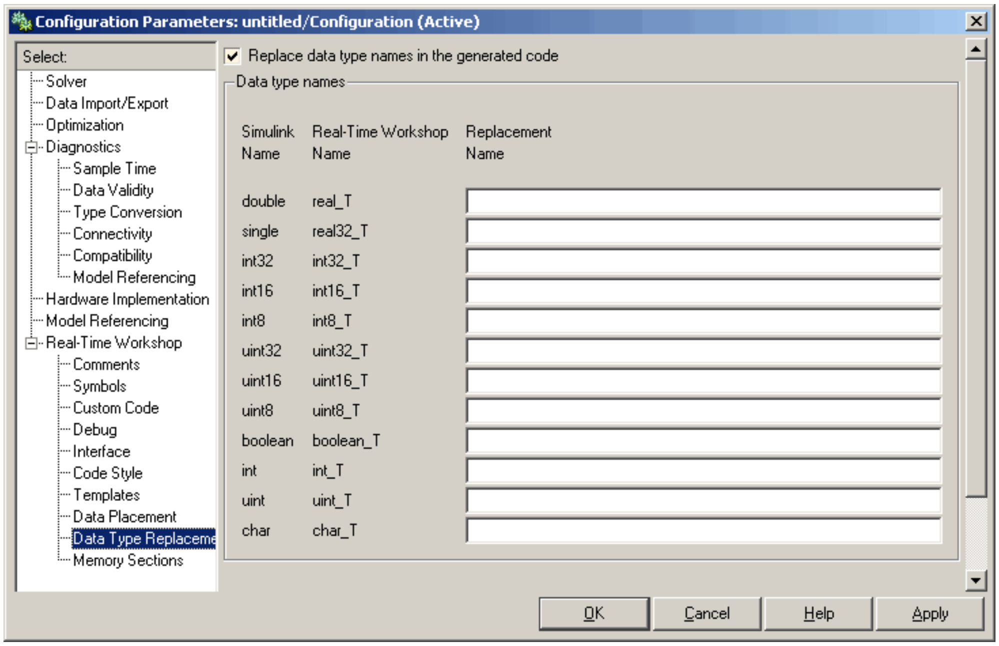
# Renaming and Replacing Data Types

## Defining Application-Specific Data Types Based On Built-In Types

You can replace built-in data type names with user-defined replacement data type names in the generated code for a model.

To configure replacement data types,

1 Click **Replace data type names in the generated code**. A **Data type names** table appears. The table lists each Simulink built-in data type name with its corresponding Real-Time Workshop data type name.



✓ Replace data type names in the generated code

Data type names

| Simulink Name | Real-Time Workshop Name | Replacement Name |
|---|---|---|
| double | real_T | |
| single | real32_T | |
| int32 | int32_T | |
| int16 | int16_T | |
| int8 | int8_T | |
| uint32 | uint32_T | |
| uint16 | uint16_T | |
| uint8 | uint8_T | |
| boolean | boolean_T | |
| int | int_T | |
| uint | uint_T | |
| char | char_T | |

2 Selectively fill in fields in the third column with your replacement data types. Each replacement data type should be the name of a `Simulink.AliasType` object that exists in the base workspace. Replacements may be specified or not for each individual built-in type.

For each replacement data type you enter, the `BaseType` property of the associated `Simulink.AliasType` object must be consistent with the built-in data type it replaces.

- For `double`, `single`, `int32`, `int16`, `int8`, `uint32`, `uint16`, `uint8`, and `boolean`, the replacement data type's `BaseType` must match the built-in data type.
- For `int`, `uint`, and `char`, the replacement data type's size must match the size displayed for `int` or `char` on the **Hardware Implementation** pane of the Configuration Parameters dialog box.

An error occurs if a replacement data type specification is inconsistent. For more information, see "Replacing Built-In Data Type Names in Generated Code" on page 11-53.

## Code Generation with User-Defined Data Types

**In this section...**

### Overview

The Real-Time Workshop Embedded Coder software supports use of user-defined data type objects in code generation. These include objects of the following classes:

- `Simulink.AliasType`
- `Simulink.Bus`
- `Simulink.NumericType`
- `Simulink.StructType`

For information on the properties and usage of these data object classes, see `Simulink.AliasType`, `Simulink.Bus`, `Simulink.NumericType`, and `Simulink.StructType` in the "Simulink Classes" section of the Simulink Reference documentation. For general information on creating and using data objects, see the "Working with Data Objects" section of the Simulink documentation

In code generation, you can use user-defined data objects to

- Map your own data type definitions to Simulink built-in data types, and specify that your data types are to be used in generated code.
- Optionally, generate `#include` directives specifying your own header files, containing your data type definitions. This technique lets you use legacy data types in generated code.

In general, code generated from user-defined data objects conforms to the properties and attributes of the objects as defined for use in simulation.

When generating code from user-defined data objects, the name of the object is the name of the data type that is used in the generated code. Exception: for `Simulink.NumericType` objects whose `IsAlias` property is false, the name of the functionally equivalent built-in or fixed-point Simulink data type is used instead.

---

**Note** The names of data types defined using `Simulink.AliasType` objects are preserved in the generated code only for installations with a Real-Time Workshop Embedded Coder license.

---

## Specifying Type Definition Location for User-Defined Data Types

When a model uses `Simulink.DataType` and `Simulink.Bus` objects, corresponding `typedef`s are needed in code. Both `Simulink.DataType` and `Simulink.Bus` objects have a `HeaderFile` property that controls the location of the object's `typedef`. Setting a `HeaderFile` is optional and affects code generation only.

### Omitting a HeaderFile Value

If the `HeaderFile` property for a `Simulink.DataType` or `Simulink.Bus` object is left empty, a generated `typedef` for the object appears in the generated file *`model`*`_types.h`.

**Example.** For a `Simulink.NumericType` object named `myfloat` with a `Category` of `double` and no `HeaderFile` property specified, *`model`*`_types.h` in the generated code contains:

```
typedef real_T myfloat;
```

### Specifying a HeaderFile Value

If the `HeaderFile` property for a `Simulink.DataType` or `Simulink.Bus` object is set to a string value,

- The string must be the name of a header file that contains a `typedef` for the object.

- The generated file *`model`*`_types.h` contains a `#include` that gives the header file name.

You can use this technique to include legacy or other externally created `typedefs` in generated code. When the generated code compiles, the specified header file must be accessible on the build process include path.

**HeaderFile Property Syntax.** The `HeaderFile` property should include the desired preprocessor delimiter (`""` or `'<>'`), as in the following examples.

This example:

```
myfloat.HeaderFile = '<legacy_types.h>'
```

generates the directive:

```
#include <legacy_types.h>
```

This example:

```
myfloat.HeaderFile = '"legacy_types.h>"'
```

generates the directive:

```
#include "legacy_types.h"
```

## Using User-Defined Data Types for Code Generation

To specify and use user-defined data types for code generation:

1. Create a user-defined data object and configure its properties, as described in the "Working with Data Objects" section of the Simulink documentation.

2. If you specified the `HeaderFile` property, copy the header file to the appropriate directory.

3. Set the output data type of selected blocks in your model to the user-defined data object. To do this, set the **Data type** parameter of the block to `Specify with dialog`. Then, enter the object name in the **Output data type** parameter.

4. The specified output data type propagates through the model and variables of the user-defined type are declared as required in the generated code.

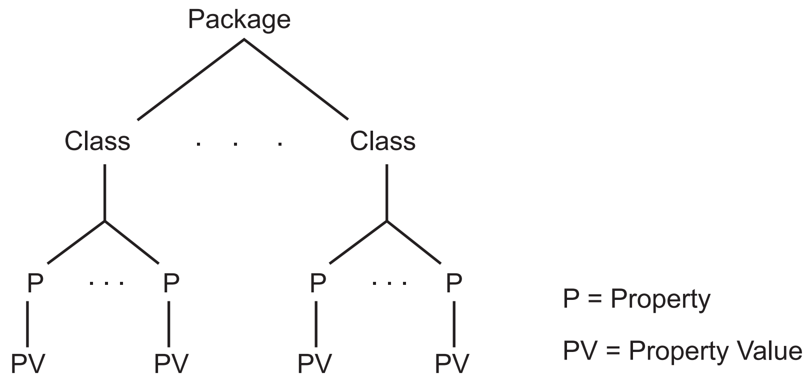
# Managing Data Definitions and Declarations With the Data Dictionary

## Overview of the Data Dictionary

A data dictionary contains all of the parameters and signals that the source code uses, and a description of their properties. The data dictionary that is created for Simulink and Stateflow models is called the code generation data dictionary. (You can use the data dictionary for simulation. This does not require that you have a Real-Time Workshop Embedded Coder license.) The dictionary is the total number of data objects that appear in the middle pane of the Model Explorer. These data objects also appear in the MATLAB workspace. The procedure described in this chapter allows you to create or edit the dictionary. The procedure allows you to control property values for each data object. This, in turn, determines how each parameter and signal is defined and declared in the automatically generated code.

The values of data object properties can affect where the code generator places a parameter or signal in the generated file. This is because some property values are associated with different template symbols. The location of a symbol in a template determines where the associated parameter or signal is located in the generated file. For details about templates and symbols, see "Configuring Templates for Customizing Code Organization and Format" on page 16-22.

It is helpful to define terms you will see when managing the dictionary, especially when you view them using the Model Explorer. The Simulink software uses a hierarchy of terms that are drawn from object-oriented programming. For details, see "Working with Data Objects" in the Simulink documentation. The sketch below summarizes this hierarchy.



`Simulink` or `mpt` is the package. Parameter and Signal are two classes in each of these packages. Each class has a number of properties associated with it. Sometimes properties are called *attributes*. Data objects (the parameters and signals) are the instances of a `package.class` that make up the data dictionary. All parameter data objects have a set of properties. All signal data objects have a different set of properties than that for parameters. For each data object, each property in the set has its own property *value* that must be specified in the dictionary.

**Note** In this document, "signal" refers to a named wire on a Simulink model, a discrete state, or a data store.

## Creating Simulink and mpt Data Objects

**In this section...**

### Overview

The Real-Time Workshop Embedded Coder software provides the `mpt` (module packaging tool) data object, which contains all the properties of Simulink data objects plus properties that provide additional control over module packaging. For a comparison of the properties of Simulink and `mpt` data objects, see "Comparing Simulink and mpt Data Objects" on page 11-13.

There are different ways of creating Simulink and `mpt` data objects for a data dictionary.

- One-by-one, either using the MATLAB command line or using the Model Explorer **Add** menu and selecting **Simulink Parameter**, **Simulink Signal**, **MPT Parameter**, or **MPT Signal**. For more information, see "Working with Data Objects" in the Simulink documentation.
- All at once, invoking Data Object Wizard for an existing model. For more information and examples, see "Data Object Wizard" in the Simulink documentation and "Creating mpt Data Objects with Data Object Wizard" on page 11-12.
- Creating data objects based on an external data dictionary. You can do this manually item by item, or all at once automatically using a script. For more information, see "Creating Data Objects Based on an External Data Dictionary" on page 11-17.

The following sections illustrate how to create Simulink and `mpt` data objects and compares their properties as data types.

## Creating Simulink Data Objects with Data Object Wizard

You can use Data Object Wizard to create data objects for your model (see "Data Object Wizard" in the Simulink documentation).

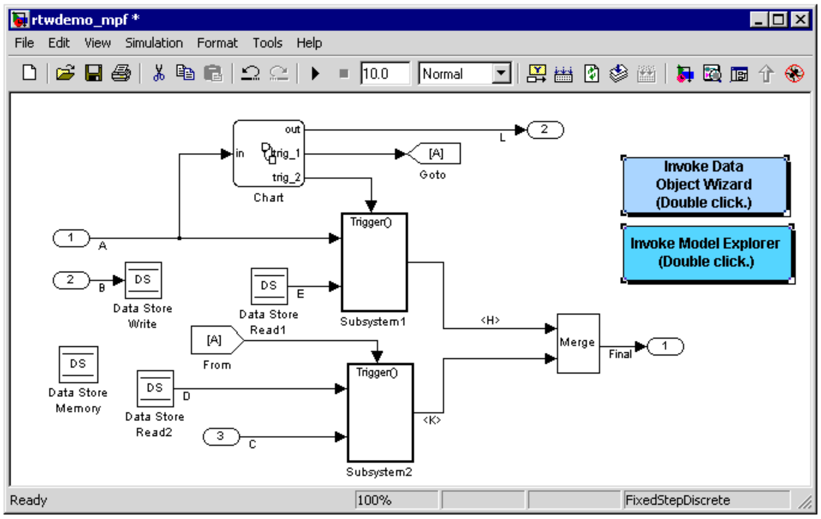
Data Object Wizard is especially useful for creating multiple data objects for

- Existing models that do not currently use data objects.
- Existing models to which you have added signals or parameters and therefore you need to create more data objects.

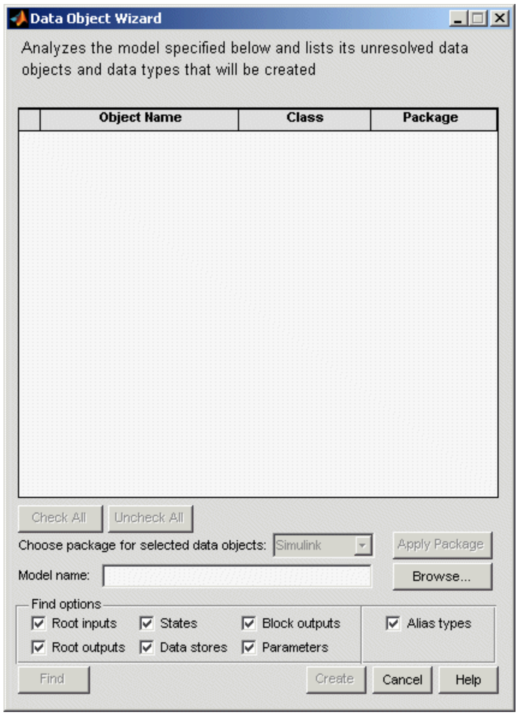
### Creating Simulink Data Objects

This procedure creates Simulink data objects using Data Object Wizard.

**1** Open the model whose data objects you want to be in the data dictionary. For example, open `rtwdemo_mpf.mdl` (which is located in `toolbox/rtw/rtwdemos`). This model appears as shown below.



2 Open Data Object Wizard by entering `dataobjectwizard` at the MATLAB command line or by selecting **Data Object Wizard** from the **Tools** menu of your model. The Data Object Wizard dialog box appears, as shown below.



Analyzes the model specified below and lists its unresolved data objects and data types that will be created

Choose package for selected data objects: Simulink

Model name:

Find options

☑ Root inputs ☑ States ☑ Block outputs ☑ Alias types

☑ Root outputs ☑ Data stores ☑ Parameters

3 In the **Model name** field, type the name of the model you opened in step 1 and press the **Enter** key, or navigate to it using the **Browse** button. The **Find** button becomes available. Notice the check boxes in the **Find options** pane.

4 In the **Find options** pane, select the desired check boxes. For descriptions of each check box, see “Data Object Wizard” in the Simulink documentation.

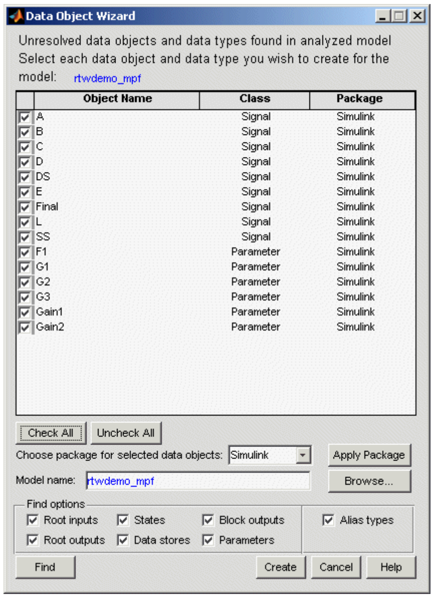
Be sure to check the **Alias types** option. This finds all user-registered data types in the `sl_customization.m` file plus all data type replacements specified for the model in the **Data Type Replacement** pane of the Configuration Parameters dialog box. Data Object Wizard can create `Simulink.AliasType` objects from these.

**5** Click the **Find** button. After a moment, a list of all of the model's potential data objects appear that are not yet in the code generation data dictionary, as shown below. This includes all of the model's signals (root inputs, root outputs, and block outputs), discrete states, data stores, and parameters, depending on

- The check boxes you selected in the previous step
- The constraint mentioned in the note above

Data Object Wizard finds only those signals, parameters, data stores, and states whose storage class is set to `Auto`. The Wizard lists each data store and discrete state that it finds as a signal class.

**6** Click **Check All** to select all data objects. Notice in the **Choose package for selected data objects** field that `Simulink`, the default, is selected. So all of the data objects are associated with the `Simulink` package, as shown below.


Data Object Wizard

Unresolved data objects and data types found in analyzed model
Select each data object and data type you wish to create for the model: rtwdemo_mpf

| | Object Name | Class | Package |
|---|---|---|---|
| ✓ | A | Signal | Simulink |
| ✓ | B | Signal | Simulink |
| ✓ | C | Signal | Simulink |
| ✓ | D | Signal | Simulink |
| ✓ | DS | Signal | Simulink |
| ✓ | E | Signal | Simulink |
| ✓ | Final | Signal | Simulink |
| ✓ | L | Signal | Simulink |
| ✓ | SS | Signal | Simulink |
| ✓ | F1 | Parameter | Simulink |
| ✓ | G1 | Parameter | Simulink |
| ✓ | G2 | Parameter | Simulink |
| ✓ | G3 | Parameter | Simulink |
| ✓ | Gain1 | Parameter | Simulink |
| ✓ | Gain2 | Parameter | Simulink |

Choose package for selected data objects: Simulink

Model name: rtwdemo_mpf

Find options
✓ Root inputs ✓ States ✓ Block outputs ✓ Alias types
✓ Root outputs ✓ Data stores ✓ Parameters

**7** Click **Create**. The data objects are added to the MATLAB workspace, and they disappear from Data Object Wizard.

**8** Click **Cancel**. The Data Object Wizard dialog box disappears.

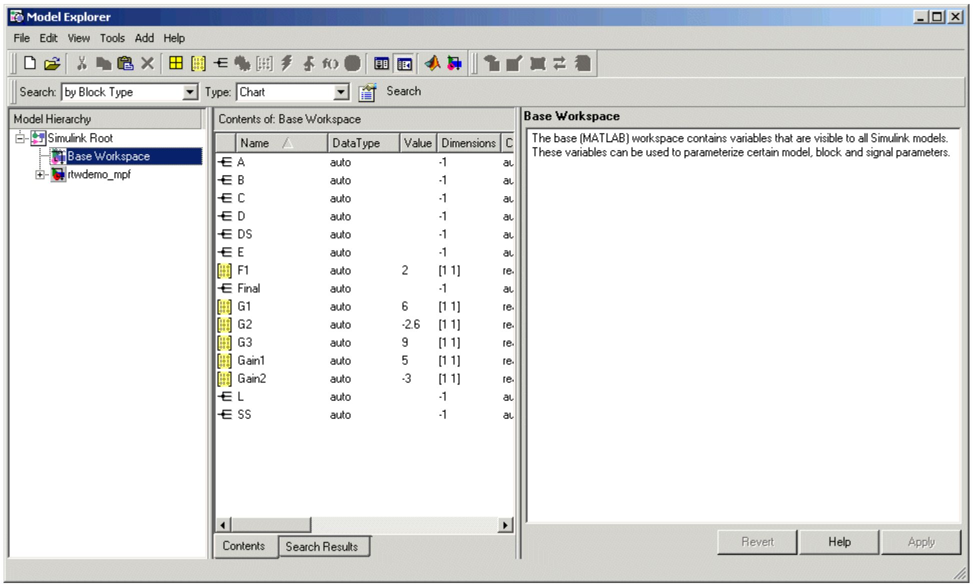
Now you can set property values for the data objects.

## Setting Property Values for Simulink Data Objects

Most of the property values of data objects are supplied by defaults. A few are from the model. Note that for Simulink data objects, the default storage class is `Auto`.

**1** Type `daexplr` on the MATLAB command line, and press **Enter**. The Model Explorer appears.

**2** In the Model Hierarchy (left) pane, select **Base Workspace**. All of the Simulink data objects in the code generation data dictionary appear in the **Contents of** (middle) pane, as shown below.

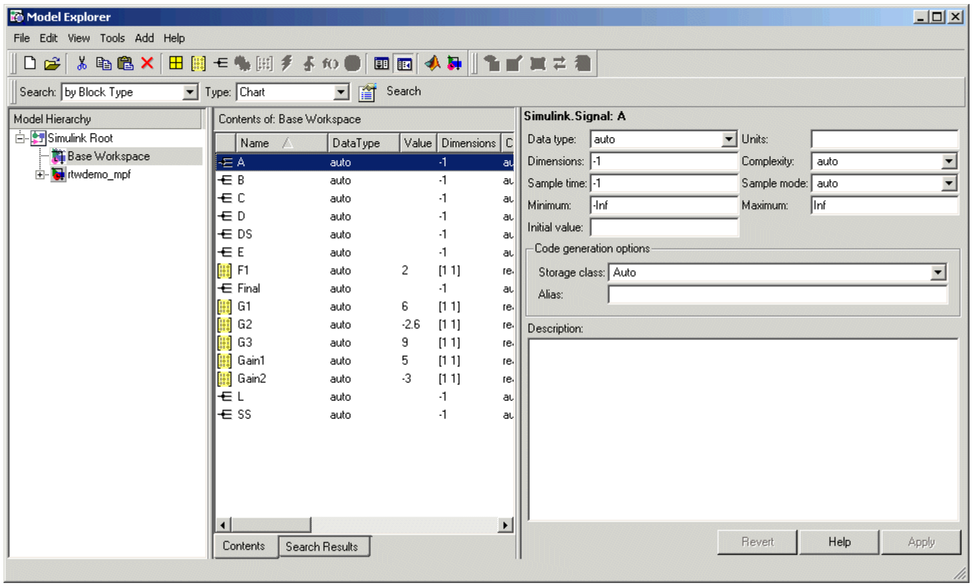


| Name | DataType | Value | Dimensions | C |
|---|---|---|---|---|
| A | auto | | -1 | au |
| B | auto | | -1 | au |
| C | auto | | -1 | au |
| D | auto | | -1 | au |
| DS | auto | | -1 | au |
| E | auto | | -1 | au |
| F1 | auto | 2 | [1 1] | re |
| Final | auto | | -1 | au |
| G1 | auto | 6 | [1 1] | re |
| G2 | auto | -2.6 | [1 1] | re |
| G3 | auto | 9 | [1 1] | re |
| Gain1 | auto | 5 | [1 1] | re |
| Gain2 | auto | -3 | [1 1] | re |
| L | auto | | -1 | au |
| SS | auto | | -1 | au |

**Base Workspace**

The base (MATLAB) workspace contains variables that are visible to all Simulink models. These variables can be used to parameterize certain model, block and signal parameters.

**3** To see the properties of a Simulink data object, select a data object in the middle pane. The right pane displays the property names, as shown below. (For descriptions of the properties, see Parameter and Signal Property Values on page 6-2.) These property names also appear as column headings in the middle pane. You have control over the values specified for these properties.



| Name | DataType | Value | Dimensions | C |
|---|---|---|---|---|
| A | auto | | -1 | au |
| B | auto | | -1 | au |
| C | auto | | -1 | au |
| D | auto | | -1 | au |
| DS | auto | | -1 | au |
| E | auto | | -1 | au |
| F1 | auto | 2 | [1 1] | re |
| Final | auto | | -1 | au |
| G1 | auto | 6 | [1 1] | re |
| G2 | auto | -2.6 | [1 1] | re |
| G3 | auto | 9 | [1 1] | re |
| Gain1 | auto | 5 | [1 1] | re |
| Gain2 | auto | -3 | [1 1] | re |
| L | auto | | -1 | au |
| SS | auto | | -1 | au |

Simulink.Signal: A

| | | | |
|---|---|---|---|
| Data type: | auto | Units: | |
| Dimensions: | -1 | Complexity: | auto |
| Sample time: | -1 | Sample mode: | auto |
| Minimum: | -Inf | Maximum: | Inf |
| Initial value: | | | |

Code generation options

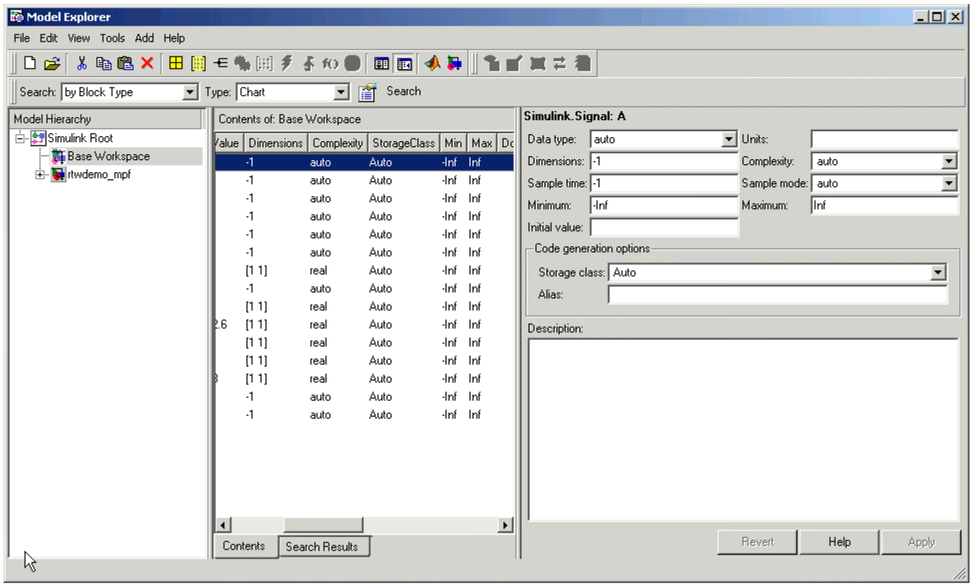
Storage class: Auto

Alias:

Description:

**4** For this example, while pressing the **Ctrl** key, select signal data object `A` and parameter data object `F1` in the middle pane.

5 In the middle pane, move the scroll bar so that you can see the **StorageClass** column, as shown below.



| /alue | Dimensions | Complexity | StorageClass | Min | Max | Dc |
|---|---|---|---|---|---|---|
| | -1 | auto | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | [1 1] | real | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | [1 1] | real | Auto | -Inf | Inf | |
| 2.6 | [1 1] | real | Auto | -Inf | Inf | |
| | [1 1] | real | Auto | -Inf | Inf | |
| | [1 1] | real | Auto | -Inf | Inf | |
| 3 | [1 1] | real | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |
| | -1 | auto | Auto | -Inf | Inf | |

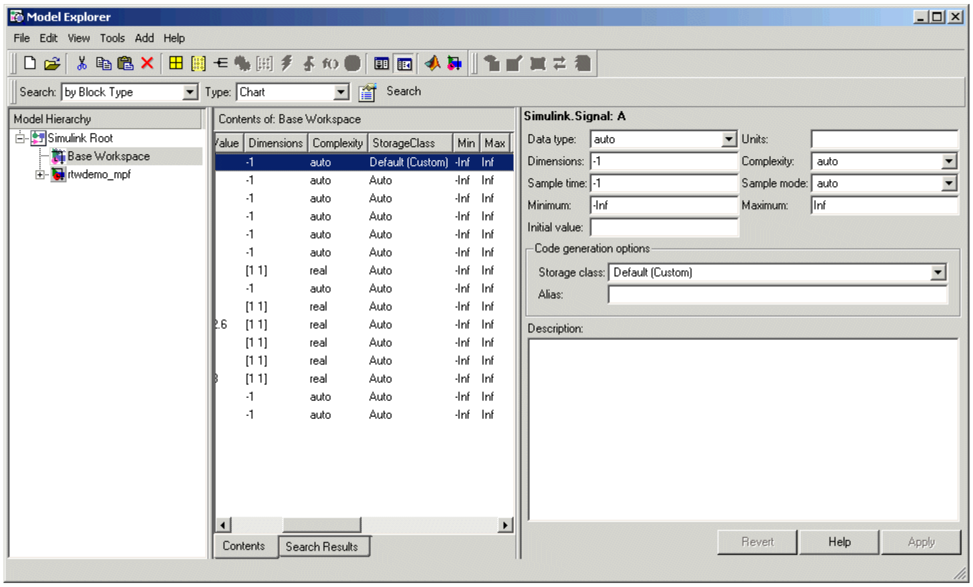
Simulink.Signal: A

Data type: auto
Units:
Dimensions: -1
Complexity: auto
Sample time: -1
Sample mode: auto
Minimum: -Inf
Maximum: Inf
Initial value:

Code generation options
Storage class: Auto
Alias:

Description:

**6** For this example, click one of the rows and select `Default (Custom)`. The **StorageClass** property value for the Simulink data object changes from the default `Auto` to `Default (Custom)`, as shown below.



Contents of: Base Workspace

| Value | Dimensions | Complexity | StorageClass | Min | Max |
|---|---|---|---|---|---|
| | -1 | auto | Default (Custom) | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | [1 1] | real | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | [1 1] | real | Auto | -Inf | Inf |
| 2.6 | [1 1] | real | Auto | -Inf | Inf |
| | [1 1] | real | Auto | -Inf | Inf |
| | [1 1] | real | Auto | -Inf | Inf |
| 3 | [1 1] | real | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |
| | -1 | auto | Auto | -Inf | Inf |

**Simulink.Signal: A**

Data type: auto
Units:
Dimensions: -1
Complexity: auto
Sample time: -1
Sample mode: auto
Minimum: -Inf
Maximum: Inf
Initial value:

Code generation options
Storage class: Default (Custom)
Alias:

Description:

## Generating and Inspecting Code

All data objects for the model are in the code generation data dictionary. You have specified property values for each data object's properties as needed. Now you generate and inspect the source code, to see if it needs correction or modification. If it does, you can change property values and regenerate the code until it is what you want.

**1** In the Configuration Parameters dialog box, click **Real-Time Workshop** in the left pane.

**2** In the **Report** pane, select the **Create code generation report** check box.

---

**Note** When you select the **Create code generation report** check box, the Real-Time Workshop Embedded Coder software automatically selects two check boxes on the pane: **Launch report automatically** and **Code-to-model**. For large models, you may find that HTML report generation (step 4 below) takes longer than you want. In this case, consider clearing the **Code-to-model** check box (and the **Model-to-code** check box if selected). The report will be generated faster.

---

3. In the **Real-Time Workshop** pane, select the **Generate code only** check box. The **Build** button changes to **Generate code**.

---

**Note** The generate code process generates the `.c/.cpp` and `.h` files. The build process adds compiling and linking to generate the executable. For details on build, see "Understanding the Build Process" in the Real-Time Workshop documentation.

---

4. Click the **Generate code** button. After a moment, the HTML report appears, listing the generated files on the left pane (under Generated Source Files).

5. Select and review files in the HTML report.

## Creating mpt Data Objects with Data Object Wizard

Create `mpt` data objects using Data Object Wizard the same way you did for Simulink data objects, as explained in "Creating Simulink Data Objects with Data Object Wizard" on page 11-5, except select `mpt` as the package instead of `Simulink`.

Set the property values for the `mpt` data objects the same way you set them for Simulink data objects, as explained in "Setting Property Values for Simulink Data Objects" on page 11-8, with the following exceptions:

- Accept the default custom storage class for `mpt` data objects, `Global(Custom)`

- For data objects `A` and `F1`, type `mydefinitionfile` in the **Definition file** field on the Model Explorer.

Then generate and inspect the code.

**Note** The **Alias** field is related to "Applying Naming Rules to Identifiers Globally" on page 11-31.

## Comparing Simulink and mpt Data Objects

The `mpt` data object contains all the properties of Simulink data objects plus properties that provide additional control over module packaging. The differences between Simulink and `mpt` data objects can be illustrated by comparing

- "Signal and Parameter Properties" on page 11-14
- "Configuration Parameters" on page 11-15
- "Generated Code" on page 11-16

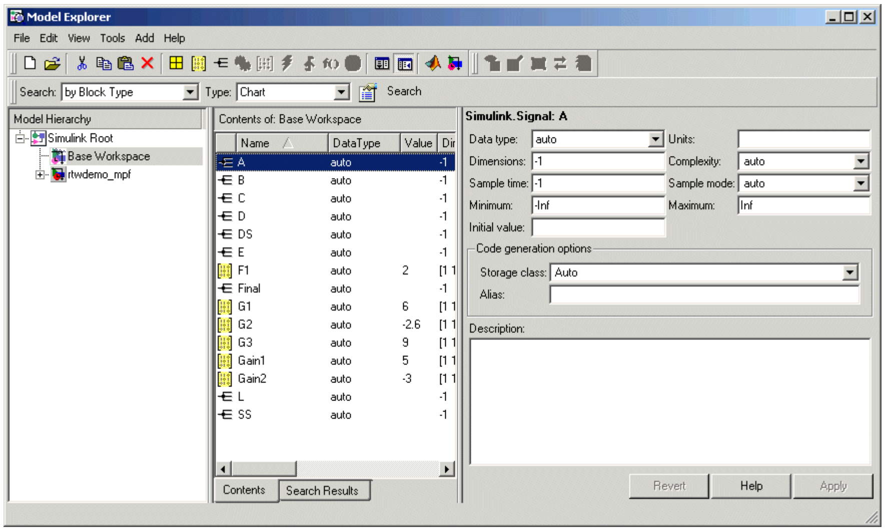
Key differences include the following:

- Different custom storage classes displayed in the Model Explorer for `mpt` data objects provide more control over the appearance of the generated code.
- Additional custom attributes (owner, definition file, persistence level, memory section) for `mpt` data objects provide more control over data packaging in the generated code.
- On the **Comments** pane of the Configuration Parameters dialog box, the **Custom comments (MPT objects only)** option allows you to add a comment just above a signal or parameter's identifier in the generated code.
- On the **Data Placement** pane of the Configuration Parameters dialog box, in the **Global data placement (MPT data objects only)** subpane:
  - The **Module naming** parameter allows you to name the module that owns the model
  - The **Signal display level** parameter allows you to specify whether or not the code generator declares a signal data object as global data

- The **Parameter tune level** parameter allows you to specify whether or not the code generator declares a parameter data object as tunable global data

## Signal and Parameter Properties

The properties that appear in Model Explorer when `mpt` is the package include all the properties that appear when `Simulink` is the package plus additional properties. Notice this by comparing the next two figures. (For descriptions of all properties in Model Explorer, see Parameter and Signal Property Values on page 6-2.)



Contents of: Base Workspace

| Name | DataType | Value | Dir |
|---|---|---|---|
| A | auto | | -1 |
| B | auto | | -1 |
| C | auto | | -1 |
| D | auto | | -1 |
| DS | auto | | -1 |
| E | auto | | -1 |
| F1 | auto | 2 | [1 1 |
| Final | auto | | -1 |
| G1 | auto | 6 | [1 1 |
| G2 | auto | -2.6 | [1 1 |
| G3 | auto | 9 | [1 1 |
| Gain1 | auto | 5 | [1 1 |
| Gain2 | auto | -3 | [1 1 |
| L | auto | | -1 |
| SS | auto | | -1 |

Simulink.Signal: A

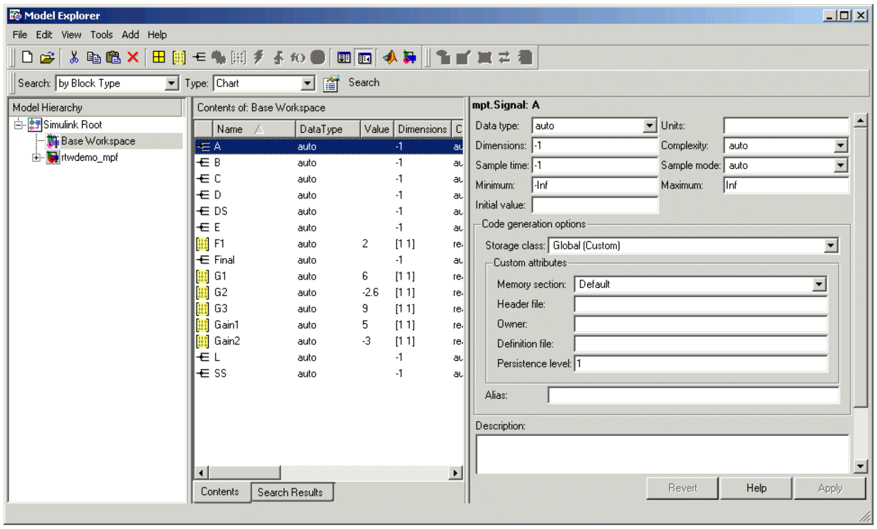
| | | | |
|---|---|---|---|
| Data type: | auto | Units: | |
| Dimensions: | -1 | Complexity: | auto |
| Sample time: | -1 | Sample mode: | auto |
| Minimum: | -Inf | Maximum: | Inf |
| Initial value: | | | |

Code generation options

Storage class: Auto

Alias:

Description:



| Name | DataType | Value | Dimensions | C |
|---|---|---|---|---|
| A | auto |  | -1 | au |
| B | auto |  | -1 | au |
| C | auto |  | -1 | au |
| D | auto |  | -1 | au |
| DS | auto |  | -1 | au |
| E | auto |  | -1 | au |
| F1 | auto | 2 | [1 1] | re |
| Final | auto |  | -1 | au |
| G1 | auto | 6 | [1 1] | re |
| G2 | auto | -2.6 | [1 1] | re |
| G3 | auto | 9 | [1 1] | re |
| Gain1 | auto | 5 | [1 1] | re |
| Gain2 | auto | -3 | [1 1] | re |
| L | auto |  | -1 | au |
| SS | auto |  | -1 | au |

**mpt.Signal: A**

| | | | |
|---|---|---|---|
| Data type: | auto | Units: | |
| Dimensions: | -1 | Complexity: | auto |
| Sample time: | -1 | Sample mode: | auto |
| Minimum: | -Inf | Maximum: | Inf |
| Initial value: | | | |

Code generation options

Storage class: Global (Custom)

Custom attributes

| | |
|---|---|
| Memory section: | Default |
| Header file: | |
| Owner: | |
| Definition file: | |
| Persistence level: | 1 |

Alias:

Description:

## Configuration Parameters

The following configuration parameters relate to Real-Time Workshop Embedded Coder module packaging features. These parameters are available in the Configuration Parameters dialog box and Model Explorer when the system target file selected for a Simulink model is `ert.tlc` (or a system target file derived from an `ert.tlc`):

- **Custom comments (MPT objects only)** option on the **Real-Time Workshop/Comments** pane
- In the **Global data placement (MPT data objects only)** subpane on the **Real-Time Workshop/Data Placement** pane:
  - **Module naming** parameter
  - **Signal display level** parameter
  - **Parameter tune level** parameter

### Generated Code

In the example used in “Setting Property Values for Simulink Data Objects” on page 11-8, you selected `Default (Custom)` in the **Storage class** field for signal `A` and parameter `F1`. You selected the default `Auto` in the **Storage class** field for the remaining data objects. But for the `mpt` data objects you used the default `Global (Custom)` in the **Storage class** field for all data objects. When you generated code, these selections resulted in the definitions and declarations shown in the table below.

| Simulink Data Object with Auto Storage Class | Simulink Data Object with Default (Custom) Storage Class | mpt Data Object with Global (Custom) Storage Class and Definition File Named mydefinitionfile |
|---|---|---|
| In `rtwdemo_mpf.c`: `/* For signal A */` `ExternalInputs rtU;` `/* For parameter F1 */` `if(rtU.A * 2.0 > 10.0) {...` In `rtwdemo_mpf.h`: `/* For signal A */` `typedef struct {` `real_T A;` `} ExternalInputs;` `extern ExternalInputs rtU;` | In `global.c`: `real_T A;` `real_T F1 = 2.0;` In `global.h`: `extern real_T A;` `extern real_T F1;` | In `mydefinitionfile.c`: `real_T A;` `real_T F1 = 2.0;` In `global.h`: `extern real_T A;` `extern real_T F1;` |

The results shown in the second and third columns of the preceding table require the following configuration parameter adjustments on the **Real-Time Workshop > Data Placement** pane:

- Set **Data definition** to `Data defined in single separate source file`.
- Set **Data definition filename** to `global.c`

- Set **Data declaration** to `Data declared in single separate source file`.
- Set **Data definition filename** to `global.h`

See the left column of the table, which shows generated code for Simulink signal and parameter data objects, whose **Storage class** field is `Auto`. The input A is defined as part of the structure `rtU` as shown above. In the case of the Simulink parameter data object `F1`, since the **StorageClass** was set to `auto`, the code generator chose to include the literal value of `F1` in the generated code. `F1` is a constant in the Stateflow diagram whose value is initialized as `2.0`:

```
if(rtU.A * 2.0 > 10.0) { ...
```

For more details, see "Introduction to Custom Storage Classes" on page 7-2 in the Real-Time Workshop Embedded Coder documentation and "Summary of Signal Storage Class Options" in the Real-Time Workshop documentation.

See the middle column of the table. The Simulink data objects whose **Storage class** is not `Auto` are defined in a definition statement in the global source file (`global.c`) and declared in a declaration statement in the global header file (`global.h`).

In the right column, Simulink data objects whose **Storage class** is not `Auto` are defined in `mydefinitionfile`, as you specified. The declarations for those objects are in the global header file.

## Creating Data Objects Based on an External Data Dictionary

This procedure creates data objects based on an external data dictionary (such as a Microsoft® Excel® file). You can do this manually (that is, one-by-one) or automatically (all at once).

## Manually Creating Objects to Represent External Data

You can create data objects (and their properties) one-by-one, based on an external data dictionary, as follows:

1. Open the external file that contains the data (such as a spreadsheet or database file).

2. Determine all of the data in this file that correspond to the parameters and signals in the model. In the code generation data dictionary, parameters in the external file belong to the Simulink parameter class and signals belong to the Simulink signal class.

3. On the MATLAB command line, type `daexplr` and press **Enter**. The Model Explorer appears.

4. On the **Model Hierarchy** (left) pane, expand **Simulink Root**, and select **Base Workspace**.

5. On the **Add** menu, select **MPT Parameter** or **Simulink Parameter**. The default name `Param` appears in the **Contents of** (middle) pane.

6. Double-click `Param` and rename this data object as desired.

7. Repeat steps 5 and 6 for each additional data item in the external file that belongs to the `mpt.Parameter` class or `Simulink.Parameter` class.

   Now you will add data items in the external file that belong to the `mpt.Signal` class or `Simulink.Signal` class.

8. On the **Add** menu, select **MPT Signal** or **Simulink Signal**. The default name `Sig` appears in the **Contents of** pane.

9. Double-click `Sig` and rename the data object as desired.

10. Repeat steps 8 and 9 for each additional data item in the external file that belongs to the `mpt.Signal` class or `Simulink.Signal` class.

    All external data items for the `mpt.Parameter` or `Simulink.Parameter` class, and the `mpt.Signal` or `Simulink.Signal` class now appear in the **Contents of** pane and in the MATLAB workspace. Therefore, they have been created in the code generation data dictionary.

**Note** The property *values* for these data objects are supplied by default.

### Automatically Creating Objects to Represent External Data

You can create data objects (and their properties) all at once, based on an external data dictionary by creating and running a `.m` file. This file contains the same MATLAB commands you could use for creating data objects one-by-one on the command line, as explained in "Working with Data Objects" in the Simulink documentation. But instead of using the command line, you place the MATLAB commands in the `.m` file for *all* of the desired data in the external file:

1 Create a new `.m` file.

2 Place information in the file that describes all of the data in the external file that you want to be data objects. For example, the following information creates two `mpt` data objects with the indicated properties. The first is for a parameter and the second is for a signal:

```
% Parameters
mptParCon = mpt.Parameter;
mptParCon.RTWInfo.CustomStorageClass ='Const';
mptParCon.value = 3;
% Signals
mptSigGlb = mpt.Signal;
mptSigGlb.DataType = 'int8';
```

3 Run the `.m` file. The data objects appear in the MATLAB workspace.

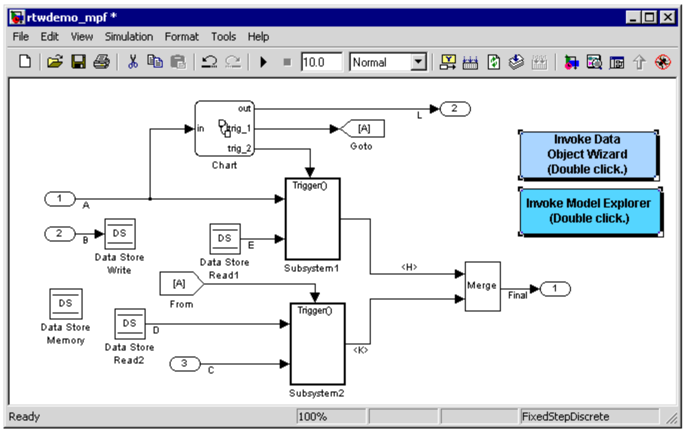
**Note** If you want to import data from an external data dictionary, you can write functions that read the information, convert these to data objects, and load them into the MATLAB workspace. Among available MATLAB functions that you can use for this process are `xmlread`, `xmlwrite`, `xlsread`, `xlswrite`, `csvread`, `csvwrite`, `dlmread`, and `dlmwrite`.

# Creating a Data Dictionary for a Model

In this procedure, you create a data dictionary for a model using Data Object Wizard, inspect the data dictionary, and generate code. Definitions for the data objects in the dictionary are generated into the model source file (`model.c`).

## Using Data Object Wizard

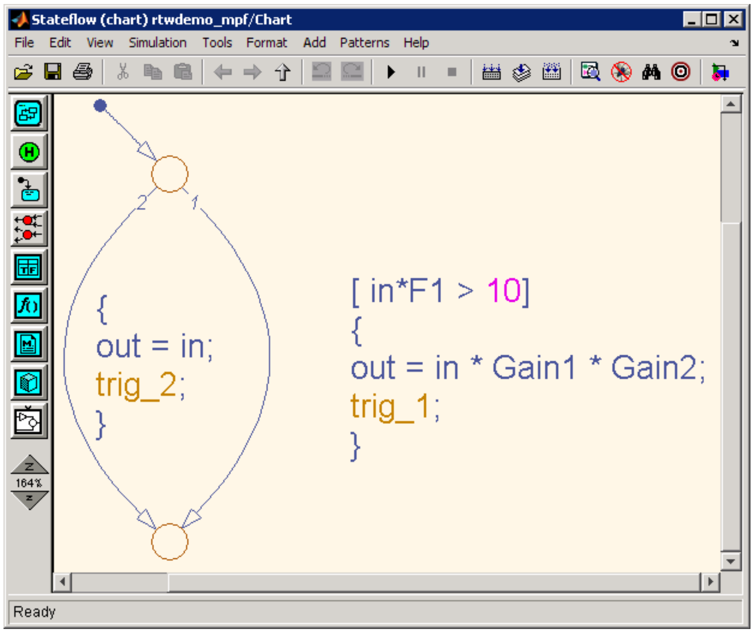
**1** Open the demo model `rtwdemo_mpf` by clicking the link or by typing `rtwdemo_mpf` in the MATLAB Command Window.



In this model,

- `A`, `B`, and `C` are input signals, and `L` and `Final` are output signals.
- Subsystem1 receives inputs `A` and `E`, and contains constants `G1` and `G2`. Signal `E` is an output from Data Store Read1.
- Subsystem2 receives inputs `C` and `D`. Signal `D` is an output from Data Store Read2. There is a constant in Subsystem2 named `G3`. Also, this subsystem has a Unit Delay block whose state name is `SS`.

**2** Double-click the Stateflow chart and notice it has constants `F1`, `Gain1`, and `Gain2`, as shown below:

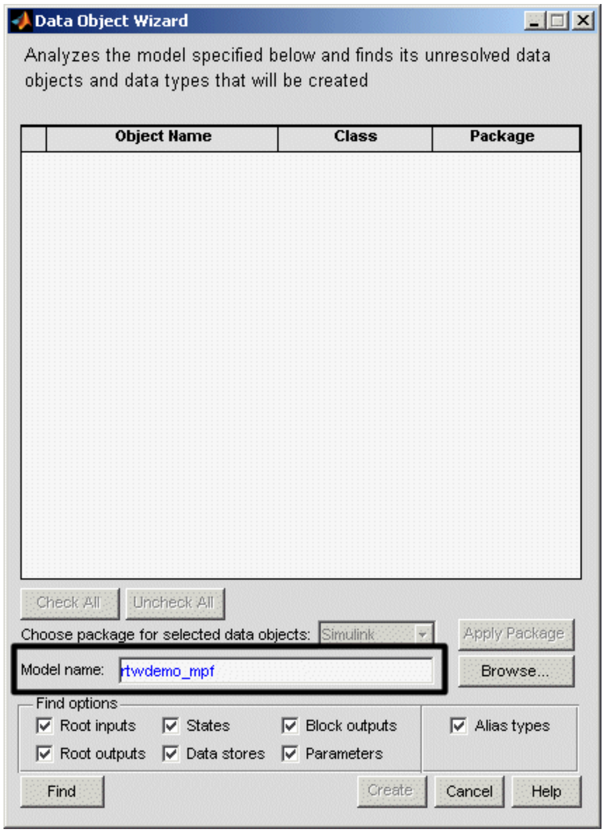

Stateflow (chart) rtwdemo_mpf/Chart
File Edit View Simulation Tools Format Add Patterns Help
164%
Ready

```
{
out = in;
trig_2;
}
```

```
[ in*F1 > 10]
{
out = in * Gain1 * Gain2;
trig_1;
}
```

**3** Change to a work directory that is not on an installation path and save the model in that work directory. The Real-Time Workshop software does not allow you to generate code from an installation directory.

**4** Double-click the **Invoke Data Object Wizard** button on the model. Or, type `dataobjectwizard('rtwdemo_mpf')` in the MATLAB Command Window. Data Object Wizard opens and `rtwdemo_mpf` appears in the **Model name** field, as shown below:


Analyzes the model specified below and finds its unresolved data objects and data types that will be created

| | Object Name | Class | Package |
|---|---|---|---|

Choose package for selected data objects: Simulink

Model name: rtwdemo_mpf

Find options

☑ Root inputs ☑ States ☑ Block outputs ☑ Alias types

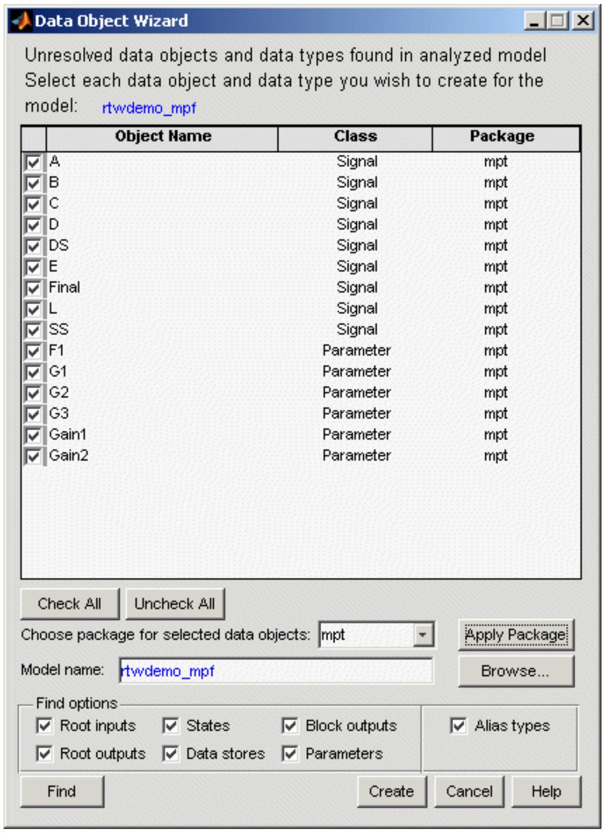
☑ Root outputs ☑ Data stores ☑ Parameters

5 Click **Find** on Data Object Wizard. After a moment, the model's parameters and signals appear in Data Object Wizard. These "data objects" make up the data dictionary.

6 Click **Check All**, to select all data objects for the data dictionary.

7 In the **Choose package for selected objects** field, select `mpt`. For an explanation of "package," see "Overview of the Data Dictionary" on page 11-2.

**8** Click **Apply Package**. Data Object Wizard associates the selected data objects with the `mpt` package, as shown below.



Unresolved data objects and data types found in analyzed model
Select each data object and data type you wish to create for the model: rtwdemo_mpf

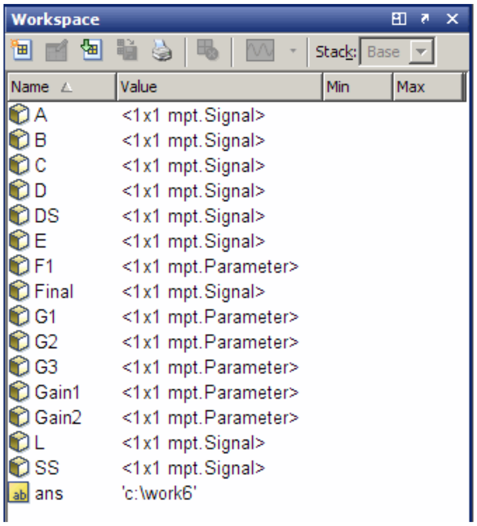
| | Object Name | Class | Package |
|---|---|---|---|
| ✓ | A | Signal | mpt |
| ✓ | B | Signal | mpt |
| ✓ | C | Signal | mpt |
| ✓ | D | Signal | mpt |
| ✓ | DS | Signal | mpt |
| ✓ | E | Signal | mpt |
| ✓ | Final | Signal | mpt |
| ✓ | L | Signal | mpt |
| ✓ | SS | Signal | mpt |
| ✓ | F1 | Parameter | mpt |
| ✓ | G1 | Parameter | mpt |
| ✓ | G2 | Parameter | mpt |
| ✓ | G3 | Parameter | mpt |
| ✓ | Gain1 | Parameter | mpt |
| ✓ | Gain2 | Parameter | mpt |

Choose package for selected data objects: mpt

Model name: rtwdemo_mpf

Find options: ✓ Root inputs, ✓ States, ✓ Block outputs, ✓ Alias types, ✓ Root outputs, ✓ Data stores, ✓ Parameters

9 Click **Create**. Data Object Wizard creates a data dictionary, consisting of data objects for the selected parameters and signals. Data Object Wizard removes the objects from its object view. Also, the objects are added to the MATLAB workspace, as shown below.



| Name | Value | Min | Max |
|---|---|---|---|
| A | <1x1 mpt.Signal> | | |
| B | <1x1 mpt.Signal> | | |
| C | <1x1 mpt.Signal> | | |
| D | <1x1 mpt.Signal> | | |
| DS | <1x1 mpt.Signal> | | |
| E | <1x1 mpt.Signal> | | |
| F1 | <1x1 mpt.Parameter> | | |
| Final | <1x1 mpt.Signal> | | |
| G1 | <1x1 mpt.Parameter> | | |
| G2 | <1x1 mpt.Parameter> | | |
| G3 | <1x1 mpt.Parameter> | | |
| Gain1 | <1x1 mpt.Parameter> | | |
| Gain2 | <1x1 mpt.Parameter> | | |
| L | <1x1 mpt.Signal> | | |
| SS | <1x1 mpt.Signal> | | |
| ans | 'c:\work6' | | |

10 Close Data Object Wizard.

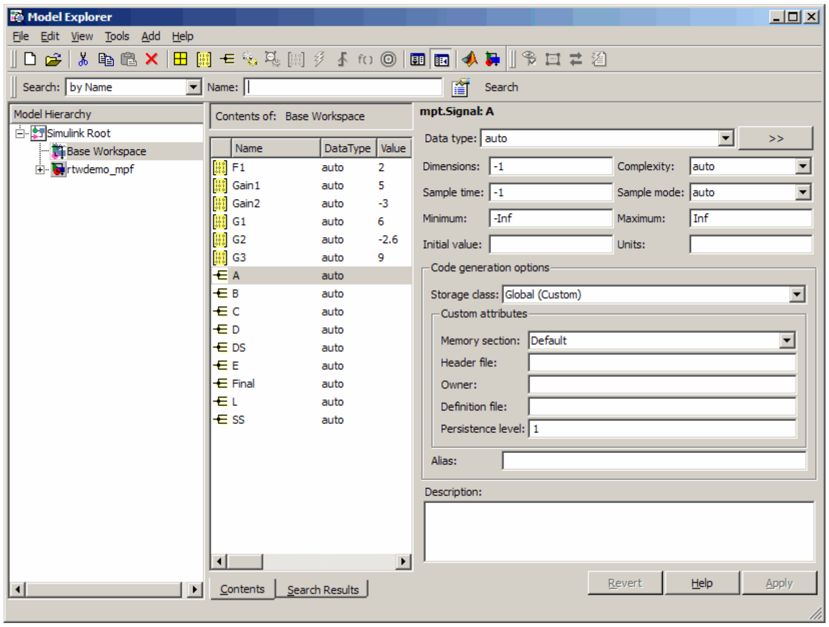
## Inspect the Data Dictionary

You can verify that each data object you selected in Data Object Wizard is in the data dictionary, using the Model Explorer:

1 Open the Model Explorer.

2 In the left pane, select **Base Workspace**. Notice that all data objects that you placed in the data dictionary appear in the middle pane.

3 In the middle pane, select data objects one at a time, and notice their property values in the right pane. The figure below shows this for signal `A`. All of the data objects have default property values. Note that for an `mpt` data object, the default in the **Storage class** field is `Global (Custom)`. For descriptions of the properties on the Model Explorer, see "Setting Property Values for Simulink Data Objects" on page 11-8.



Contents of: Base Workspace

| Name | DataType | Value |
|---|---|---|
| F1 | auto | 2 |
| Gain1 | auto | 5 |
| Gain2 | auto | -3 |
| G1 | auto | 6 |
| G2 | auto | -2.6 |
| G3 | auto | 9 |
| A | auto | |
| B | auto | |
| C | auto | |
| D | auto | |
| DS | auto | |
| E | auto | |
| Final | auto | |
| L | auto | |
| SS | auto | |

mpt.Signal: A

Data type: auto
Dimensions: -1
Complexity: auto
Sample time: -1
Sample mode: auto
Minimum: -Inf
Maximum: Inf
Initial value:
Units:

Code generation options
Storage class: Global (Custom)
Custom attributes
Memory section: Default
Header file:
Owner:
Definition file:
Persistence level: 1
Alias:

Description:

## Generate and Inspect Code

1 In the left pane of the Model Explorer, expand the **rtwdemo_mpf** node.

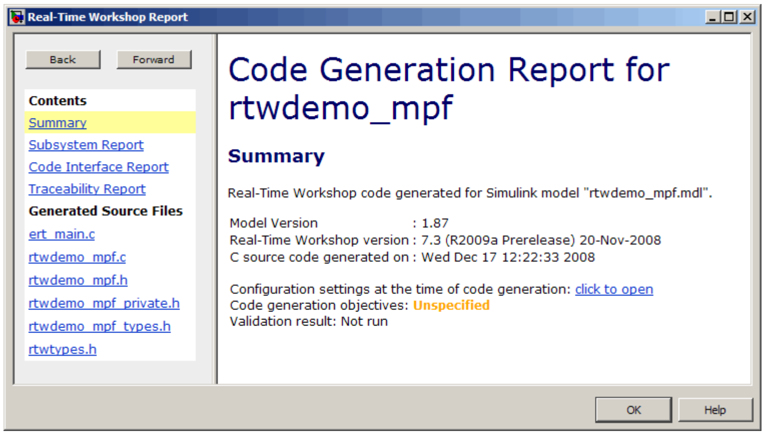
2 In the left pane, click **Configuration (Active)**.

3 In the center pane, click **Real-Time Workshop**. The active Real-Time Workshop configuration parameters appear in the right pane.

4 Click the **Report** tab.

5 In the Report tab, select **Create code generation report**

**6** Select the **General** tab. Select **Generate code only**, and then click **Generate code**. After a few moments, the names of the generated files are listed on the Real-Time Workshop Report, as shown below.



Contents
Summary
Subsystem Report
Code Interface Report
Traceability Report

Generated Source Files
ert_main.c
rtwdemo_mpf.c
rtwdemo_mpf.h
rtwdemo_mpf_private.h
rtwdemo_mpf_types.h
rtwtypes.h

Code Generation Report for rtwdemo_mpf

Summary

Real-Time Workshop code generated for Simulink model "rtwdemo_mpf.mdl".

```
Model Version                : 1.87
Real-Time Workshop version : 7.3 (R2009a Prerelease) 20-Nov-2008
C source code generated on : Wed Dec 17 12:22:33 2008
```

Configuration settings at the time of code generation: click to open
Code generation objectives: Unspecified
Validation result: Not run

**7** Open and inspect the content of the model source file `rtwdemo_mpf.c`. The following data objects in the data dictionary are initialized in this file.

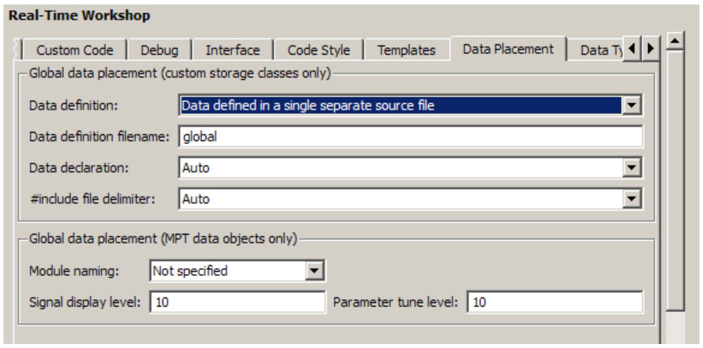
```
real_T F1 = 2.0;
real_T G1 = 6.0;
real_T G2 = -2.6;
real_T G3 = 9.0;
real_T Gain1 = 5.0;
real_T Gain2 = -3.0;
```

## Defining All Global Data Objects in a Separate File

The previous procedure placed all of the model's data objects in the model source file. Now you place all of the global data objects in a file separate from the model source file:

**1** Configure the model's generated code to include all Simulink data objects (signal and parameter) in a separate definition file. Set **Diagnostics > Data Validity > Signal resolution** to `Explicit and implicit`.

**2** Specify that data be defined in a separate file. Set **Real-Time Workshop > Data Placement > Data definition** to `Data defined in single separate source file.` . Accept the default for **Data definition filename**, `global.c`


Real-Time Workshop

Global data placement (custom storage classes only)

Data definition: Data defined in a single separate source file

Data definition filename: global

Data declaration: Auto

#include file delimiter: Auto

Global data placement (MPT data objects only)

Module naming: Not specified

Signal display level: 10

Parameter tune level: 10

**3** Specify that data be declared in a separate file. Set **Data declaration** to `Data declared in a single separate header file` and accept the default for **Data declaration filename**, `global.h`. Then, click **Apply**.

**4** Click **Generate code**. Notice that the code generation report lists `global.c` and `global.h` files.

**5** Inspect the code generation report. Notice that

- The data objects formerly initialized in `rtwdemo_mpf.c` now are initialized in `global.c`.
- The file `rtwdemo_mpf.c` includes `rtwdemo_mpf.h`.

- The file `rtwdemo_mpf.h` includes `global.h`.

## Defining a Specific Global Data Object in Its Own File

The previous procedure placed all global data objects in a separate definition file, in one operation. You named that file `global.c`. (You named the corresponding declaration file `global.h`.) MPF allows you to override this and place a specific data object in its own definition file. In the following procedure, you move the `Final` signal to a file called `finalsig.c`, and keep all the other data objects defined in `global.c`:

1. In the Model Explorer, display the base workspace and select the `Final` signal object. The **mpt.Signal** properties appear in the right pane.

2. In the **Code generation options** section, type `finalsig.h` in the **Header file** text box, type `finalsig.c` in the **Definition file** text box, and click **Apply**.

3. On the Real-Time Workshop **General** pane, click**Generate code**. The code generation report still lists `global.c` and `global.h`, but adds `finalsig.c` and `finalsig.h`.

4. Open all four files to inspect them. Notice that the `Final` signal is defined in `finalsig.c`. All other data objects in the dictionary are defined in `global.c`.

## Saving and Loading Data Objects

In a `.mat` file, you can save the set of data objects (and their properties) that you have created and load this information for later use or exchange it with another user. You can save some of the data objects in the workspace or all of them. See Opening, Loading, Saving Files in the MATLAB documentation.

## Applying Naming Rules to Identifiers Globally

**In this section...**

**Note** The capabilities described in this section apply both to Simulink and `mpt` data objects.

### Overview

Signal and parameter names appear on a Simulink model. The same names appear as data objects on the Model Explorer. By default, these names are replicated exactly in the generated code. For example, `"Speed"` on the model (and workspace) appears as the identifier `"Speed"` in the code, by default. But you can change how they appear in the code. For example, if desired, you can change `"Speed"` to `SPEED` or `speed`. Or, you can choose to use a different name altogether in the generated code, like `MPH`. The only restriction is that you follow ANSI C[2]/C++ rules for naming identifiers.

There are two ways of changing how a signal name or parameter name is represented in the generated code. You can do this *globally*, by following the procedure in this section. This procedure makes selections on the Configuration Parameters dialog box to change *all* of the names when code generation occurs, according to the same rule. Or, you can change the names *individually* by following the steps described in "Setting Property Values for Simulink Data Objects" on page 11-8. The relevant field in that procedure is **Alias** on the Model Explorer.

2. ANSI® is a registered trademark of the American National Standards Institute, Inc.

If the **Alias** field is empty, the naming rule that you select on the Configuration Parameters dialog box applies to all data objects. But if you do specify a name in the **Alias** field, this overrides the naming rule for that data object. The table below illustrates these cases. The table assumes that you selected `Force lower case` as the naming rule. But with the information provided, you can determine how any of the naming rules works for an `mpt` data object or a Simulink data object (`Force upper case`, `Force lower case`, or `Custom M-function`).

**Naming Rules and Alias Override (Global Change of Force Lower Case Rule)**

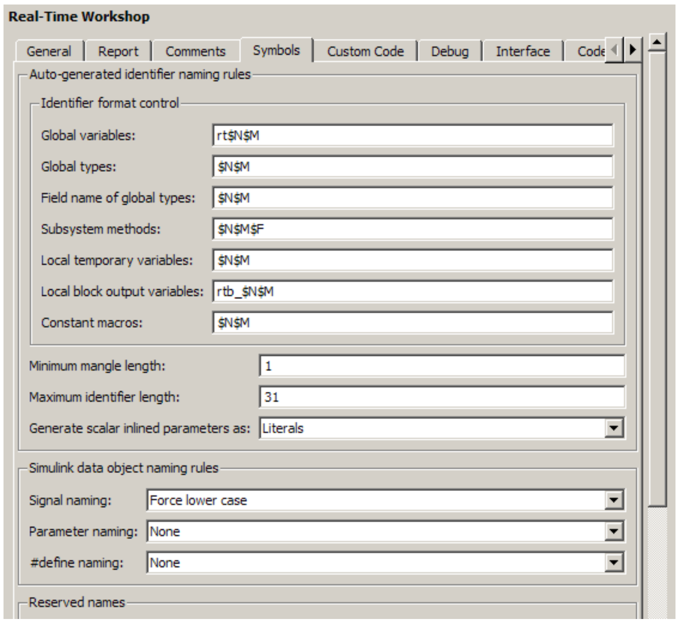
| Name of Data Object in Model | Name in Alias Field | Package | Result in Generated Code |
|---|---|---|---|
| A | | `Simulink` or `mpt` | a |
| A | D | `Simulink` or `mpt` | D |

## Changing Names of Identifiers

This procedure changes the names of all signal identifiers, except one, so that they are spelled with all lowercase letters. For example, `A` in the definition statement located in `global.c` is changed to `a`. The one exception is the `Final` signal in the `finalsig.c` file. You change this identifier name to `Final_Signal`. The names of the rest of the identifiers in the generated files remain the same:

1 Open the **Real-Time Workshop > Symbols** pane of the Configuration Parameters dialog.

2 In the **Simulink data object naming rules** section, set **Signal naming** to `Force lower case`, and click **Apply**.


Real-Time Workshop

General | Report | Comments | Symbols | Custom Code | Debug | Interface | Code

Auto-generated identifier naming rules

Identifier format control

| | |
|---|---|
| Global variables: | rt$N$M |
| Global types: | $N$M |
| Field name of global types: | $N$M |
| Subsystem methods: | $N$M$F |
| Local temporary variables: | $N$M |
| Local block output variables: | rtb_$N$M |
| Constant macros: | $N$M |
| Minimum mangle length: | 1 |
| Maximum identifier length: | 31 |
| Generate scalar inlined parameters as: | Literals |

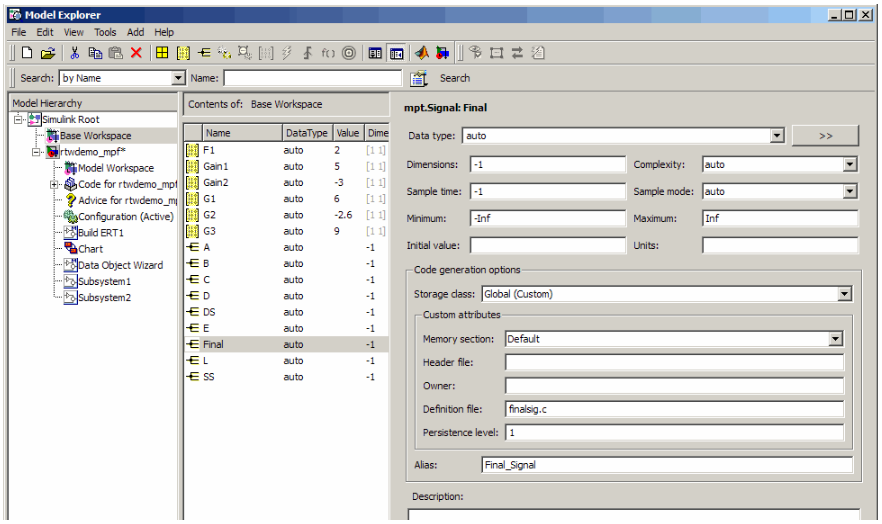
Simulink data object naming rules

| | |
|---|---|
| Signal naming: | Force lower case |
| Parameter naming: | None |
| #define naming: | None |

Reserved names

**3** Display the base workspace and select `Final`.

**4** In the right pane, type `Final_Signal` in the **Alias** text box, then click **Apply**.



| Name | DataType | Value | Dime |
|---|---|---|---|
| F1 | auto | 2 | [1 1] |
| Gain1 | auto | 5 | [1 1] |
| Gain2 | auto | -3 | [1 1] |
| G1 | auto | 6 | [1 1] |
| G2 | auto | -2.6 | [1 1] |
| G3 | auto | 9 | [1 1] |
| A | auto |  | -1 |
| B | auto |  | -1 |
| C | auto |  | -1 |
| D | auto |  | -1 |
| DS | auto |  | -1 |
| E | auto |  | -1 |
| Final | auto |  | -1 |
| L | auto |  | -1 |
| SS | auto |  | -1 |

mpt.Signal: Final

Data type: auto

Dimensions: -1 Complexity: auto

Sample time: -1 Sample mode: auto

Minimum: -Inf Maximum: Inf

Initial value: Units:

Code generation options

Storage class: Global (Custom)

Custom attributes

Memory section: Default

Header file:

Owner:

Definition file: finalsig.c

Persistence level: 1

Alias: Final_Signal

Description:

**5** On the Real-Time Workshop **General** pane, click**Generate code** .Now, the signal identifiers in `global.c` and `global.h` appear with lowercase letters.

```
real_T F1 = 0.0;
real_T G1 = 1.0;
real_T G2 = 1.0;
real_T G3 = 1.0;
real_T Gain1 = 0.0;
real_T Gain2 = 0.0;
real_T a;
real_T b;
real_T c;
real_T d;
real_T ds;
real_T e;
real_T l;
real_T ss;
```

The statement defining the `Final` signal in `finalsig.c` looks like this:

```
real T Final_Signal;
```

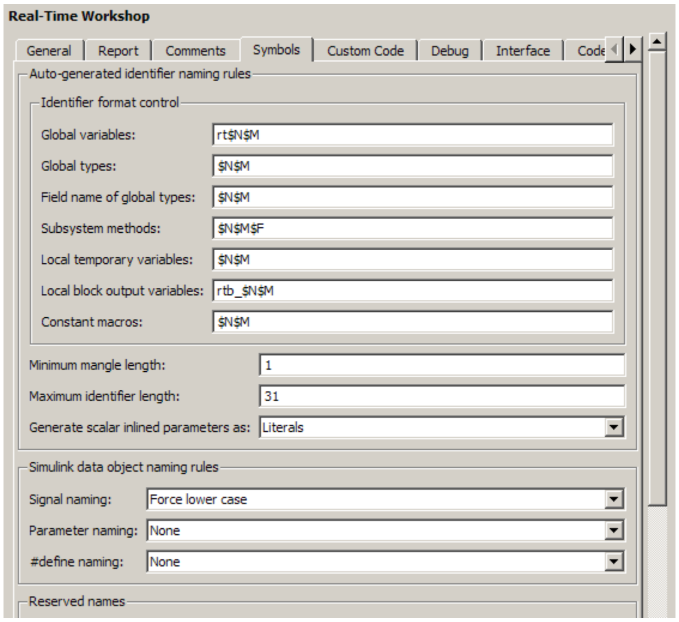
The statement declaring this identifier in `finalsig.h` looks like this:

```
extern real_T Final_Signal;
```

## Specifying Simulink Data Object Naming Rules

You specify Simulink data object naming rules on the **Real-Time Workshop > Symbols** pane of the Configuration Parameters dialog box. To access that pane,

1. Open an ERT-based model.
2. Open the Configuration Parameters dialog box from the **Simulation** menu or Model Explorer.
3. Open the **Real-Time Workshop > Symbols** pane. See the subpane **Simulink data object naming rules**.



Auto-generated identifier naming rules

Identifier format control

| | |
|---|---|
| Global variables: | rt$N$M |
| Global types: | $N$M |
| Field name of global types: | $N$M |
| Subsystem methods: | $N$M$F |
| Local temporary variables: | $N$M |
| Local block output variables: | rtb_$N$M |
| Constant macros: | $N$M |
| Minimum mangle length: | 1 |
| Maximum identifier length: | 31 |
| Generate scalar inlined parameters as: | Literals |

Simulink data object naming rules

| | |
|---|---|
| Signal naming: | Force lower case |
| Parameter naming: | None |
| #define naming: | None |

Reserved names

Notice the preconfigured settings on this pane. If all of these are acceptable as is, proceed to "Creating User Data Types" on page 11-39. Otherwise, follow the procedures below, as desired, to change signal names, parameter names, or parameter names that you want to use in a `#define` preprocessor directive. "Real-Time Workshop Pane: Symbols" in the Real-Time Workshop documentation describes all fields on this pane and their possible settings for these procedures.

- "Defining Rules That Change All Signal Names" on page 11-36
- "Defining Rules That Change All Parameter Names" on page 11-36
- "Defining Rules That Change All #defines" on page 11-37

## Defining Rules That Change All Signal Names

This procedure allows you to change all of the model's signal names, using the same rule. The new names will appear as identifiers in the generated code:

1. In the **Signal naming** menu, click the desired selection. ("Signal naming" explains the possible selections.) The default is `None`. If you selected `Custom M-function`, go to the next step. Otherwise, click **Apply** and then generate and inspect code.
2. Write a function in M-code that changes all occurrences of signal names in the model to appear the way you want as identifiers in the generated code. (An example is shown in "Defining Rules That Change All Parameter Names" on page 11-36.)
3. Save the function as a `.m` file in any folder that is in the MATLAB path.
4. In the **M-function** field under **Signal naming**, type the name of the file you saved in the previous step.
5. Click **Apply** and then generate and inspect code.

## Defining Rules That Change All Parameter Names

This procedure allows you to change all of the model's parameter names, using the same rule. The new names will appear as identifiers in the generated code:

1. In the **Parameter naming** field, click the desired selection. ("Parameter naming" explains the possible selections.) The default is `None`. If you selected `Custom M-function`, go to the next step. Otherwise, click **Apply**, and proceed to "Defining Rules That Change All Signal Names" on page 11-36.

2 Write a function in M-code that changes all occurrences of parameter names in the model to appear the way you want as identifiers in the generated code. For example, the code below changes all parameter names as necessary to make their first letter uppercase, and their remaining letters lowercase.

```
function
revisedName = initial_caps_only(name, object)
% INITIAL_CAPS_ONLY: User-defined naming rule causing each
% identifier in the generated code to have initial cap(s).
%
% name: name as spelled in model.
% object: the object of name; includes name's properties.
%
% revisedName: manipulated name returned to MPT for the
code.
%
%
:
revisedName = [upper(name(1)),lower(name(2:end))];
:
```

3 Save the function as a `.m` file in any folder that is in the MATLAB path.

4 In the **M-function** field under **Parameter naming**, type the name of the file you saved in the previous step.

5 Click **Apply** and then define rules that apply to all signal names.

## Defining Rules That Change All #defines

This procedure allows you to change all of the model's parameter names whose storage class you selected as `Define` in "Creating mpt Data Objects with Data Object Wizard" on page 11-12, using the same rule. The new names will appear as identifiers in the generated code:

1 In **#define naming**, click the desired selection. ("#define naming" explains the possible selections.) The default is `None`. If you select `Custom M-function`, go to the next step. Otherwise, click **Apply** and proceed to "Defining Rules That Change All Parameter Names" on page 11-36.

2 Write a function in M-code that changes all occurrences of the parameter name whose storage class you specified as `Define` in "Creating mpt Data Objects with Data Object Wizard" on page 11-12 so that it appears the way you want as an identifier in the generated code. (An example is shown below.)

3 Save the function as a `.m` file in any folder that is in the MATLAB path.

4 In the **M-function** field under **#define naming**, type the name of the file you saved in the previous step.

5 Click **Apply** and then define rules that change all parameter names.

## Creating User Data Types

**In this section...**

---

**Note** The capabilities described in this section apply both to Simulink and `mpt` data objects.

---

### Overview

By default, MathWorks data types (such as `real32_T` and `uint8_T`) are used to define data in the generated code. If you prefer using your company-standard data types (such as `DBL` and `U8`), you can define user data types. To use this feature, you must register and create your data types so that the code generator can associate them with the corresponding MathWorks C/C++ data types. Then, the code generator will use your user data types in the generated code instead of the MathWorks C/C++ data types.

The Real-Time Workshop software automatically associates the MathWorks C/C++ data types with the equivalent ANSI[3] C/C++ data types. If you want to use only the default MathWorks C/C++ data types, you do not need to register and create your own data types.

To register user data types, use the Simulink customization file `sl_customization.m`. This file is a mechanism that allows you to use M-code to perform customizations of the standard Simulink user interface. The Simulink software reads the `sl_customization.m` file, if present on the MATLAB path, when it starts and the customizations specified in the file are applied to the Simulink session. For more information on the `sl_customization.m` customization file, see "Customizing the Simulink User Interface" in the Simulink documentation.

3. ANSI® is a registered trademark of the American National Standards Institute, Inc.

Once you have registered your user data types using `sl_customization.m`, you must create the `Simulink.AliasType` objects corresponding to your user data types. If your model references a user data type either directly (for example, in the output data type of a block) or indirectly (for example, a `Simulink.Signal` object data type is set to the user data type), you must create the corresponding `Simulink.AliasType` object before updating the model, running a simulation, or generating code. To create the `Simulink.AliasType` objects, you can:

- Invoke the MATLAB function `ec_create_type_obj` to programmatically create all the required `Simulink.AliasType` objects
- Create `Simulink.AliasType` objects one at a time by selecting **Add > Simulink.AliasType** in the Model Explorer
- Create `Simulink.AliasType` objects one at a time by entering the MATLAB command *`userdatatype`* `= Simulink.AliasType`, where *`userdatatype`* is a user data type registered in `sl_customization.m`

## Registering User Data Types Using sl_customization.m

To register user data type customizations, you create an instance of `sl_customization.m` and include it on the MATLAB path of the Simulink installation that you want to customize. The `sl_customization` function accepts one argument: a handle to a customization manager object. For example,

```
function sl_customization(cm)
```

As a starting point for your customizations, the `sl_customization` function must first get the default (factory) customizations, using the following assignment statement:

```
hObj = cm.slDataObjectCustomizer;
```

You then invoke methods to register your customizations. The customization manager object includes the following methods for registering Simulink user data type customizations:

- `addUserDataType(hObj, userName, builtinName, userHeader)`

  `addUserDataType(hObj, userName, builtinName)` `addUserDataType(hObj, userName, aliasTypeObj)`

`addUserDataType(hObj, userName, numericTypeObj)`

`addUserDataType(hObj, userName, fixdtString)`

Registers the specified user-defined data type and adds it to the top of the data type list, as displayed in the **Data type** pull-down list in the Model Explorer.

- `userName` — Name of the user data type
- `builtinName` — MathWorks C/C++ data type to which `userName` is mapped
- `userHeader` — Name of the user header file that includes the definition of the user data type
- `aliasTypeObj`, `numericTypeObj`, or `fixdtString` — `Simulink.AliasType`, `Simulink.NumericType`, or `fixdt` to which `userName` is mapped

**Note** If a `Simulink.AliasType` or `Simulink.NumericType` object of the same name as your registered user data type is already defined in the base workspace, the definitions of the existing object and the registered user data type must be consistent or a consistency warning will be displayed.

- `moveUserDataTypeToTop(hObj, userName)`

  Moves the specified user-defined data type to the top of the data type list, as displayed in the **Data type** pull-down list in the Model Explorer.

- `moveUserDataTypeToEnd(hObj, userName)`

  Moves the specified user-defined data type to the end of the data type list, as displayed in the **Data type** pull-down list in the Model Explorer.

- `removeUserDataType(hObj, userName)`

  Removes the specified user-defined data type from the data type list.

Your instance of the `sl_customization` function should use these methods to register user data types for your Simulink installation.

The Simulink software reads the `sl_customization.m` file when it starts. If you subsequently change the file, you must restart your Simulink session or enter the following command at the MATLAB command line to effect the changes:

```
sl_refresh_customizations
```

## Example User Data Type Customization Using sl_customization.m

The `sl_customization.m` file shown in Example 1: sl_customization.m for User Data Type Customizations on page 11-42 uses the following methods:

- `addUserDataType` to register the user-defined data types `MyInt16`, `MyInt32`, `MyBool`, and `fixdt(1,8)`
- `moveUserDataTypeToTop` to move `MyBool` to the top of the data type list, as displayed in the **Data type** pull-down list in the Model Explorer
- `removeUserDataType` to remove the built-in data types `boolean` and `double` from the data type list

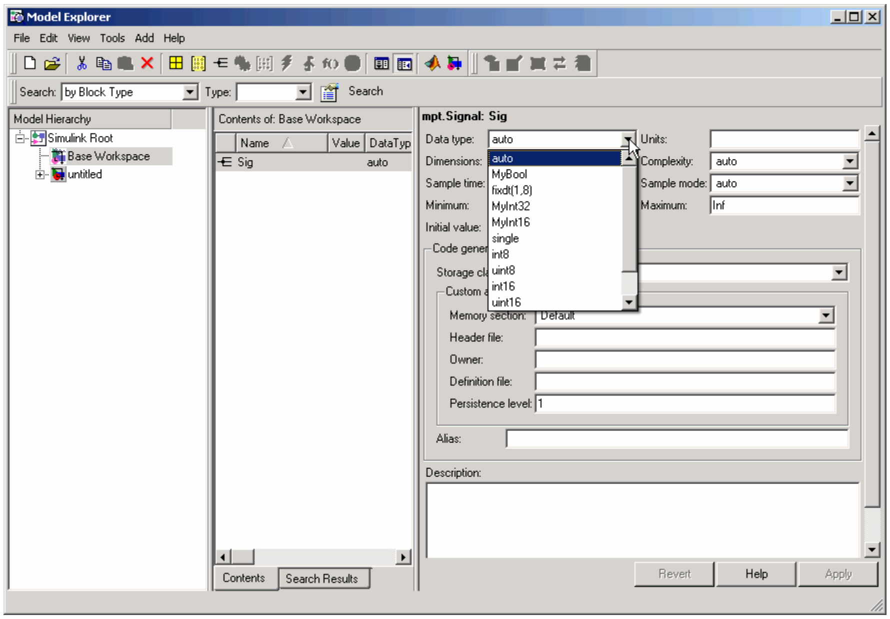
### Example 1: sl_customization.m for User Data Type Customizations

```
function sl_customization(cm)
% Register user customizations

% Get default (factory) customizations
hObj = cm.slDataObjectCustomizer;

% Add custom types
hObj.addUserDataType('MyInt16', 'int16_T', '<mytypes.h>');
hObj.addUserDataType('MyInt32', 'int32_T', '<mytypes.h>');
hObj.addUserDataType('MyBool','boolean_T');
hObj.addUserDataType('fixdt(1,8)');

% Make MyBool first in the list
hObj.moveUserDataTypeToTop('MyBool');

% Remove built-in boolean and double from the list
hObj.removeUserDataType('boolean');
hObj.removeUserDataType('double');
```

```
end
```

If you include the above file on the MATLAB path of the Simulink installation that you want to customize, the specified customizations will appear in Model Explorer. For example, you could view the customizations as follows:

1. Start a MATLAB session.
2. Open Model Explorer, for example, by entering the MATLAB command `daexplr`.
3. Select **Base Workspace**.
4. Add an `mpt` signal, for example, by selecting **Add > MPT Signal**.
5. In the right-hand pane display for the added `mpt` signal, examine the **Data type** drop-down list, noting the impact of the changes specified in Example 1: sl_customization.m for User Data Type Customizations on page 11-42.



mpt.Signal: Sig

Data type: auto

auto
MyBool
fixdt(1,8)
MyInt32
MyInt16
single
int8
uint8
int16
uint16

Units:
Dimensions:
Complexity: auto
Sample time:
Sample mode: auto
Minimum:
Maximum: Inf
Initial value:
Code gener
Storage cl
Custom a
Memory section: Default
Header file:
Owner:
Definition file:
Persistence level: 1
Alias:
Description:

## Selecting User Data Types for Signals and Parameters

**In this section...**

### Preparing User Data Types

You can use user-defined data types for Simulink signals and parameters and their corresponding identifiers in generated code. This is true whether or not a signal or parameter has a Simulink data object associated with it.

Before you can select a user data type for a signal or parameter, you must:

1. Create a user data type (alias), as explained in the description of `Simulink.AliasType` in the Simulink documentation. For the example in "Selecting the User Data Types" on page 11-46 demonstrating how to select user data types for signals and parameters, create the alias data type `f32`.

2. Register the user data type so that it is associated with the corresponding MathWorks C/C++ data type, as explained in "Creating User Data Types" on page 11-39. For the example, register the data type `f32` so that it is associated with type `real32_T`. The call to function `addUserDataType` in the `sl_customization.m` file you use for the registration must specify:

   - `f32` as the user data type
   - `real32_T` as the built-in data type
   - `<userdata_types.h>` as the user header file that is to include the user data type definition

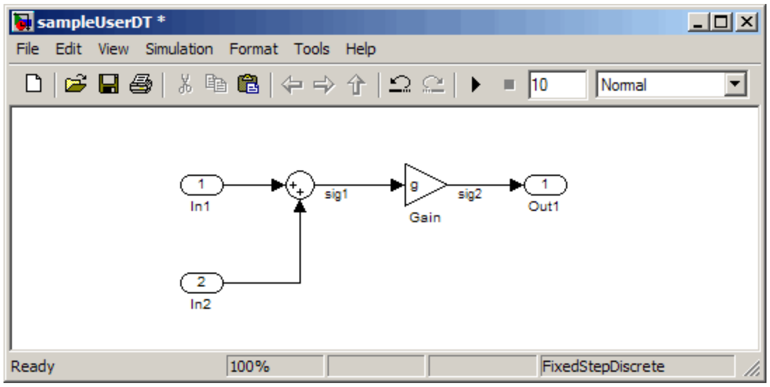
   For example,

   ```
   function sl_customization(cm)

   hObj = cm.slDataObjectCustomizer;

   addUserDataType(hObj, 'f32', 'real32_T', '<userdata_types.h>');
   ```

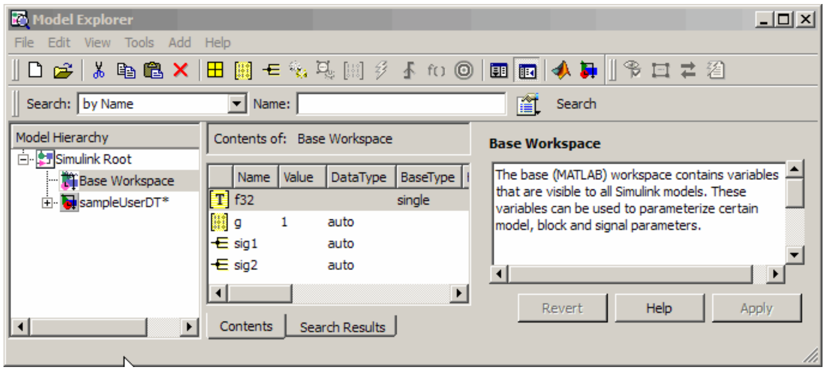
```
    end
```

**3** If you have not already done so, add the directory containing the `sl_customization.m` file that you created or modified in step 1 to the MATLAB search path.

**4** Open a model. The example uses the following model.



**5** Create a data dictionary for the model, as explained in “Creating Simulink and mpt Data Objects” on page 11-4, to associate signals and parameters with data objects. For the example, the Model Explorer display must appear as shown below. The three data objects that appear, `sig1` , `sig2`, and `g`, and the registered user data type, `f32`, appear in the middle pane. The "**T**" indicates that `f32` is an alias data type.



| Name | Value | DataType | BaseType |
|---|---|---|---|
| f32 | | | single |
| g | 1 | auto | |
| sig1 | | auto | |
| sig2 | | auto | |

The base (MATLAB) workspace contains variables that are visible to all Simulink models. These variables can be used to parameterize certain model, block and signal parameters.

For the selection procedure and to continue with the example, continue to “Selecting the User Data Types” on page 11-46.

## Selecting the User Data Types

After completing the preparation explained in “Preparing User Data Types” on page 11-44, you can use the user-defined data types for Simulink signals and parameters and for their corresponding identifiers in the generated code. You can use user-defined data types with signals and parameters whether or not they have Simulink objects associated with them.

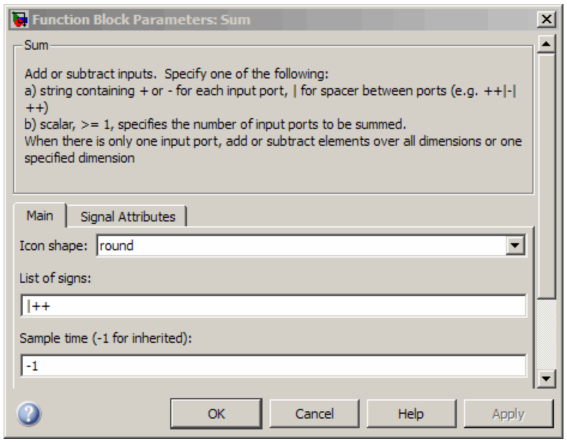
1. For an `mpt` object that is associated with a signal or parameter in your model, in the **Data type** field, select the user data type that you want. For example, select `f32`, for `sig1`.

   This selects `f32` for the `sig1` data object in the data dictionary, but does not select `f32` for the corresponding labeled signal in the model. Therefore, the two may be in conflict. If you try to update the model, you could get an error message.

   To continue with the example, type `f32` into the **Data type** field for `sig1`.

2. Select the model and double-click the signal or parameter source block. (The source block of a model signal or parameter controls the signal’s or parameter’s data type.) For example, in the example model the Sum block is the source block for `sig1`. Double-click the Sum block.

   The Function Block Parameters dialog box opens.



Sum

Add or subtract inputs. Specify one of the following:
a) string containing + or - for each input port, | for spacer between ports (e.g. ++|-|++)
b) scalar, >= 1, specifies the number of input ports to be summed.
When there is only one input port, add or subtract elements over all dimensions or one specified dimension

Main | Signal Attributes

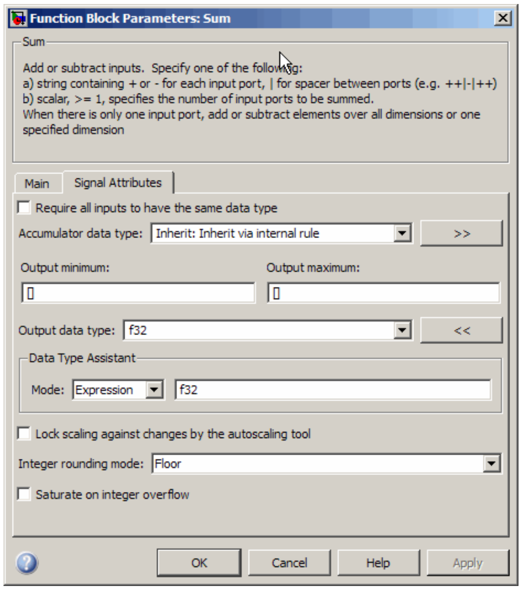
Icon shape: round

List of signs: |++

Sample time (-1 for inherited): -1

**3** Select the **Signal Attributes** tab.

**4** In the **Output data type** or **Parameter data type** field, type the name of the user data type that you specified for the data object in step 1, and click **Apply**. The user data type of the signal in the model and that of the signal object are now the same.



Sum

Add or subtract inputs. Specify one of the following:
a) string containing + or - for each input port, | for spacer between ports (e.g. ++|-|++)
b) scalar, >= 1, specifies the number of input ports to be summed.
When there is only one input port, add or subtract elements over all dimensions or one specified dimension

Main | Signal Attributes

☐ Require all inputs to have the same data type

Accumulator data type: Inherit: Inherit via internal rule

Output minimum: []

Output maximum: []

Output data type: f32

Data Type Assistant

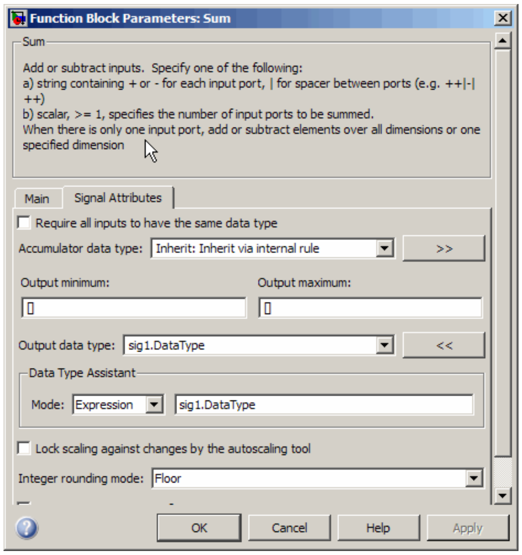
Mode: Expression f32

☐ Lock scaling against changes by the autoscaling tool

Integer rounding mode: Floor

☐ Saturate on integer overflow

Alternatively, you can use dictionary-driven data typing. In the **Output data type** field, specify *`object`*`.DataType`, where *`object`* is the case-sensitive object name. For example, you can specify `sig1.DataType` instead of `f32`.



Function Block Parameters: Sum

Sum

Add or subtract inputs. Specify one of the following:
a) string containing + or - for each input port, | for spacer between ports (e.g. ++|-|++)
b) scalar, >= 1, specifies the number of input ports to be summed.
When there is only one input port, add or subtract elements over all dimensions or one specified dimension

Main | Signal Attributes

☐ Require all inputs to have the same data type

Accumulator data type: Inherit: Inherit via internal rule

Output minimum: []

Output maximum: []

Output data type: sig1.DataType

Data Type Assistant

Mode: Expression sig1.DataType

☐ Lock scaling against changes by the autoscaling tool

Integer rounding mode: Floor

The advantage of using the alternative is that subsequent user data type changes for the object in the dictionary automatically change the user data type of the corresponding model signal or parameter.

**5** Repeat steps 1 through 4 for each remaining model signal and parameter that has a corresponding signal object for which you selected a user data type.

**6** Save the model and save all of the data objects in the MATLAB base workspace in a `.mat` file for reuse later. Generated code for `sig1` in the example model (with default MPF settings) would appear as follows:

| | |
|---|---|
| In `sampleUserDT.c` | `f32 sig1;` |
| In `sampleUserDT_types.h` | `#include <userdata_types.h>` |

## Registering mpt User Object Types

**In this section...**

### Introduction

Real-Time Workshop Embedded Coder software allows you to create custom `mpt` object types and specify properties and property values to be associated with them (see "Creating mpt Data Objects with Data Object Wizard" on page 11-12). Once created, a user object type can be applied to data objects displayed in Model Explorer. When you apply a user object type to a data object, by selecting a type name in the **User object type** pull-down list in Model Explorer, the data object is automatically populated with the properties and property values that you specified for the user object type.

To register `mpt` user object type customizations, use the Simulink customization file `sl_customization.m`. This file is a mechanism that allows you to use M-code to perform customizations of the standard Simulink user interface. The Simulink software reads the `sl_customization.m` file, if present on the MATLAB path, when it starts and the customizations specified in the file are applied to the Simulink session. For more information on the `sl_customization.m` customization file, see "Customizing the Simulink User Interface" in the Simulink documentation.

### Registering mpt User Object Types Using sl_customization.m

To register `mpt` user object type customizations, you create an instance of `sl_customization.m` and include it on the MATLAB path of the Simulink installation that you want to customize. The `sl_customization` function accepts one argument: a handle to a customization manager object. For example,

```
function sl_customization(cm)
```

As a starting point for your customizations, the `sl_customization` function must first get the default (factory) customizations, using the following assignment statement:

```
hObj = cm.slDataObjectCustomizer;
```

You then invoke methods to register your customizations. The customization manager object includes the following methods for registering `mpt` user object type customizations:

- `addMPTObjectType(hObj, objectTypeName, classtype, propName1, propValue1, propName2, propValue2, ...)`

  `addMPTObjectType(hObj, objectTypeName, classtype, {propName1, propName2, ...}, {propValue1, propValue2, ...})`

  Registers the specified user object type, along with specified values for object properties, and adds the object type to the top of the user object type list, as displayed in the **User object type** pull-down list in the Model Explorer.

  - `objectTypeName` — Name of the user object type
  - `classType` — Class to which the user object type applies: `'Signal'`, `'Parameter'`, or `'Both'`
  - `propName` — Name of a property of an `mpt` or `mpt`-derived data object to be populated with a corresponding `propValue` when the registered user object type is selected
  - `propValue` — Specifies the value for a corresponding `propName`
- `moveMPTObjectTypeToTop(hObj, objectTypeName)`

  Moves the specified user object type to the top of the user object type list, as displayed in the **User object type** pull-down list in the Model Explorer.
- `moveMPTObjectTypeToEnd(hObj, objectTypeName)`

  Moves the specified user object type to the end of the user object type list, as displayed in the **User object type** pull-down list in the Model Explorer.
- `removeMPTObjectType(hObj, objectTypeName)`

Removes the specified user object type from the user object type list.

Your instance of the `sl_customization` function should use these methods to register `mpt` object type customizations for your Simulink installation.

The Simulink software reads the `sl_customization.m` file when it starts. If you subsequently change the file, you must restart your MATLAB session to effect the changes.

## Example mpt User Object Type Customization Using sl_customization.m

The `sl_customization.m` file shown in Example 2: sl_customization.m for mpt Object Type Customizations on page 11-51 uses the `addMPTObjectType` method to register the user signal types `EngineType` and `FuelType` for `mpt` objects.

### Example 2: sl_customization.m for mpt Object Type Customizations

```
function sl_customization(cm)
% Register user customizations

% Get default (factory) customizations
hObj = cm.slDataObjectCustomizer;

% Add commonly used signal types
hObj.addMPTObjectType(...
    'EngineType','Signal',...
    'DataType', 'uint8',...
    'Min', 0,...
    'Max', 255,...
    'DocUnits','m/sec');

hObj.addMPTObjectType(...
    'FuelType','Signal',...
    'DataType', 'int16',...
    'Min', -12,...
    'Max', 3000,...
    'DocUnits','mg/hr');
```

```
end
```

If you include the above file on the MATLAB path of the Simulink installation that you want to customize, the specified customizations will appear in Model Explorer. For example, you could view the customizations as follows:

1 Start a MATLAB session.

2 Open Model Explorer, for example, by entering the MATLAB command `daexplr`.

3 Select **Base Workspace**.

4 Add an `mpt` signal, for example, by selecting **Add > MPT Signal**.

5 In the right-hand pane display for the added `mpt` signal, examine the **User object type** drop-down list, noting the impact of the changes specified in Example 2: sl_customization.m for mpt Object Type Customizations on page 11-51.

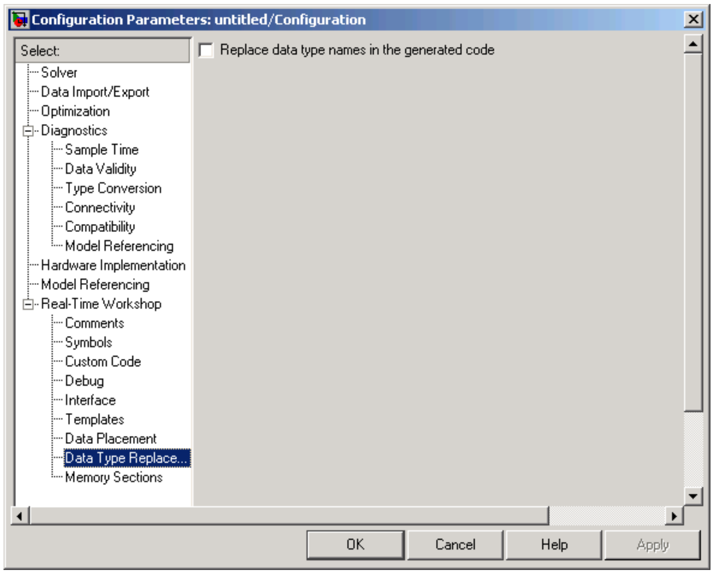
6 From the **User object type** drop-down list, select one of the registered user signal types, for example, `FuelType`, and verify that the displayed settings are consistent with the arguments specified to the `addMPTObjectType` method in `sl_customization.m`.

# Replacing Built-In Data Type Names in Generated Code

**In this section...**

## Replacing Built-In Data Type Names

If your application requires you to replace built-in data type names with user-defined replacement data type names in the generated code, you can do so from the **Real-Time Workshop > Data Type Replacement** pane of the Configuration Parameters dialog box, shown below in the Model Explorer view.



Replace data type names in the generated code [ ]

This pane is available for ERT target based Simulink models. In addition to providing a mechanism for mapping built-in data types to user-defined replacement data types, this feature:

- Performs consistency checks to ensure that your specified data type replacements are consistent with your model's data types.

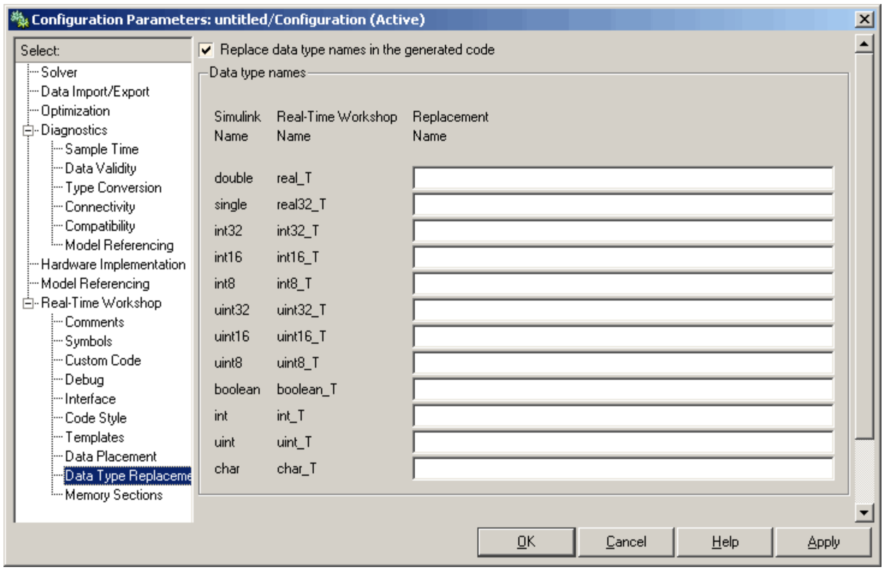
- Allows many-to-one data type replacement, the ability to map multiple built-in data types to one replacement data type in generated code. For example, built-in data types `uint8` and `boolean` could both be replaced in your generated code by a data type `U8` that you have previously defined.

---

**Note** For limitations that apply, see "Data Type Replacement Limitations" on page 11-58.

---

If you select **Replace data type names in the generated code**, the **Data type names** table is displayed:



[✓] Replace data type names in the generated code

Data type names

| Simulink Name | Real-Time Workshop Name | Replacement Name |
|---|---|---|
| double | real_T | |
| single | real32_T | |
| int32 | int32_T | |
| int16 | int16_T | |
| int8 | int8_T | |
| uint32 | uint32_T | |
| uint16 | uint16_T | |
| uint8 | uint8_T | |
| boolean | boolean_T | |
| int | int_T | |
| uint | uint_T | |
| char | char_T | |

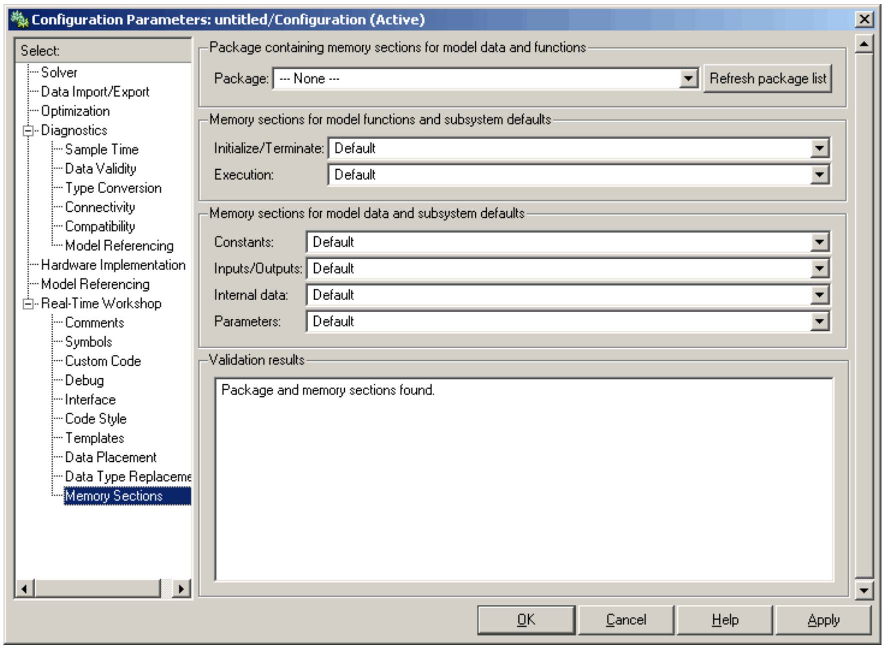
The table **Data type names** lists each Simulink built-in data type name along with its Real-Time Workshop data type name. Selectively fill in fields in the third column with your replacement data types. Each replacement data type should be the name of a `Simulink.AliasType` object that exists in the base workspace. Replacements may be specified or not for each individual built-in type.

For each replacement data type entered, the `BaseType` property of the associated `Simulink.AliasType` object must be consistent with the built-in data type it replaces. For `double`, `single`, `int32`, `int16`, `int8`, `uint32`, `uint16`, `uint8`, and `boolean`, the replacement data type's `BaseType` must match the built-in data type. For `int`, `uint`, and `char`, the replacement data type's size must match the size displayed for `int` or `char` on the **Hardware Implementation** pane of the Configuration Parameters dialog box. An error occurs if a replacement data type specification is inconsistent.

For example, suppose that you have previously defined the following replacement data types, which exist as `Simulink.AliasType` objects in the base workspace:

| User-Defined Name | Description |
|---|---|
| `FLOAT64` | 64-bit floating point |
| `FLOAT32` | 32-bit floating point |
| `S32` | 32-bit integer |
| `S16` | 16-bit integer |
| `S8` | 8-bit integer |
| `U32` | Unsigned 32-bit integer |
| `U16` | Unsigned 16-bit integer |
| `U8` | Unsigned 8-bit integer |
| `CHAR` | Character data |

You can fill in the **Data Type Replacement** pane with a one-to-one replacement mapping, as follows:



Package containing memory sections for model data and functions

Package: --- None ---

Memory sections for model functions and subsystem defaults

Initialize/Terminate: Default

Execution: Default

Memory sections for model data and subsystem defaults

Constants: Default

Inputs/Outputs: Default

Internal data: Default

Parameters: Default

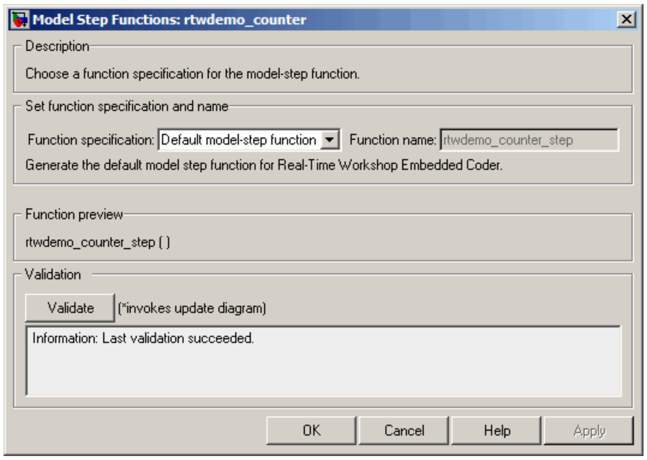
Validation results

Package and memory sections found.

You can also apply a many-to-one data type replacement mapping. For example, in the following display:

- `int32` and `int` are replaced with user type `S32`
- `uint32` and `uint` are replaced with user type `U32`
- `uint8` and `boolean` are replaced with user type `U8`

**Note** Many-to-one data type replacement does not support the `char` (`char_T`) built-in data type. Use `char` only in one-to-one data type replacements.



Description

Choose a function specification for the model-step function.

Set function specification and name

Function specification: Default model-step function Function name: rtwdemo_counter_step

Generate the default model step function for Real-Time Workshop Embedded Coder.

Function preview

rtwdemo_counter_step ( )

Validation

Validate (*invokes update diagram)

Information: Last validation succeeded.

The user-defined replacement types you specify will appear in your model's generated code in place of the corresponding built-in data types. For example, if you specify user-defined data type `FLOAT64` to replace built-in data type `real_T` (`double`), then the original generated code shown in Example 3: Generated Code with real_T Built-In Data Type on page 11-58 will become the modified generated code shown in Example 4: Generated Code with FLOAT64 Replacement Data Type on page 11-58.

#### Example 3: Generated Code with real_T Built-In Data Type

```
...
/* Model initialize function */
void sinwave_initialize(void)
{
...
  {real_T *dwork_ptr = (real_T *) &sinwave_DWork.lastSin;
...
}
...
```

#### Example 4: Generated Code with FLOAT64 Replacement Data Type

```
...
/* Model initialize function */
void sinwave_initialize(void)
{
...
  {FLOAT64 *dwork_ptr = (FLOAT64 *) &sinwave_DWork.lastSin;
...
}
...
```

## Data Type Replacement Limitations

- Data type replacement does not support multiple levels of mapping. Each replacement data type name maps directly to one or more built-in data types.
- Data type replacement is not supported for simulation target code generation for referenced models.
- Data type replacement is not supported if the **GRT compatible call interface** option is selected for your model.
- Data type replacement occurs during code generation for all `.c`, `.cpp`, and `.h` files generated in build directories (including top and referenced model build directories) and in the `_sharedutils` directory. *Exceptions* are as follows:

  ```
  rtwtypes.h
  ```

`model_sf.c` or `.cpp` (ERT S-function wrapper)
`model_dt.h` (C header file supporting external mode)
`model_capi.c` or `.cpp`
`model_capi.h`

- Data type replacement is not supported for complex data types.
- Many-to-one data type replacement is not supported for the `char` built-in data type. Attempting to use `char` as part of a many-to-one mapping to a user-defined data type introduces a violation of the MISRA C® specification. Specifically, if `char` (`char_T`) and either `int8` (`int8_T`) or `uint8` (`uint8_T`) are mapped to the same user replacement type, the result is a MISRA C violation. Additionally, if you try to generate C++ code, invalid implicit type casts are made and compile-time errors may result. Use `char` only in one-to-one data type replacements.

## Customizing Data Object Wizard User Packages

**In this section...**

### Introduction

Data Object Wizard (DOW) can be run in connection with a Simulink model to quickly determine which model data are not associated with data objects and to create and associate data objects with the data. (For more information about Data Object Wizard, see "Data Object Wizard" in the Simulink documentation and "Creating Simulink Data Objects with Data Object Wizard" on page 11-5.) If you want the wizard to use data object classes from a package other than the standard Simulink class package to create the data objects, you select the package from the wizard's **Choose package for selected data objects** list. This package list can be customized in various ways, including adding or removing packages and modifying the list order.

To register Data Object Wizard user package customizations, use the Simulink customization file `sl_customization.m`. This file is a mechanism that allows you to use M-code to perform customizations of the standard Simulink user interface. The Simulink software reads the `sl_customization.m` file, if present on the MATLAB path, when it starts and the customizations specified in the file are applied to the Simulink session. For more information on the `sl_customization.m` customization file, see "Customizing the Simulink User Interface" in the Simulink documentation.

### Registering Data Object Wizard User Packages Using sl_customization.m

To register Data Object Wizard user package customizations, you create an instance of `sl_customization.m` and include it on the MATLAB path of the Simulink installation that you want to customize. The `sl_customization` function accepts one argument: a handle to a customization manager object. For example,

```
function sl_customization(cm)
```

As a starting point for your customizations, the `sl_customization` function must first get the default (factory) customizations, using the following assignment statement:

```
hObj = cm.slDataObjectCustomizer;
```

You then invoke methods to register your customizations. The customization manager object includes the following methods for registering DOW user package customizations:

- `addUserPackage(hObj, packageName)`

  `addUserPackage(hObj, cellArrayOfStrings)`

  Adds the specified user package(s) to the top of the package list, as displayed in the **Choose package for selected data objects** pull-down list in Data Object Wizard.
- `moveUserPackageToTop(hObj, packageName)`

  Moves the specified user package to the top of the package list, as displayed in the **Choose package for selected data objects** pull-down list in Data Object Wizard.
- `moveUserPackageToEnd(hObj, packageName)`

  Moves the specified user package to the end of the package list, as displayed in the **Choose package for selected data objects** pull-down list in Data Object Wizard.
- `removeUserPackage(hObj, packageName)`

  Removes the specified user package from the package list.
- `setUserPackages(hObj, cellArrayOfStrings)`

  Replaces the entire package list with a specified list of user packages.

Your instance of the `sl_customization` function should use these methods to register DOW user package customizations for your Simulink installation.

The Simulink software reads the `sl_customization.m` file when it starts. If you subsequently change the file, you must restart your Simulink session or enter the following command at the MATLAB command line to effect the changes:

```
sl_refresh_customizations
```

## Example Data Object Wizard User Package Customization Using sl_customization.m

The `sl_customization.m` file shown in Example 5: sl_customization.m for DOW User Package Customizations on page 11-62 uses the following methods:

- `addUserPackage` to add the user packages `ECoderDemos` and `SimulinkDemos` (present by default in the MATLAB path) to the top of the package list, as displayed in the **Choose package for selected data objects** pull-down list in Data Object Wizard
- `moveUserPackageToEnd` to move `SimulinkDemos` to the end of the package list

### Example 5: sl_customization.m for DOW User Package Customizations

```
function sl_customization(cm)
% Register user customizations

% Get default (factory) customizations
hObj = cm.slDataObjectCustomizer;

% Add user packages
hObj.addUserPackage({'ECoderDemos', 'SimulinkDemos'});

% Move SimulinkDemos to end of list
hObj.moveUserPackageToEnd('SimulinkDemos');

end
```

If you include the above file on the MATLAB path of the Simulink installation that you want to customize, the specified customizations will appear in Data Object Wizard. For example, you could view the customizations as follows:

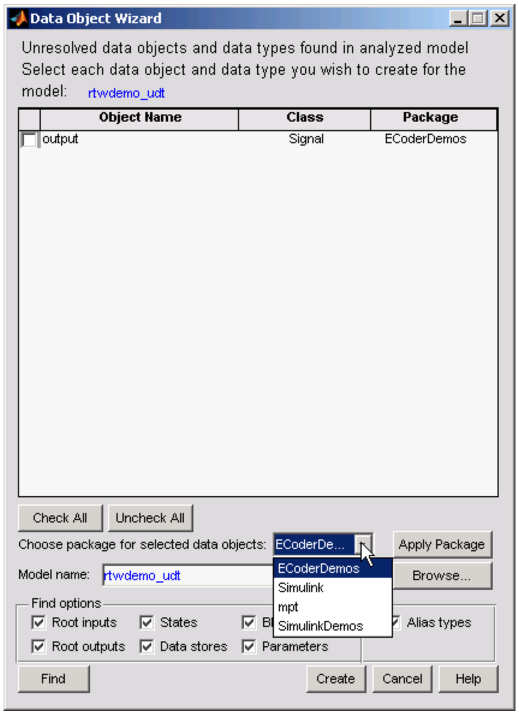
**1** Start a MATLAB session.

**2** Launch a model, such as `rtwdemo_udt`.

**3** Open Data Object Wizard, for example, by selecting **Tools > Data Object Wizard** in the Simulink window.

**4** In the Data Object Wizard dialog box, click the **Find** button to generate a list of one or more data objects.

**5** Examine the **Choose package for selected data objects** drop-down list, noting the impact of the changes specified in Example 5: sl_customization.m for DOW User Package Customizations on page 11-62.


Data Object Wizard

Unresolved data objects and data types found in analyzed model
Select each data object and data type you wish to create for the model: rtwdemo_udt

|  | Object Name | Class | Package |
|---|---|---|---|
| ☐ | output | Signal | ECoderDemos |

Choose package for selected data objects: ECoderDe...

Model name: rtwdemo_udt

Find options: ☑ Root inputs ☑ States ☑ Bl ☑ Alias types ☑ Root outputs ☑ Data stores ☑ Parameters

To replace the entire Data Object Wizard package list with a specified list of user packages, you can use a method invocation similar to the following:

```
hObj.setUserPackages({'myPackage1', 'ECoderDemos', 'mpt'});
```

# Managing Placement of Data Definitions and Declarations

## Overview of Data Placement

This chapter focuses on module packaging features (MPF) settings that are interdependent. Their combined values, along with Simulink partitioning, determine the file placement of data definitions and declarations, or *data placement*. This includes

- The number of files generated.
- Whether or not the generated files contain definitions for a model's global identifiers. And, if a definition exists, the settings determine the files in which MPF places them.
- Where MPF places global data declarations (`extern`).

The following six MPF settings are distributed among the main procedures and form an important interdependency:

- The **Data definition** field on the **Data Placement** pane of the Configuration Parameters dialog box.
- The **Data declaration** field on the **Data Placement** pane of the Configuration Parameters dialog box.
- The **Owner** field of the data object in the Model Explorer, and the **Module naming** and **Module name** fields on the **Data Placement** pane of the Configuration Parameters dialog box. The term "ownership settings" refers to **Owner**, **Module naming**, and **Module name** together.
- The **Definition file** field of the data object on the Model Explorer.
- The **Header file** field of the data object on the Model Explorer.
- The **Memory section** field of the data object on the Model Explorer.

# Priority and Usage

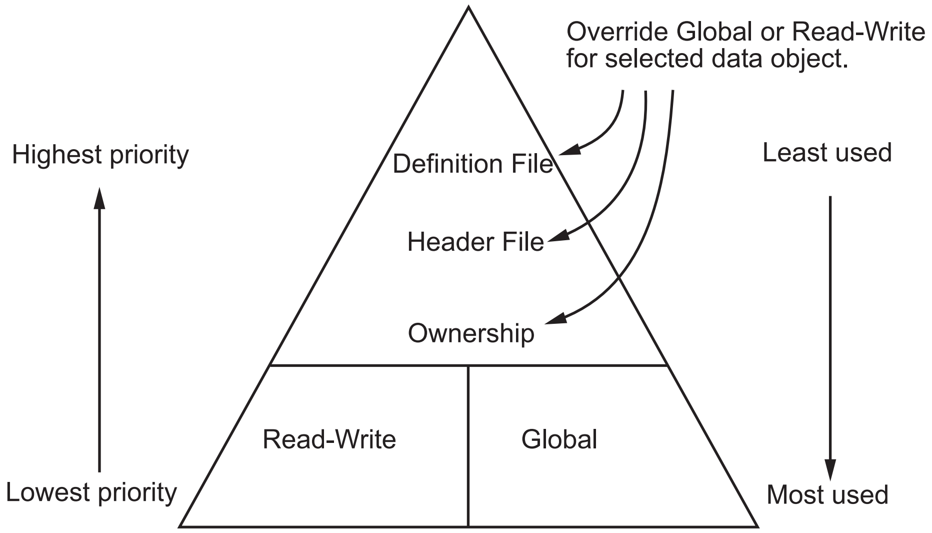
**In this section...**

## Overview

There is a priority order among interdependent MPF settings. From highest to lowest, the priorities are

- Definition File priority
- Header File priority
- Ownership priority
- Read-Write priority or Global priority

Priority order varies inversely with frequency of use, as illustrated below. For example, Definition File is highest priority but least used.



**MPF Settings Priority and Usage**

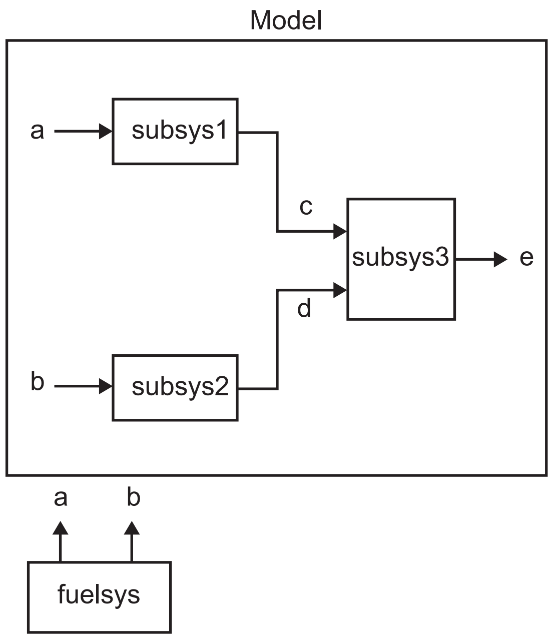
Unless they are overridden, the Read-Write and Global priorities place in the generated files *all* of the model's MPF-derived data objects that you selected using Data Object Wizard. (See "Creating Simulink Data Objects with Data Object Wizard" on page 11-5 for details.) Before generating the files, you can use the higher priority Definition file, Header file, and Ownership, as desired, to override Read-Write or Global priorities for single data objects. Most users will employ Read-Write or Global, without an override. A few users, however, will want to do an override for certain data objects. We expect that those users whose applications include multiple modules will want to use the Ownership priority.

The priorities are in effect only for those data objects that are derived from `Simulink.Signal` and `Simulink.Parameter`, and whose custom storage classes are specified using the Custom Storage Class Designer. (For details, see "Designing Custom Storage Classes and Memory Sections" on page 7-12 in the Real-Time Workshop Embedded Coder documentation.) Otherwise, the Real-Time Workshop build process determines the data placement.

## Read-Write Priority

This is the lowest priority. Consider that a model consists of one or more Simulink blocks or Stateflow diagrams. There can be subsystems within these. For the purpose of illustration, think of a model with one top-level block called `fuelsys`. You double-clicked the block and now see three subsystems labeled `subsys1`, `subsys2` and `subsys3`, as shown in the next figure. Signals `a` and `b` are outputs from the top-level block (`fuelsys`). Signal `a` is an input to `subsys1` and `b` is input to `subsys2`. Signal `c` is an output from `subsys1`. Notice the other inputs and outputs (`d` and `e`). Signals `a` through `e` have corresponding data objects and are part of the code generation data dictionary.

As explained in Chapter 11, "Managing Data Definitions and Declarations With the Data Dictionary", MPF provides you with the means of selecting a data object that you want defined as an identifier in the generated code. MPF also allows you to specify property values for each data object. For this illustration, we choose to include all of the data objects to be in the dictionary.

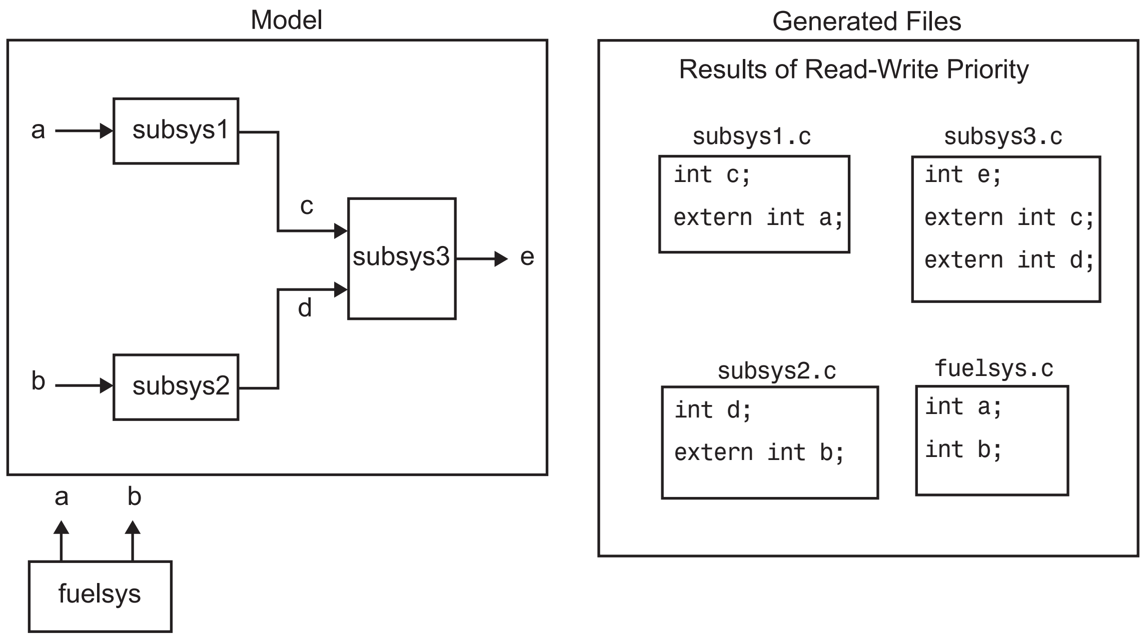


## The Generated Files

We generate code for this model. As shown in the figure below, this results in a `.c` source file corresponding to each of the subsystems. (In actual applications, there could be more than one `.c` source file for a subsystem. This is based on the file partitioning previously selected for the model. But for our illustration, we only need to show one for each subsystem.) Data objects `a` through `e` have corresponding identifiers in the generated files.

A `.c` source file has one or more functions in it, depending on the internal operations (functions) of its corresponding subsystem. An identifier in a generated `.c` file has local scope when it is used only in one function of that `.c` file. An identifier has file scope when more than one function in the same `.c` file uses it. An identifier has global scope when more than one of the generated files uses it.

A subsystem's source file always contains the definitions for all of that subsystem's data objects that have local scope or file scope. (These definitions are not shown in the figure.) But where are the definitions and declarations for data objects of global scope? These are shown in the next figure.



```
subsys1.c
int c;
extern int a;
```

```
subsys3.c
int e;
extern int c;
extern int d;
```

```
subsys2.c
int d;
extern int b;
```

```
fuelsys.c
int a;
int b;
```

When the Read-Write priority is in effect, this source file contains the definitions for the subsystem's global data objects, if this is the file that first writes to the data object's address. Other files that read (use) that data object only include a reference to it. This is why this priority is called Read-Write. Since a read and a write of a file are analogous to input and output of a model's block, respectively, there is another way of saying this. The definitions of a block's global data objects are located in the corresponding generated file, if that data object is an output from that block. The declarations (`extern`) of a block's global data objects are located in the corresponding generated file, if that data object is an input to that block.

### Settings for Read-Write Priority

The generated files and what they include, as just described, occur when the Read-Write priority is in effect. For this to be the case, the other priorities are turned off. That is,

- The **Data definition** field on the **Data Placement** pane is set to `Data defined in source file`.
- The **Data declaration** field on the **Data Placement** pane is set to `Data declared in source file`.
- The **Owner** field on the Model Explorer is blank, and the **Module naming** field on the **Data Placement** pane is set to `Not specified`. (When `Not specified` is selected, the **Module name** field does not appear.)
- **Definition file** and **Header file** on the Model Explorer are blank.

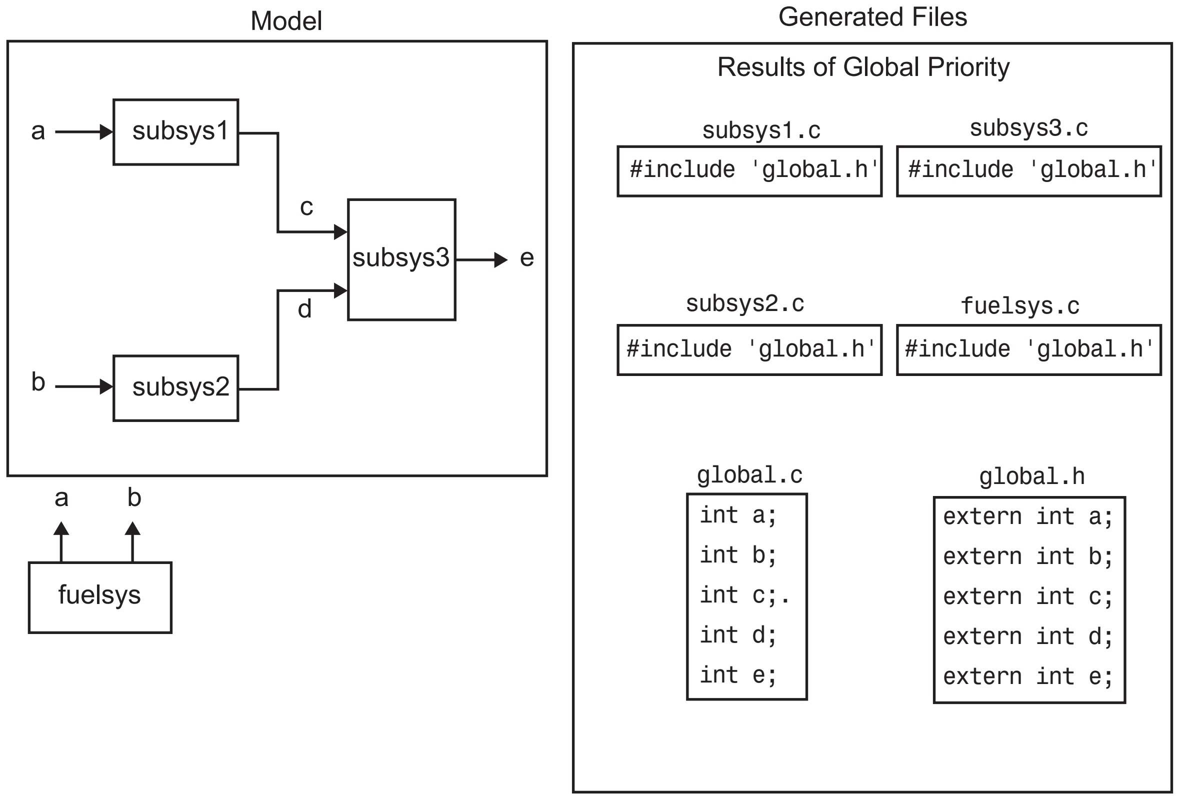
## Global Priority

This has the same priority as Read-Write (the lowest) priority. The settings for this are the same as for Read-Write Priority, except

- The **Data definition** field on the **Data Placement** pane is set to `Data defined in single separate source file.`
- The **Data declaration** field on the **Data Placement** pane is set to `Data declared in single separate header file.`

The generated files that result are shown in the next figure. A subsystem's data objects of local or file scope are defined in the `.c` source file where the subsystem's functions are located (not shown). The data objects of global scope are defined in another .c file (called global.c in the figure). The declarations for the subsystem's data objects of global scope are placed in a .h file (called global.h).

For example, all data objects of local and file scope for subsys1 are defined in subsys1.c. Signal c in the model is an output of subsys1 and an input to subsys2. So c is used by more than one subsystem and thus is a global data object. Since global priority is in effect, the definition for c (int c;) is in global.c. The declaration for c (extern int c;) is in global.h. Since subsys2 uses (reads) c, #include "global.h" is in subsys2.c.



## Definition File, Header File, and Ownership Priorities

While the Read-Write and Global priorities operate on *all* MPF-derived data objects that you want defined in the generated code, the remaining priorities allow you to override the Read-Write or Global priorities for one or more particular data objects. There is a high-to-low priority among these remaining priorities — Definition File, Header File, and Ownership — for a particular data object, as shown in MPF Settings Priority and Usage on page 12-4

## Ownership Settings

*Ownership settings* refers to the values specified for the **Module naming** and **Module names** fields on the **Data Placement** pane of the Configuration Parameters dialog box, and the **Owner** field of a data object in the Model Explorer. These settings have no effect on what files are generated. Their effects only have to do with definitions and `extern` statements. There are five possible configurations, as shown in "Effects of Ownership Settings" on page 12-22.

## Memory Section Settings

Memory sections allow you to specify storage directives for a data object. As shown in Parameter and Signal Property Values on page 6-2, the possible values for the **Memory section** property of a parameter or signal object are `Default`, `MemConst`, `MemVolatile` or `MemConstVolatile`.

If you specify a filename for **Definition file**, and select `Default`, `MemConst`, `MemVolatile` or `MemConstVolatile` for the **Memory section** property, the Real-Time Workshop Embedded Coder software generates a `.c` file and an `.h` file. The `.c` file contains the definition for the data object with the `pragma` statement or qualifier associated with the **Memory section** selection. The `.h` file contains the declaration for the data object. The `.h` file can be included, using the preprocessor directive `#include`, in any file that needs to reference the data object.

You can add more memory sections. For more information, see "Designing Custom Storage Classes and Memory Sections" on page 7-12 and Chapter 8, "Inserting Comments and Pragmas in Generated Code".

## Data Placement Rules

For a complete set of data placement rules in convenient tabular form, based on the priorities discussed in this chapter, see “Data Placement Rules and Effects” on page 12-22.

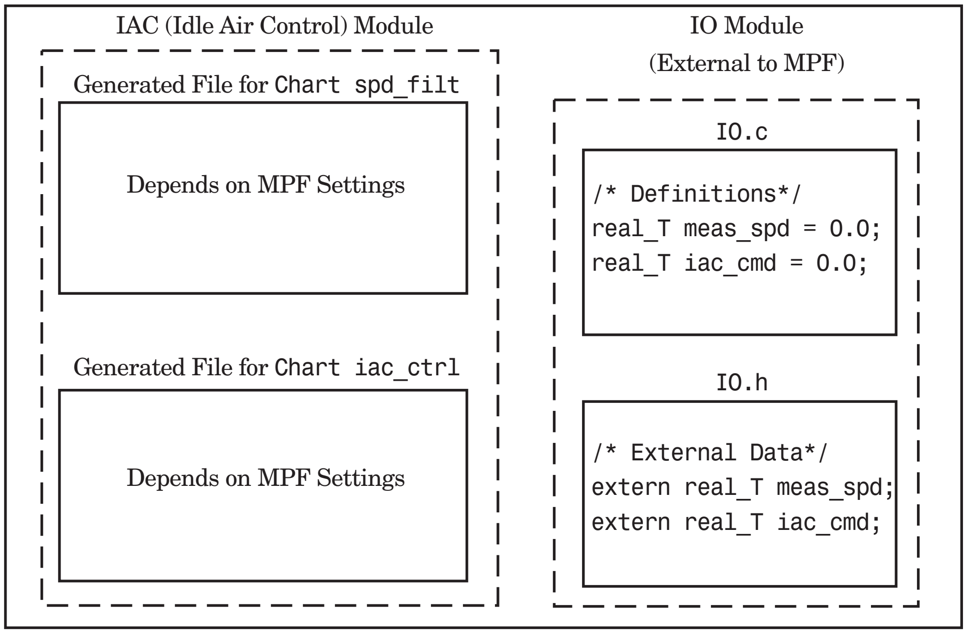
## Example Settings

**In this section...**

### Introduction

"Example Settings and Resulting Generated Files" on page 12-23 provides example settings for one data object of a model. Eight examples are listed so that you can see the generated files that result from a wide variety of settings. Four examples from this table are discussed below in more detail. These discussions provide adequate information for understanding the effects of any settings you might choose. For illustration purposes, the four examples assume that we are dealing with an overall system that controls engine idle speed.

The next figure shows that the software component of this example system consists of two modules, IAC (Idle Air Control), and IO (Input-Output).


IAC (Idle Air Control) Module
Generated File for Chart spd_filt
Depends on MPF Settings
Generated File for Chart iac_ctrl
Depends on MPF Settings
IO Module
(External to MPF)
IO.c
IO.h

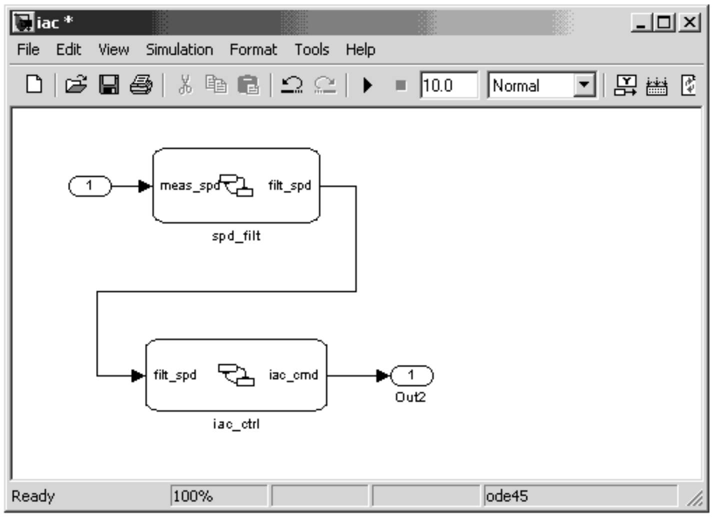
```
/* Definitions*/
real_T meas_spd = 0.0;
real_T iac_cmd = 0.0;
```

```
/* External Data*/
extern real_T meas_spd;
extern real_T iac_cmd;
```

Engine Idle Speed Control System

The code in the IO module controls the system's IO hardware. Code is generated only for the IAC module. (Some other means produced the code for the IO module, such as hand-coding.) So the code in IO is external to MPF, and can illustrate legacy code. To simplify matters, the IO code contains one source file, called IO.c, and one header file, called IO.h.

The IAC module consists of two Stateflow charts, spd_filt and iac_ctrl. The spd_filt chart has two signals (meas_spd) and filt_spd), and one parameter (a). The iac_ctrl chart also has two signals (filt_spd and iac_cmd) and a parameter (ref_spd). (The parameters are not visible in the top-level charts.) One file for each chart is generated. This example system allows us to illustrate referencing from file to file within the MPF module, and model to external module. It also illustrates the case where there is no such referencing.



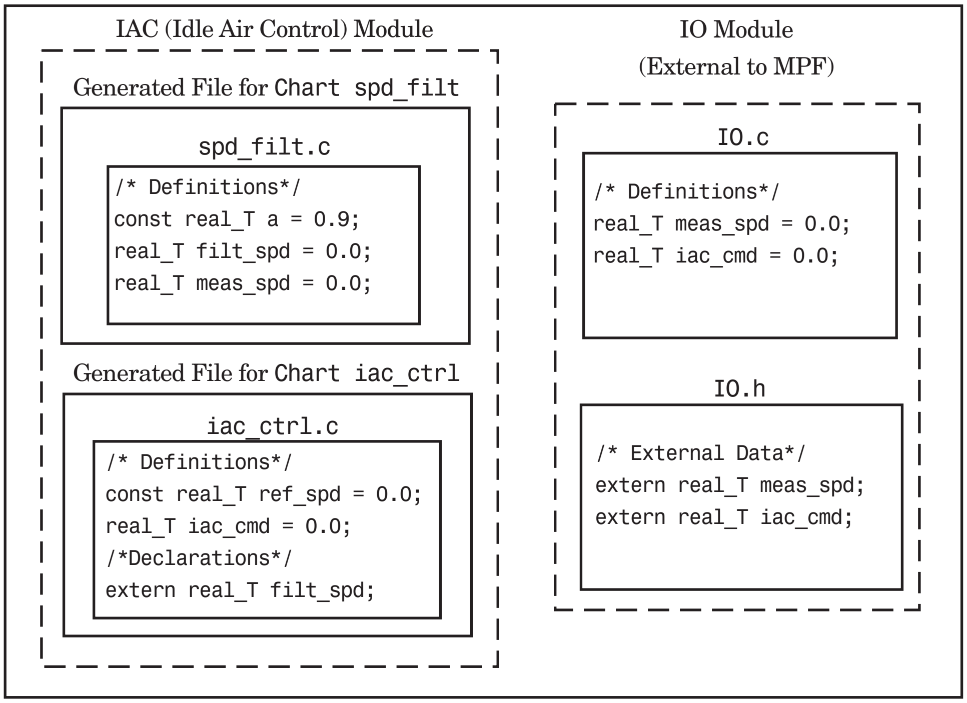
Proceed to the discussion of the desired example settings:

- “Read-Write Example” on page 12-15
- “Ownership Example” on page 12-17
- “Header File Example” on page 12-18
- “Definition File Example” on page 12-20

## Read-Write Example

These settings and the generated files that result are shown as Example Settings 1 in “Example Settings and Resulting Generated Files” on page 12-23. As you can see from the table, this example illustrates the case in which only one `.c` source file (for each chart) is generated.

So, for the IAC model, select the following settings. Accept the `Data defined in source file` in the **Data definition** field and the `Data declared in source file` in the **Data declaration** field on the **Data Placement** pane of the Configuration Parameters dialog box. Accept the default `Not specified` selection in the **Module naming** field. Accept the default blank settings for the **Owner**, **Definition file** and **Header file** fields on the Model Explorer. For **Memory section**, accept `Default`. Now the Read-Write priority is in effect. Generate code. The next figure shows the results in terms of definition and declaration statements.



Engine Idle Speed Control System (Read-Write Example)

The code generator generated a `spd_filt.c` for the `spd_filt` chart and `iac_ctrl.c` for the `iac_ctrl` chart. As you can see, MPF placed all definitions of data objects for the `spd_filt` chart in `spd_filt.c`. It placed all definitions of data objects for the `iac_ctrl` chart in `iac_ctrl.c`.

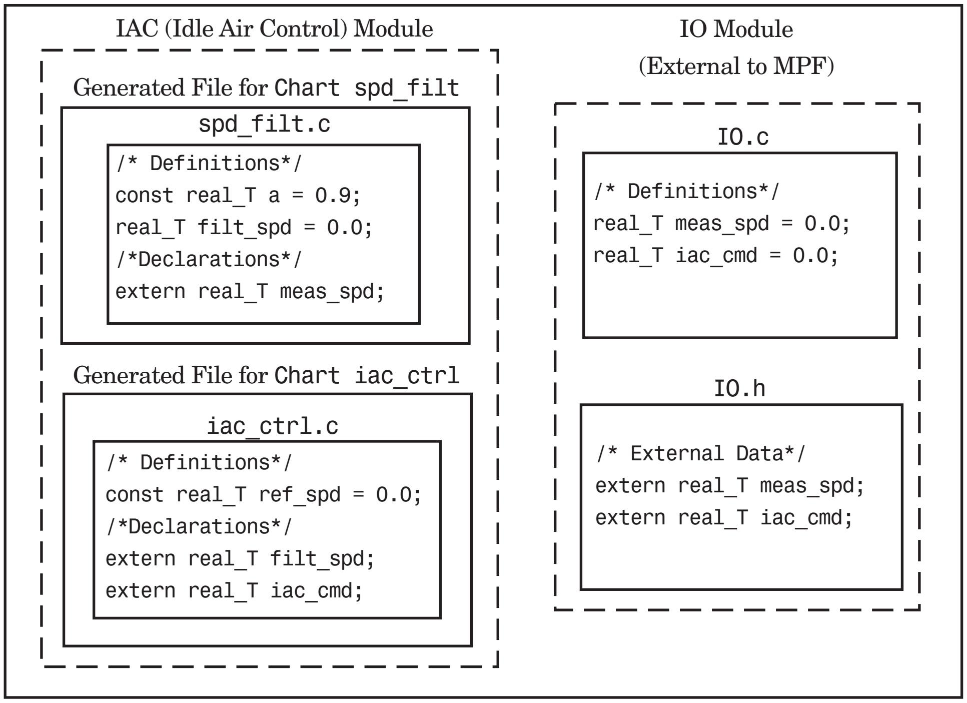
However, notice `real_T filt_spd`. This data object is defined in `spd_filt.c` and declared in `iac_ctrl.c`. That is, since the Read-Write priority is in effect, `filt_spd` is defined in the file that first writes to its address. And, it is declared in the file that reads (uses) it. Further, `real_T meas_spd` is defined in both `spd_filt.c` and the external `IO.c`. And, `real_T iac_cmd` is defined in both `iac_ctrl.c` and `IO.c`.

## Ownership Example

See tables “Effects of Ownership Settings” on page 12-22 and “Example Settings and Resulting Generated Files” on page 12-23. In the “Read-Write Example” on page 12-15, there are several instances where the same data object is defined in more than one `.c` source file, and there is no declaration (`extern`) statement. This would result in compiler errors during link time. But in this example, we configure MPF Ownership rules so that adequate linking can take place. Notice the Example Settings 2 row in “Example Settings and Resulting Generated Files” on page 12-23. Except for the ownership settings, assume these are the settings you made for the model in the IAC module. Since this example has no **Definition file** or **Header file** specified, now Ownership takes priority. (If there *were* a **Definition file** or **Header file** specified, MPF would ignore the ownership settings.)

On the **Data Placement** pane of the Configuration Parameters dialog box, select `User specified` in the **Module naming** field, and specify IAC in the **Module name** field (case sensitive). Open the Model Explorer (by issuing the MATLAB command `daexplr`) and, for all data objects except `meas_spd` and `iac_cmd`, type IAC in the **Owner** field (case sensitive). Then, only for the `meas_spd` and `iac_cmd` data objects, type IO as their **Owner** (case sensitive). Generate code.

The results are shown in the next figure. Notice the `extern real_T meas_spd` statement in `spd_filt.c`, and `extern real_T iac_cmd` in `iac_ctrl.c`. MPF placed these declaration statements in the correct files where these data objects are used. This allows the generated source files (`spd_filt.c` and `iac_ctrl.c`) to be compiled and linked with `IO.c` without errors.


IAC (Idle Air Control) Module
Generated File for Chart spd_filt
spd_filt.c
Generated File for Chart iac_ctrl
iac_ctrl.c
IO Module
(External to MPF)
IO.c
IO.h

```
/* Definitions*/
const real_T a = 0.9;
real_T filt_spd = 0.0;
/*Declarations*/
extern real_T meas_spd;
```

```
/* Definitions*/
const real_T ref_spd = 0.0;
/*Declarations*/
extern real_T filt_spd;
extern real_T iac_cmd;
```

```
/* Definitions*/
real_T meas_spd = 0.0;
real_T iac_cmd = 0.0;
```

```
/* External Data*/
extern real_T meas_spd;
extern real_T iac_cmd;
```

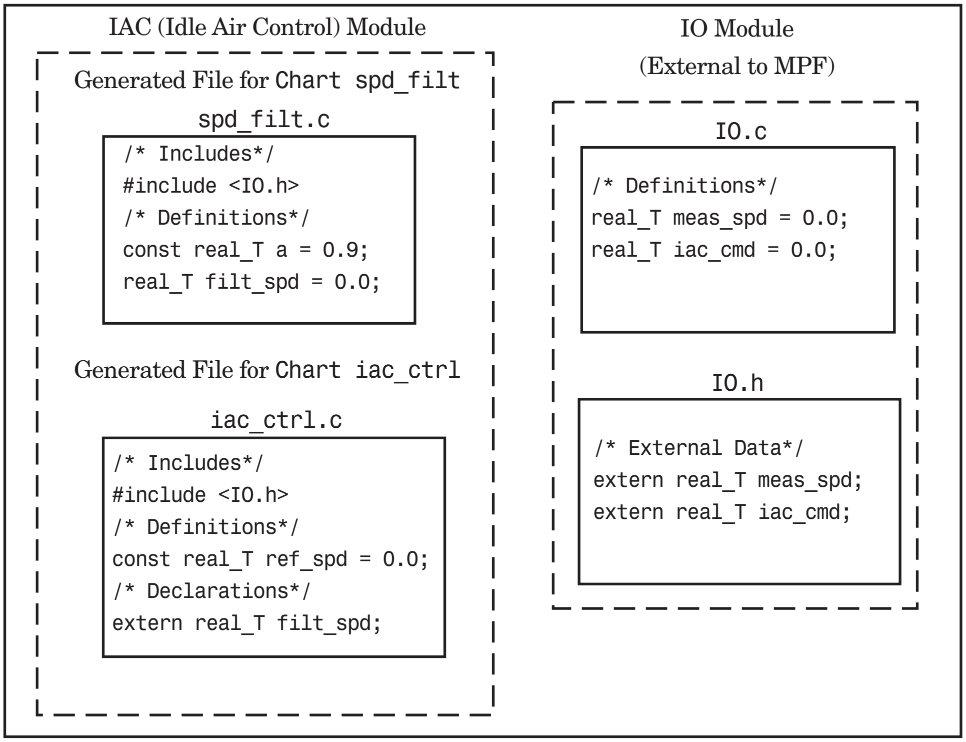
Engine Idle Speed Control System (Ownership Example)

## Header File Example

These settings and the generated files that result are shown as Example Settings 3 in “Example Settings and Resulting Generated Files” on page 12-23. Since this example has no **Definition file** specified, it allows us to describe the effects of the **Header file** setting. (If there *were* a **Definition file**, MPF would ignore the **Header file** setting.) The focus of this example is to show how the **Header file** settings result in the linking of the two chart source files to the external IO files, shown in the next figure. (Also, ownership settings will be used to link the two chart files with each other.)

As you can see in the figure, the `meas_spd` and `iac_cmd` identifiers are defined in `IO.c` and declared in `IO.h`. Both of these identifiers are external to the generated `.c` files. You open the Model Explorer and select both the `meas_spd` and `iac_cmd` data objects. For each of these data objects, in the **Header file** field, specify `IO.h`, since this is where these two objects are declared. This setting ensures that the `spd_filt.c` source file will compile and link with the external `IO.c` file without errors.

Now we configure the ownership settings. In the Model Explorer, select the `filt_spd` data object and set its **Owner** field to `IAC`. Then, on the **Data Placement** pane of the Configuration Parameters dialog box, select `User specified` in the **Module naming** field, and specify IAC in the **Module Name** field. This ensures that the `spd_filt` source file will link to the `iac_ctrl` source file. Generate code. See the figure below.


IAC (Idle Air Control) Module
Generated File for Chart spd_filt
spd_filt.c
Generated File for Chart iac_ctrl
iac_ctrl.c
IO Module
(External to MPF)
IO.c
IO.h

```
/* Includes*/
#include <IO.h>
/* Definitions*/
const real_T a = 0.9;
real_T filt_spd = 0.0;
```

```
/* Includes*/
#include <IO.h>
/* Definitions*/
const real_T ref_spd = 0.0;
/* Declarations*/
extern real_T filt_spd;
```

```
/* Definitions*/
real_T meas_spd = 0.0;
real_T iac_cmd = 0.0;
```

```
/* External Data*/
extern real_T meas_spd;
extern real_T iac_cmd;
```

Engine Idle Speed Control System (Header File Example)

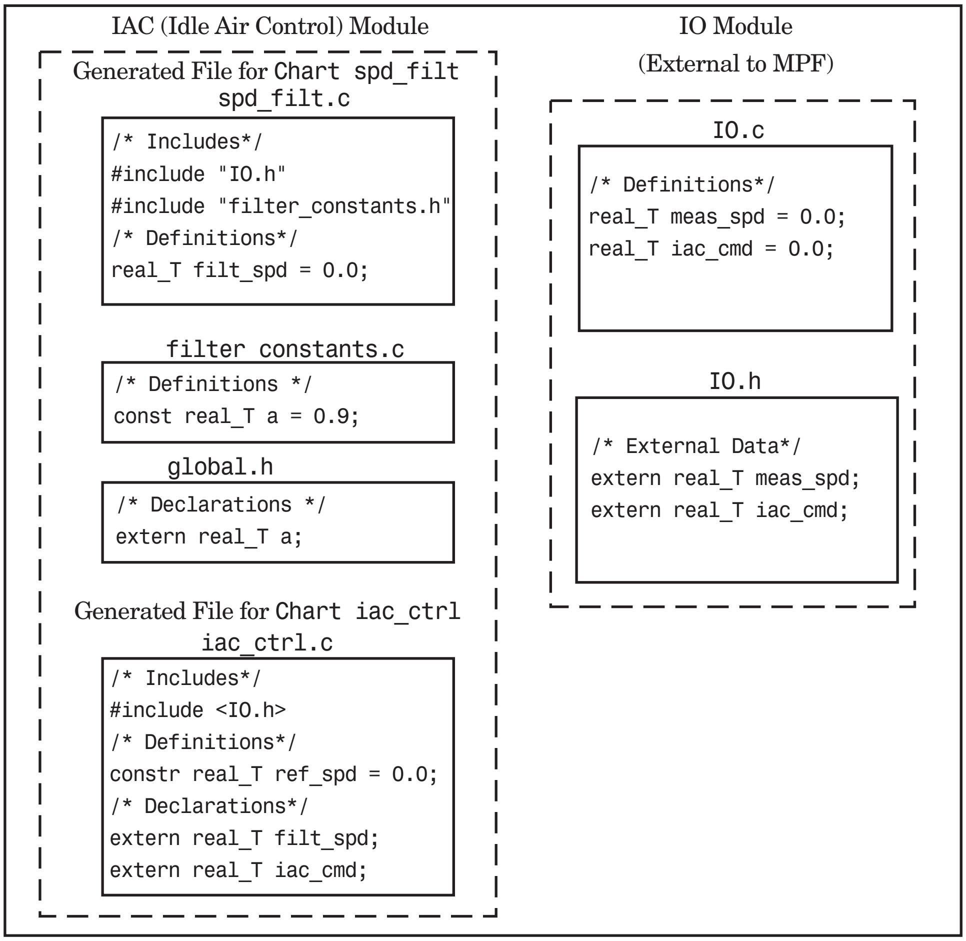
Since you specified the `IO.h` filename for the **Header file** field for the `meas_spd` and `iac_ctrl` objects, the code generator assumed correctly that their declarations are in `IO.h`. So the code generator placed `#include IO.h` in each source file: `spd_filt.c` and `iac_ctrl.c`. So these two files will link with the external IO files. Also, due to the ownership settings that were specified, the code generator places the `real_T filt_spd = 0.0;` definition in `spd_filt.c` and declares the `filt_spd` identifier in `iac_ctrl.c` with `extern real_T iac_cmd;`. Consequently, the two source files will link together.

## Definition File Example

These settings and the generated files that result are shown as Example Settings 4 in "Example Settings and Resulting Generated Files" on page 12-23. Notice that a definition filename is specified. The settings in the table only apply to the data object called `a`. You have decided that you do not want this object defined in `spd_filt.c`, the generated source file for the `spd_filt` chart. (There are many possible organizational reasons one might want an object declared in another file. It is not important for this example to specify the reason.)

For this example, assume the settings for all data objects are the same as those indicated in "Header File Example" on page 12-18, except for the data object `a`. The description below identifies only the differences that result from this.

Open the Model Explorer, and select data object `a`. In the **Definition file** field you specify any desired filename. Choose `filter_constants.c`. Generate code. The results are shown in the next figure.


IAC (Idle Air Control) Module
Generated File for Chart spd_filt
spd_filt.c
filter_constants.c
global.h
Generated File for Chart iac_ctrl
iac_ctrl.c
IO Module
(External to MPF)
IO.c
IO.h

```
/* Includes*/
#include "IO.h"
#include "filter_constants.h"
/* Definitions*/
real_T filt_spd = 0.0;
```

```
/* Definitions */
const real_T a = 0.9;
```

```
/* Declarations */
extern real_T a;
```

```
/* Includes*/
#include <IO.h>
/* Definitions*/
constr real_T ref_spd = 0.0;
/* Declarations*/
extern real_T filt_spd;
extern real_T iac_cmd;
```

```
/* Definitions*/
real_T meas_spd = 0.0;
real_T iac_cmd = 0.0;
```

```
/* External Data*/
extern real_T meas_spd;
extern real_T iac_cmd;
```

Engine Idle Speed Control System (Definition File Example)

The code generator generates the same files as in the “Header File Example” on page 12-18, and adds a new file, `filter_constants.c`. Data object `a` now is defined in `filter_constants.c`, rather than in the source file `spd_filt.c`, as it is in the example. This data object is declared with an `extern` statement in `global.h`

## Data Placement Rules and Effects

**In this section...**

### Effects of Ownership Settings

| Row Number | Module Naming Setting | Owner Setting | Effect* |
|---|---|---|---|
| 1 | `Not specified**` | Blank** | There is a definition for the selected data object. The code generator places this definition in the `.c`/`.cpp` source file that uses it. There is also an `extern` declaration for this data object. The code generator places this `extern` declaration in one or more `.h` header files, as needed. |
| 2 | `Not specified**` | A name is specified. | Same effect as stated above. |
| 3 | Either `Same as model` or `User specified` is selected. | Blank** | Same as Row 1. |
| 4 | Either `Same as model` or `User specified is selected`, and this name is the same as that specified as the **Owner** property. | A name is specified and it is the same as that specified in the **Module naming > Module name** field. | Same as Row 1. |
| 5 | Either `Same as model` or `User specified` is selected, and this name is different than that specified as the **Owner** property. | A name is specified but it is different from that specified in the **Module naming > Module name** field. | There is no definition for the selected data object. However, there is an `extern` declaration for the object. The `extern` declaration is placed in one or more header files, as needed. |

* See also "Ownership Settings" on page 12-10.
** Default.

## Example Settings and Resulting Generated Files

| | **Data Defined In...** | **Data Declared In...** | **Owner-ship*** | **Defined File**** | **Header File** | **Generated Files** |
|---|---|---|---|---|---|---|
| Example Settings 1 (Rd-Write Example) | Source file | Source file | Blank | Blank | Blank | `.c/.cpp` source file |
| Example Settings 2 (Owner- ship Example) | Source file | Source file | Name of module specified | Blank | Blank | `.c/.cpp` source file |
| Example Settings 3 (Header File Example) | Source file | Source file | Blank | Blank | Desired include filename specified. | `.c/.cpp` source file<br>`.h` definition file |
| Example Settings 4 (Def. File Example) | Source file | Source file | Blank | Desired definition filename specified. | Desired include filename specified. | `.c/.cpp` source file<br>`.c/.cpp` definition file*<br>`.h` definition file* |
| Example Settings 5 | Single separate source file | Source file | Blank | Blank | Blank | `.c/.cpp` source file<br>global `.c/.cpp` |
| Example Settings 6 | Single separate source file | Single separate header file | Blank | Blank | Blank | `.c/.cpp` source file<br>`global .c/.cpp`<br>`global.h` |

| | **Data Defined In...** | **Data Declared In...** | **Owner-ship*** | **Defined File**** | **Header File** | **Generated Files** |
|---|---|---|---|---|---|---|
| Example Settings 7 | Single separate source file | Single separate header file | Name of module specified | Blank | Blank | `.c/.cpp` source file `global.c/.cpp` `global.h` |
| Example Settings 8 | Single separate source file | Single separate header file | Blank | Blank | Desired include filename specified. | `.c/.cpp` source file `global.c/.cpp` `global.h` `.h` definition file |

* "Blank" in ownership setting means `Not specified` is selected in the **Module naming** field on the **Data Placement** pane, and the **Owner** field on the Model Explorer is blank. "Name of module specified" can be a variety of ownership settings as defined in "Effects of Ownership Settings" on page 12-22.

** The code generator generates a definition `.c/.cpp` file for every data object for which you specified a definition filename (unless you selected `#DEFINE` for the **Memory section** field). For example, if you specify the same definition filename for all data objects, only one definition `.c/.cpp` file is generated. The code generator places declarations in `*model*.h` by default, unless you specify `Data declared in single separate header file` for the **Data declaration** option on the **Real-Time Workshop > Data Placement** pane of the Configuration Parameter dialog box. If you select that data placement option, the code generator places declarations in `global.h`. If you specify a definition filename for each data object, the code generator generates one definition `.c/.cpp` file for each data object and places declarations in `*model*.h` by default, unless you specify `Data declared in single separate header file` for **Data declaration**. If you select that data placement option, the code generator places declarations in `global.h`.

**Note** If you generate C++ rather than C code, the `.c` files listed in the following table will be `.cpp` files.

## Data Placement Rules

| | Global Settings: | | Override Settings for Specific Data Object: | | | Results in Generated Files: | | |
|---|---|---|---|---|---|---|---|---|
| **Storage Class Setting** | **Data Def.** | **Data Dec.** | **Def. File** | **Owner** | **Header File** | **Where Data Def. Is** | **Where Data Dec. Is** | **Dec. Inclusion** |
| *mpt or Simulink Noncustom Storage Classes:* | | | | | | | | |
| `auto` | N/A | N/A | N/A | N/A | N/A | Note 12 | `model.h` | Note 1 |
| `Exported-Global` | N/A | N/A | N/A | N/A | N/A | `model.c` | `model.h` | Note 1 |
| `Imported--Extern`, `Imported--Extern-Pointer` | N/A | N/A | N/A | N/A | N/A | None. External | `model_-private.h` | Note 2 |
| `Simulink-Global` | N/A | N/A | N/A | N/A | N/A | Note 13 | `model.h` | Note 1 |
| *mpt or Simulink Custom Storage Class: Imported Data*: | | | | | | | | |
| `Imported--FromFile` | D/C | D/C | D/C | N/A | null | None | `model_-private.h` | Note 3 |
| `Imported--FromFile` | D/C | D/C | D/C | N/A | `hdr.h` | None | `model_-private.h` | Note 4 |
| *Simulink Custom Storage Class: #define Data*: | | | | | | | | |
| `Define` | D/C | D/C | N/A | N/A | N/A | N/A | `#define`, `model.h` | Note 5 |
| *mpt Custom Storage Class: #define Data*: | | | | | | | | |
| `Define` | D/C | D/C | N/A | N/A | null | N/A | `#define`, `model.h` | Note 5 |
| `Define` | D/C | D/C | N/A | N/A | `hdr.h` | N/A | `#define`, `model.h` | Note 6 |
| *mpt or Simulink Custom Storage Class: GetSet*: | | | | | | | | |
| `GetSet` | D/C | D/C | N/A | N/A | `hdr.h` | N/A | External `hdr.h` | Note 4 |

| | Global Settings: | | Override Settings for Specific Data Object: | | | Results in Generated Files: | | |
|---|---|---|---|---|---|---|---|---|
| **Storage Class Setting** | **Data Def.** | **Data Dec.** | **Def. File** | **Owner** | **Header File** | **Where Data Def. Is** | **Where Data Dec. Is** | **Dec. Inclusion** |
| *mpt or Simulink Custom Storage Class: Bitfield, Struct*: | | | | | | | | |
| `Bitfield, Struct` | D/C | D/C | N/A | N/A | N/A | `model.c` | `model.h` | Note 7 |
| *mpt Custom Storage Class: Global, Const, ConstVolatile, Volatile*: | | | | | | | | |
| `Global, Const, Const-Volatile, Volatile` | `auto` | `auto` | null | null or locally owned | null | `model.c` | `model.h` | Note 1 |
| `Global, Const, Const-Volatile, Volatile` | `src` | `auto` | null | null or locally owned | null | `src.c` | `model.h` | Note 1 |
| `Global, Const, Const-Volatile, Volatile` | `sep` | `auto` | null | null or locally owned | null | `glb.c` | `model.h` | Note 1 |
| `Global, Const, Const-Volatile, Volatile` | `auto` | `src` | null | null or locally owned | null | `model.c` | `src.c` | Note 8 |
| `Global, Const, Const-Volatile, Volatile` | `src` | `src` | null | null or locally owned | null | `src.c` | `src.c` | Note 8 |
| `Global, Const, Const-Volatile, Volatile` | `sep` | `src` | null | null or locally owned | null | `glb.c` | `src.c` | Note 8 |
| `Global, Const, Const-Volatile, Volatile` | `auto` | `sep` | null | null or locally owned | null | `model.c` | `glb.h` | Note 9 |
| `Global, Const, Const-Volatile, Volatile` | `src` | `sep` | null | null or locally owned | null | `src.c` | `glb.h` | Note 9 |
| `Global, Const, Const-Volatile, Volatile` | `sep` | `sep` | null | null or locally owned | null | `glb.c` | `glb.h` | Note 9 |
| `Global, Const, Const-Volatile, Volatile` | D/C | D/C | data.c | D/C | null | `data.c` | See Note 10. | Note 10 |

| | Global Settings: | | Override Settings for Specific Data Object: | | | Results in Generated Files: | | |
|---|---|---|---|---|---|---|---|---|
| Storage Class Setting | Data Def. | Data Dec. | Def. File | Owner | Header File | Where Data Def. Is | Where Data Dec. Is | Dec. Inclusion |
| Global, Const, Const-Volatile, Volatile | D/C | D/C | data.c | D/C | hdr.h | data.c | hdr.h | Note 11 |
| Global, Const, Const-Volatile, Volatile | auto | D/C | null | null | hdr.h | model.c | hdr.h | Note 11 |
| Global, Const, Const-Volatile, Volatile | src | D/C | null | null | hdr.h | src.c | hdr.h | Note 11 |
| Global, Const, Const-Volatile, Volatile | sep | D/C | null | null | hdr.h | glb.c | hdr.h | Note 11 |
| Global, Const, Const-Volatile, Volatile | D/C | auto | null | External owner | null | External user--supplied file | model.h | Note 1 |
| Global, Const, Const-Volatile, Volatile | D/C | src | null | External owner | null | External user--supplied file | src.c | Note 8 |
| Global, Const, Const-Volatile, Volatile | D/C | sep | null | External owner | null | External user--supplied file | glb.h | Note 9 |
| Global, Const, Const-Volatile, Volatile | D/C | D/C | null | External owner | header.h | External user--supplied file | hdr.h | Note 11 |
| Global, Const, Const-Volatile, Volatile | D/C | D/C | null | External owner | header.h | External user--supplied file | hdr.h | Note 11 |
| *mpt Custom Storage Class: Exported Data*: | | | | | | | | |

| | Global Settings: | | Override Settings for Specific Data Object: | | | Results in Generated Files: | | |
|---|---|---|---|---|---|---|---|---|
| **Storage Class Setting** | **Data Def.** | **Data Dec.** | **Def. File** | **Owner** | **Header File** | **Where Data Def. Is** | **Where Data Dec. Is** | **Dec. Inclusion** |
| `ExportTo-File` | `auto` | `auto` | null | null | null | `model.c` | `model.h` | Note 1 |
| `ExportTo-File` | `src` | `auto` | null | null | null | `src.c` | `model.h` | Note 1 |
| `ExportTo-File` | `sep` | `auto` | null | null | null | `glb.c` | `model.h` | Note 1 |
| `ExportTo-File` | `auto` | `src` | null | null | null | `model.c` | `src.c` | Note 8 |
| `ExportTo-File` | `src` | `src` | null | null | null | `src.c` | `src.c` | Note 8 |
| `ExportTo-File` | `sep` | `src` | null | null | null | `glb.c` | `src.c` | Note 8 |
| `ExportTo-File` | `auto` | `sep` | null | null | null | `model.c` | `glb.h` | Note 9 |
| `ExportTo-File` | `src` | `sep` | null | null | null | `src.c` | `glb.h` | Note 9 |
| `ExportTo-File` | `sep` | `sep` | null | null | null | `glb.c` | `glb.h` | Note 9 |
| `ExportTo-File` | D/C | D/C | `data.c` | null | null | `data.c` | See Note 10. | Note 10 |
| `ExportTo-File` | D/C | D/C | `data.c` | null | `hdr.h` | `model.c` | `hdr.h` | Note 11 |
| `ExportTo-File` | `auto` | D/C | null | null | `hdr.h` | `src.c` | `hdr.h` | Note 11 |
| `ExportTo-File` | `sep` | D/C | null | null | `hdr.h` | `glb.c` | `hdr.h` | Note 11 |
| *Simulink Custom Storage Class: Default, Const, ConstVolatile, Volatile*: | | | | | | | | |
| `Default, Const, Const-Volatile, Volatile` | `auto` | `auto` | N/A | N/A | N/A | `model.c` | `model.h` | Note 1 |
| `Default, Const, Const-Volatile, Volatile` | `src` | `auto` | N/A | N/A | N/A | `src.c` | `model.h` | Note 1 |
| `Default, Const, Const-Volatile, Volatile` | `sep` | `auto` | N/A | N/A | N/A | `glb.c` | `model.h` | Note 1 |
| `Default, Const, Const-Volatile, Volatile` | `auto` | `src` | N/A | N/A | N/A | `model.c` | `src.c` | Note 8 |
| `Default, Const, Const-Volatile, Volatile` | `src` | `src` | N/A | N/A | N/A | `src.c` | `src.c` | Note 8 |

| | Global Settings: | | Override Settings for Specific Data Object: | | | Results in Generated Files: | | |
|---|---|---|---|---|---|---|---|---|
| Storage Class Setting | Data Def. | Data Dec. | Def. File | Owner | Header File | Where Data Def. Is | Where Data Dec. Is | Dec. Inclusion |
| `Default`, `Const`, `Const-Volatile`, `Volatile` | `sep` | `src` | N/A | N/A | N/A | `glb.c` | `src.c` | Note 8 |
| `Default`, `Const`, `Const-Volatile`, `Volatile` | `auto` | `sep` | N/A | N/A | N/A | `model.c` | `glb.h` | Note 9 |
| `Default`, `Const`, `Const-Volatile`, `Volatile` | `src` | `sep` | N/A | N/A | N/A | `src.c` | `glb.h` | Note 9 |
| `Default`, `Const`, `Const-Volatile`, `Volatile` | `sep` | `sep` | N/A | N/A | N/A | `glb.c` | `glb.h` | Note 9 |
| *Simulink Custom Storage Class: Exported Data*: | | | | | | | | |
| `ExportTo-File` | `auto` | `auto` | N/A | N/A | null | `model.c` | `model.h` | Note 1 |
| `ExportTo-File` | `src` | `auto` | N/A | N/A | null | `src.c` | `model.h` | Note 1 |
| `ExportTo-File` | `sep` | `auto` | N/A | N/A | null | `glb.c` | `model.h` | Note 1 |
| `ExportTo-File` | `auto` | `src` | N/A | N/A | null | `model.c` | `src.c` | Note 8 |
| `ExportTo-File` | `src` | `src` | N/A | N/A | null | `src.c` | `src.c` | Note 8 |
| `ExportTo-File` | `sep` | `src` | N/A | N/A | null | `glb.c` | `src.c` | Note 8 |
| `ExportTo-File` | `auto` | `sep` | N/A | N/A | null | `model.c` | `glb.h` | Note 9 |
| `ExportTo-File` | `src` | `sep` | N/A | N/A | null | `src.c` | `glb.h` | Note 9 |
| `ExportTo-File` | `sep` | `sep` | N/A | N/A | null | `glb.c` | `glb.h` | Note 9 |
| `ExportTo-File` | `auto` | D/C | N/A | N/A | `hdr.h` | `model.c` | `hdr.h` | Note 11 |
| `ExportTo-File` | `src` | D/C | N/A | N/A | `hdr.h` | `src.c` | `hdr.h` | Note 11 |
| `ExportTo-File` | `sep` | D/C | N/A | N/A | `hdr.h` | `glb.c` | `hdr.h` | Note 11 |

## Notes

In the previous table:

- A Declaration Inclusion Approach is a file in which the header file that contains the data declarations is included.
- D/C stands for don't care.
- Dec stands for declaration.
- Def stands for definition.
- `gbl` stands for global.
- `hdr` stands for header.
- N/A stands for not applicable.
- null stands for field is blank.
- `sep` stands for separate.

**Note 1:** `model.h` is included directly in all source files.

**Note 2:** `model_private.h` is included directly in all source files.

**Note 3:** `extern` is included in `model_private.h`, which is in `source.c`.

**Note 4:** `header.h` is included in `model_private.h`, which is in `source.c`.

**Note 5:** `model.h` is included directly in all source files that use `#define`.

**Note 6:** `header.h` is included in `model.h`, which is in source files that use `#define`.

**Note 7:** `model.h` is included in all `source.c` files.

**Note 8:** `extern` is inlined in source files where data is used.

**Note 9:** `global.h` is included in `model.h`, which is in all source files.

**Note 10:** When you specify a definition filename for a data object, no header file is generated for that data object. The code generator declares the data object according to the data placement priorities.

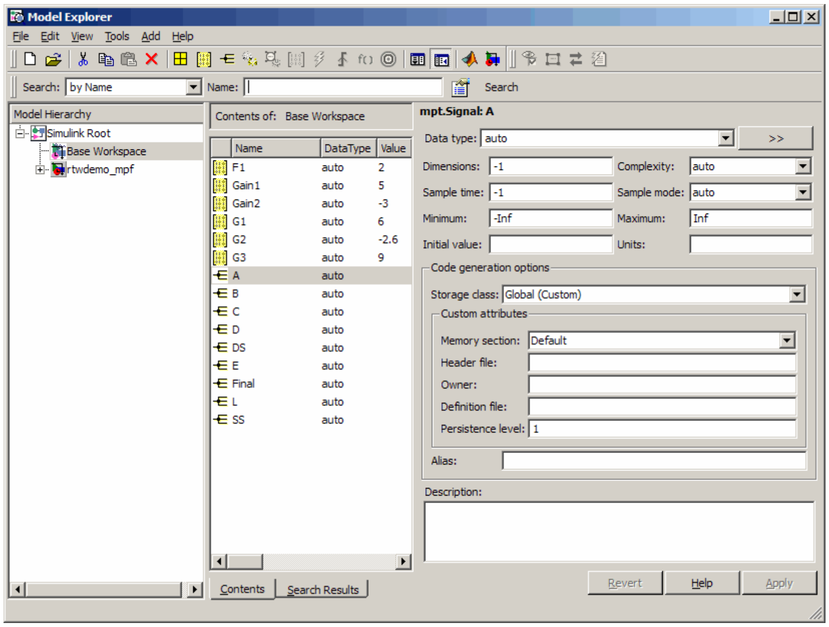
**Note 11:** `header.h` is included in `model.h`, which is in all source files.

**Note 12:** Signal: Either not defined because it is expression folded, or local data, or defined in a structure in `model.c`, all depending on model's code generation settings. Parameter: Either inlined in the code, or defined in `model_data.c`.

**Note 13:** Signal: In a structure that is defined in `model.c`. Parameter: In a structure that is defined in `model_data.c.`

# Specifying the Persistence Level for Signals and Parameters

With this procedure, you can control the persistence level of signal and parameter objects associated with a model. Persistence level allows you to make intermediate variables or parameters global during initial development. At the later stages of development, you can use this procedure to remove these signals and parameters for efficiency. Notice the **Persistence Level** field on the Model Explorer, as illustrated in the figure below. For descriptions of the properties on the Model Explorer, see Parameter and Signal Property Values on page 6-2.



Contents of: Base Workspace

| Name | DataType | Value |
|---|---|---|
| F1 | auto | 2 |
| Gain1 | auto | 5 |
| Gain2 | auto | -3 |
| G1 | auto | 6 |
| G2 | auto | -2.6 |
| G3 | auto | 9 |
| A | auto | |
| B | auto | |
| C | auto | |
| D | auto | |
| DS | auto | |
| E | auto | |
| Final | auto | |
| L | auto | |
| SS | auto | |

mpt.Signal: A

| | | | |
|---|---|---|---|
| Data type: | auto | | |
| Dimensions: | -1 | Complexity: | auto |
| Sample time: | -1 | Sample mode: | auto |
| Minimum: | -Inf | Maximum: | Inf |
| Initial value: | | Units: | |

Code generation options

Storage class: Global (Custom)

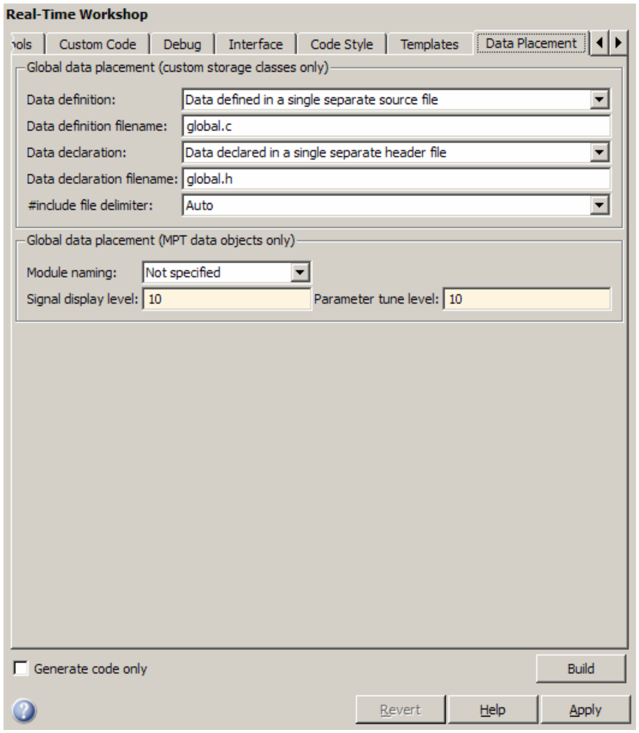
Custom attributes

| | |
|---|---|
| Memory section: | Default |
| Header file: | |
| Owner: | |
| Definition file: | |
| Persistence level: | 1 |

Alias:

Description:

Notice also the **Signal display level** and **Parameter tune level** fields on the **Data Placement** pane of the Configuration Parameters dialog box, as illustrated in the next figure.



Real-Time Workshop

Global data placement (custom storage classes only)

Data definition: Data defined in a single separate source file
Data definition filename: global.c
Data declaration: Data declared in a single separate header file
Data declaration filename: global.h
#include file delimiter: Auto

Global data placement (MPT data objects only)

Module naming: Not specified
Signal display level: 10
Parameter tune level: 10

☐ Generate code only

The **Signal display level** field allows you to specify whether or not the code generator defines a signal data object as global data in the generated code. The number you specify in this field is relative to the number you specify in the **Persistence level** field. The **Signal display level** number is for all `mpt` (module packaging tool) signal data objects in the model. The **Persistence level** number is for a *particular* `mpt` signal data object. If the data object's **Persistence level** is equal to or less than the **Signal display level**, the signal appears in the generated code as global data with all of the properties (custom attributes) specified in "Creating mpt Data Objects with Data Object Wizard" on page 11-12. For example, this would occur if **Persistence level** is `2` and **Signal display level** is `5`.

Otherwise, the code generator automatically determines how the particular signal data object appears in the generated code. Depending on the settings on the **Optimization** pane of the Configuration Parameters dialog box, the signal data object could appear in the code as local data and thus have none of the custom attributes you specified for that data object. Or, based on expression folding, the code generator could remove the data object so that it does not appear in the code. (See “Tips for Optimizing the Generated Code” on page 20-19 in the Real-Time Workshop Embedded Coder documentation and “Optimizing Generated Code” in the Real-Time Workshop documentation for details on optimization.)

The **Parameter tune level** field allows you to specify whether or not the code generator declares a parameter data object as tunable global data in the generated code.

The number you specify in this field is relative to the number you specify in the **Persistence level** field. The **Parameter tune level** number is for all `mpt` parameter data objects in the model. The **Persistence level** number is for a *particular* `mpt` parameter data object. If the data object’s **Persistence level** is equal to or less than the **Parameter tune level**, the parameter appears in the generated code with all of the properties (custom attributes) specified in “Creating mpt Data Objects with Data Object Wizard” on page 11-12, and thus is tunable. For example, this would occur if **Persistence level** is `2` and **Parameter tune level** is `5`.

Otherwise, the parameter is inlined in the generated code, and Real-Time Workshop settings determine its exact form.

Note that, in the initial stages of development, you may be more concerned about debugging than code size. Or, you may want to ensure that one or more particular data objects appear in the code so that you can analyze intermediate calculations of an equation. In this case, you may want to specify the **Parameter tune level** (**Signal display level** for signals) to be higher than **Persistence level** for some or all `mpt` parameter (or signal) data objects. This results in larger code size, because the code generator defines the parameter (or signal) data objects as global data, which have all the custom properties you specified. As you approach production code generation, however, you may have more concern about reducing the size of the code and less need for debugging or intermediate analyses. In this stage of the tradeoff, you could make the **Parameter tune level** (**Signal display level** for signals) greater than **Persistence level** for one or more data objects, generate code and observe the results. Repeat until satisfied.

1. With the model open, in the Configuration Parameters dialog box, click **Data Placement** under **Real-Time Workshop**.

2. Type the desired number in the **Signal display level** or **Parameter tune level** field, and click **Apply**.

3. In the Model Explorer, type the desired number in the **Persistence** field for the selected signal or parameter, and click **Apply**.

4. Save the model and generate code.

# Preparing Models for Code Generation

# Mapping Application Objectives to Model Configuration Parameters

## Considerations When Mapping Application Objectives

The first step in applying Real-Time Workshop Embedded Coder configuration options to the application development process is to consider how your application objectives, particularly with respect to efficiency, traceability, and safety, map to code generation options in a model configuration set.

Parameters that you set in the **Solver**, **Data Import/Export**, **Diagnostics**, and **Real-Time Workshop** panes of the Configuration Parameters dialog box affect the behavior of a model in simulation and the code generated for the model.

Consider questions such as the following:

- What settings might help you debug your application?
- What is the highest objective for your application — efficiency, traceability, extra safety precaution, debugging, or some other criteria?
- What is the second highest objective?
- Can the objective at the start of the project differ from the objective required for the end result? What tradeoffs can you make?

After you answer these questions:

1. Define your objectives in the configuration set. For more information, see "Defining High-Level Code Generation Objectives" on page 14-3.
2. Use the Code Generation Advisor to identify parameter values that are not configured for the objectives that you selected. For more information, see "Determining Whether the Model is Configured for Specified Objectives" on page 14-4.

## Defining High-Level Code Generation Objectives

When you are considering the objectives for your application, there are many different criteria. The Real-Time Workshop software identifies four high-level objectives that you might consider for your application:

- Efficiency — Configure code generation settings to reduce RAM, ROM, and execution time.
- Traceability — Configure code generation settings to provide mapping between model elements and code.
- Safety precaution — Configure code generation settings to increase clarity, determinism, robustness, and verifiability of the code.
- Debugging — Configure code generation settings to debug the code generation build process.

Once you have identified which of these four objectives are important for your application, you can use the Code Generation Advisor to identify the parameters that are not configured for the objectives that you selected. Review “Recommended Settings Summary” to see the settings the Code Generation Advisor recommends.

You can specify and prioritize any combination of the available objectives for the Code Generation Advisor to take into consideration. For more information, see “Determining Whether the Model is Configured for Specified Objectives” on page 14-4.

## Determining Whether the Model is Configured for Specified Objectives

You can use the Code Generation Advisor to review your model and identify the parameters that are not configured for your objective. The Code Generation Advisor reviews a subset of model configuration parameters and displays the results in the **Check model configuration settings against code generation objectives** check.

The Code Generation Advisor uses the information presented in "Mapping of Application Requirements to the Optimization Pane" to determine the recommended values. When there is a conflict due to multiple objectives, the higher-priority objective takes precedence.

---

**Tip** You can use the Code Generation Advisor to review a model before generating code, or as part of the code generation process. When you choose to review a model before generating code, you specify which model, subsystem, or referenced model the Code Generation Advisor reviews (see "Reviewing the Model Without Generating Code" on page 14-7). When you choose to review a model as part of the code generation process, the Code Generation Advisor reviews the entire system (see "Reviewing the Model During Code Generation" on page 14-9).

---

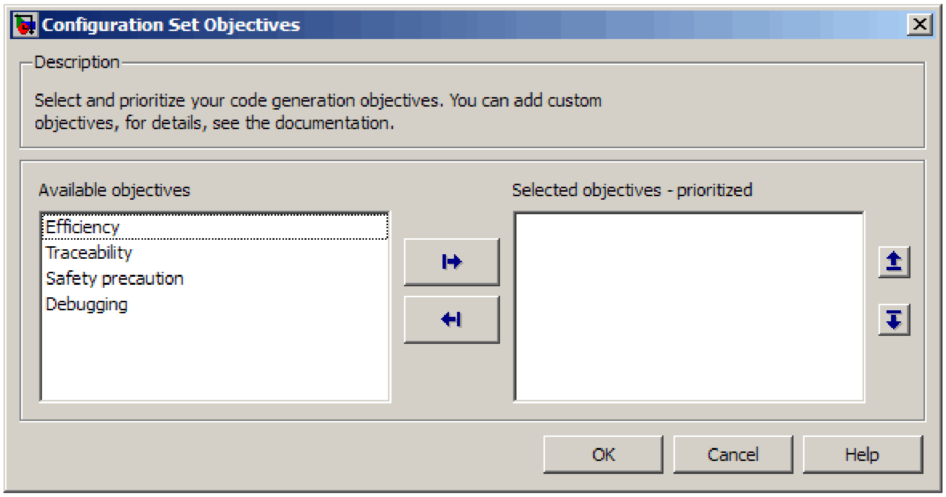
### Specifying Code Generation Objectives Using the GUI

To specify code generation objectives in the Configuration Parameters dialog box:

1. Open the Configuration Parameters dialog box and select the **Real-Time Workshop** pane.

2. Specify a system target file. If you specify an ERT-based target, more objectives are available. For the purposes of this example, choose an ERT-based target such as `ert.tlc`.

**3** Click **Set objectives**. The Configuration Set Objectives dialog box opens.

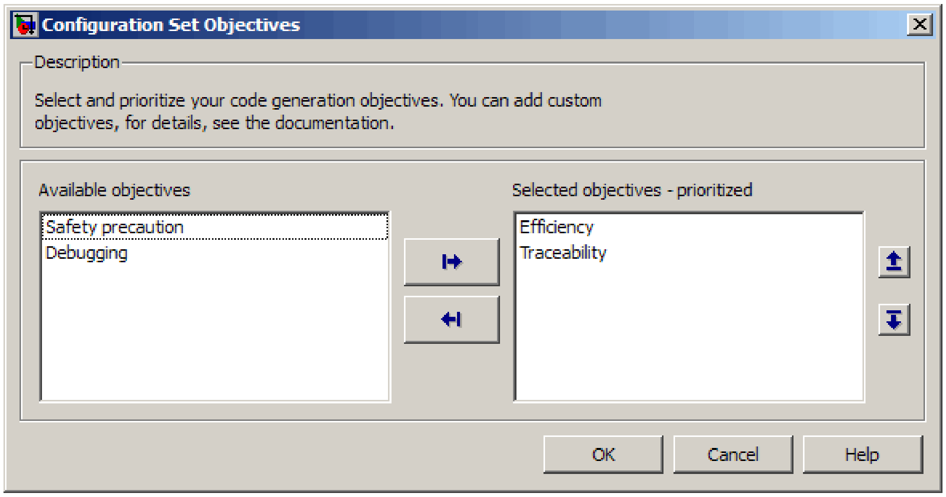


Select and prioritize your code generation objectives. You can add custom objectives, for details, see the documentation.

**4** In the Configuration Set Objectives dialog box, specify your objectives. For example, if your objectives are efficiency and traceability, in that priority, do the following:

**a** In **Available objectives**, double-click `Efficiency`. `Efficiency` is added to **Prioritized objectives**.

**b** In **Available objectives**, double-click `Traceability`. `Traceability` is added to **Prioritized objectives** below `Efficiency`.


Configuration Set Objectives

Description

Select and prioritize your code generation objectives. You can add custom objectives, for details, see the documentation.

Available objectives
- Safety precaution
- Debugging

Selected objectives - prioritized
- Efficiency
- Traceability

**c** Click **OK** to accept the objectives. In the Configuration Parameters dialog box, **Prioritized objectives** is updated.

## Specifying Code Generation Objectives at the Command Line

To specify code generation objectives by scripting an M-file or entering commands at the command line:

**1** Specify a system target file. If you specify an ERT-based target, more objectives are available. For the purposes of this example, specify `ert.tlc`, where *`model_name`* is the name or handle to the model.

```
set_param(model_name, 'SystemTargetFile', 'ert.tlc');
```

**2** Specify your objectives. For example, if your objectives are efficiency and traceability, in that priority, enter:

```
set_param(model_name, 'ObjectivePriorities', {'Efficiency',
'Traceability'});
```

**Caution** When you specify a GRT-based system target file, you can specify any objective at the command line. If you specify `Efficiency`, `Traceability`, or `Safety precaution`, the build process changes the objective to `Unspecified` because you have specified a value that is invalid when using a GRT-based target.

## Reviewing Objectives in Referenced Models

When you review a model during the code generation process, you must specify the same objectives in the top model and referenced models. If you specify different objectives for the top model and referenced model, the build process generates an error.

To specify different objectives for the top model and each referenced model, review the models separately without generating code.

## Reviewing the Model Without Generating Code

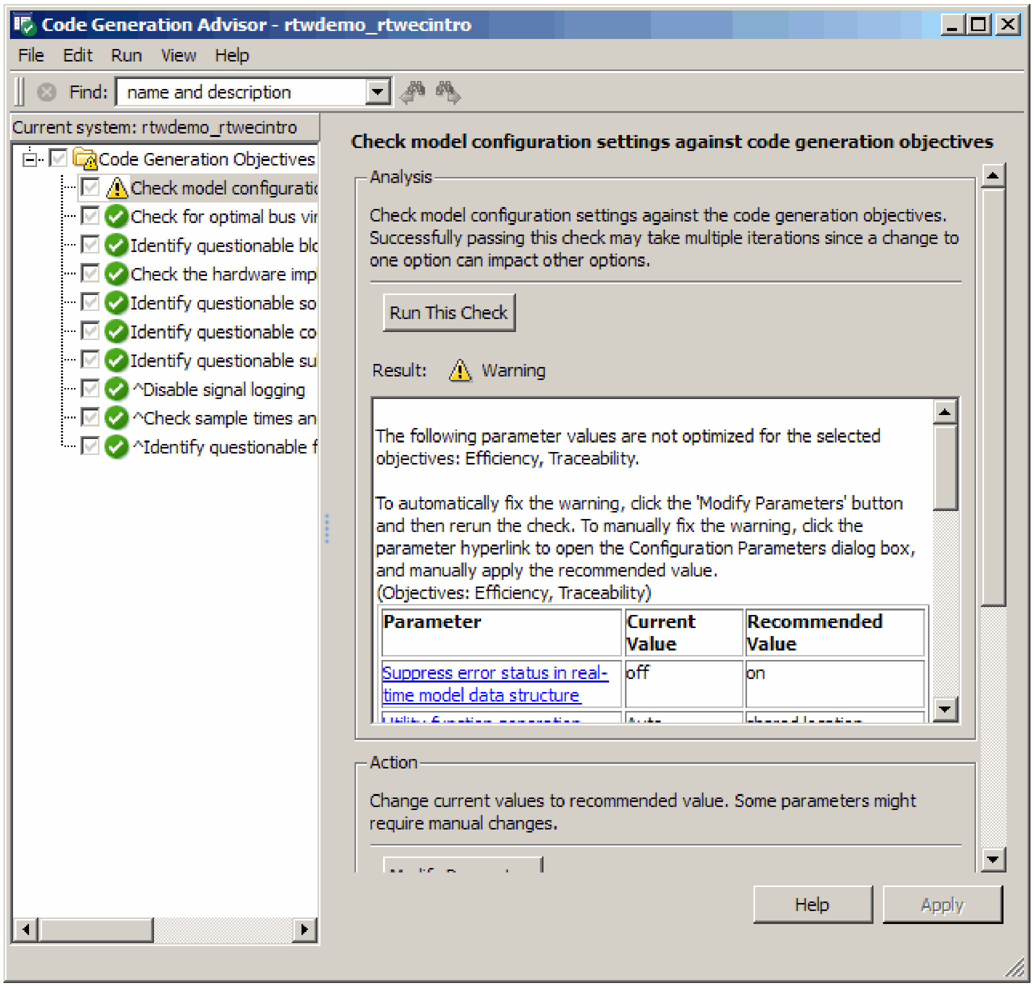
To review a model without generating code using the Code Generation Advisor:

1. Specify your code generation objectives.

2. In the **Configuration Parameters > Real-Time Workshop** pane, click **Check model**. The System Selector window opens.

3. Select the model or subsystem that you want to review and click **OK**. The Code Generation Advisor opens and reviews the model or subsystem that you specified.

**4** In the Code Generation Advisor window, review the results by selecting a check from the left pane. The right pane populates the results for that check.



Code Generation Advisor - rtwdemo_rtwecintro

File Edit Run View Help

Find: name and description

Current system: rtwdemo_rtwecintro

- Code Generation Objectives
  - Check model configurati
  - Check for optimal bus vir
  - Identify questionable blo
  - Check the hardware imp
  - Identify questionable so
  - Identify questionable co
  - Identify questionable su
  - ^Disable signal logging
  - ^Check sample times an
  - ^Identify questionable f

**Check model configuration settings against code generation objectives**

Analysis

Check model configuration settings against the code generation objectives. Successfully passing this check may take multiple iterations since a change to one option can impact other options.

Run This Check

Result: Warning

The following parameter values are not optimized for the selected objectives: Efficiency, Traceability.

To automatically fix the warning, click the 'Modify Parameters' button and then rerun the check. To manually fix the warning, click the parameter hyperlink to open the Configuration Parameters dialog box, and manually apply the recommended value.
(Objectives: Efficiency, Traceability)

| Parameter | Current Value | Recommended Value |
|---|---|---|
| Suppress error status in real-time model data structure | off | on |

Action

Change current values to recommended value. Some parameters might require manual changes.

Help Apply

**5** After reviewing the check results, you can choose to fix warnings and failures, as described in “Fixing a Warning or Failure” in the *Simulink User’s Guide*.

**Caution** When you specify an efficiency or safety precaution objective, the Code Generation Advisor includes additional checks. When you make changes to one of these checks, the other check results are no longer valid and you must run the check again for accurate results.

## Reviewing the Model During Code Generation

To review a model as part of the code generation process using the Code Generation Advisor:

1. Specify your code generation objectives.

2. In the **Configuration Parameters > Real-Time Workshop** pane, select one of the following from **Check model before generating code**:

   - `On (proceed with warnings)`
   - `On (stop for warnings)`

3. Select **Generate code only** if you only want to generate code; otherwise clear the check box to build an executable.

4. Apply your changes and then click **Generate code/Build**. The Code Generation Advisor starts and reviews the top model and subsystems.

   If there are no failures or warnings in the Code Generation Advisor, the build process proceeds. If there are failures or warnings and you specified:

   - `On (proceed with warnings)` — The Code Generation Advisor window opens while the build process proceeds. You can review the results after the build process is complete.
   - `On (stop for warnings)` — The build process halts and displays the diagnostics viewer. To continue, you must review and resolve the Code Generation Advisor results or change the **Check model before generating code** selection.

5. In the Code Generation Advisor window, review the results by selecting a check from the left pane. The right pane populates the results for that check.

6 After reviewing the check results, you can choose to fix warnings and failures as described in “Fixing a Warning or Failure” in the *Simulink User’s Guide*.

---

**Caution** When you specify an efficiency or safety precaution objective, the Code Generation Advisor includes additional checks. When you make changes to one of these checks, the other check results are no longer valid and you must run the check again for accurate results.

---

# Creating Custom Objectives

**In this section...**

The Code Generation Advisor reviews your model based on objectives that you specify. If the predefined efficiency, traceability, safety precaution, and debugging objectives do not meet your requirements, you can create custom objectives.

You can create custom objectives by:

- Creating a new objective and adding parameters and checks to a new objective.
- Creating a new objective based on an existing objective, then adding, modifying and removing the parameters and checks within the new objective.

## Specifying Parameters in Custom Objectives

When you create a custom objective, you specify the values of configuration parameters that the Code Generation Advisor reviews using the following methods:

- `addParam` — Add parameters and specify the values that the Code Generation Advisor reviews in **Check model configuration settings against code generation objectives**. When you add parameters that have dependencies, the software includes the dependencies in the list of parameter values that the Code Generation Advisor reviews.
- `modifyInheritedParam` — Modify inherited parameter values that the Code Generation Advisor reviews in **Check model configuration settings against code generation objectives**.

- `removeInheritedParam` — Remove inherited parameters from a new objective that is based on an existing objective. When a user selects multiple objectives, if another selected objective includes this parameter, the Code Generation Advisor reviews the parameter value in **Check model configuration settings against code generation objectives**.

## Specifying Checks in Custom Objectives

All objectives include the **Check model configuration settings against code generation objectives** check by default. When you create a custom objective, you specify the list of additional checks that are associated with the custom objective using the following methods:

- `addCheck` — Add checks to the Code Generation Advisor. When a user selects the custom objective, the Code Generation Advisor displays the check, unless the user specifies an additional objective with a higher priority that excludes the check.

  For example, you might add a check to the Code Generation Advisor to include a custom check in the automatic model checking process.

- `excludeCheck` — Exclude checks from the Code Generation Advisor. When a user selects multiple objectives, if the user specifies an additional objective that includes this check as a higher priority objective, the Code Generation Advisor displays this check.

  For example, you might exclude a check from the Code Generation Advisor when a check takes a long time to process.

- `removeInheritedCheck` — Remove inherited checks from a new objective that is based on an existing objective. When a user selects multiple objectives, if another selected objective includes this check, the Code Generation Advisor displays the check.

  For example, you might remove an inherited check, rather than exclude the check, when the check takes a long time to process, but the check is important for another objective.

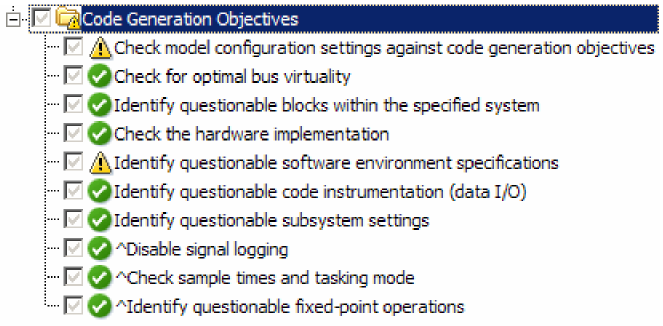
## Determining Checks and Parameters in Existing Objectives

When you base a new objective on an existing objective, you can determine what checks and parameters the existing objective contains. Select the existing objective and check the model. The Code Generation Advisor lists the checks and parameters associated with the existing objective.

The Code Generation Advisor contains the list of checks in each objective. For example, the `Efficiency` objective includes ten checks, which you can see in the Code Generation Advisor if you:

1. Open the `rtwdemo_rtwecintro` model.
2. Specify an ERT-based target.
3. Specify the `Efficiency` objective.
4. Check the model.

The Code Generation Advisor displays in the right pane the list of checks in the `Efficiency` objective.



Code Generation Objectives
- Check model configuration settings against code generation objectives
- Check for optimal bus virtuality
- Identify questionable blocks within the specified system
- Check the hardware implementation
- Identify questionable software environment specifications
- Identify questionable code instrumentation (data I/O)
- Identify questionable subsystem settings
- ^Disable signal logging
- ^Check sample times and tasking mode
- ^Identify questionable fixed-point operations

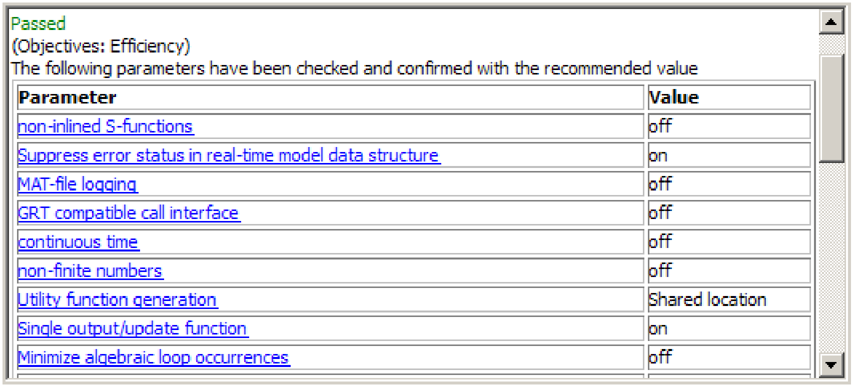
**Caution** The following objectives *exclude* the listed checks. For more information about excluding checks, see `excludeCheck`.

| Objective | Excluded Checks |
|---|---|
| Traceability | • Identify questionable software environment specifications<br>• Identify questionable code instrumentation (data I/O)<br>• Disable signal logging |
| Debugging | • Identify questionable code instrumentation (data I/O)<br>• Disable signal logging |

The first check, **Check model configuration settings against code generation objectives**, lists all parameters and values specified by the objective. For example, the Code Generation Advisor displays the list of parameters and the recommended values in the `Efficiency` objective, if you:

1. Run **Check model configuration settings against code generation objectives**.
2. Click **Modify Parameters**.
3. Rerun the check.

The Code Generation Advisor displays in the check results the list of parameters and recommended values in the `Efficiency` objective.



Passed
(Objectives: Efficiency)
The following parameters have been checked and confirmed with the recommended value

| Parameter | Value |
|---|---|
| non-inlined S-functions | off |
| Suppress error status in real-time model data structure | on |
| MAT-file logging | off |
| GRT compatible call interface | off |
| continuous time | off |
| non-finite numbers | off |
| Utility function generation | Shared location |
| Single output/update function | on |
| Minimize algebraic loop occurrences | off |

## How to Create Custom Objectives

To create a custom objective:

**1** Create an `sl_customization.m` file.

---

**Note**

- Specify all custom objectives in a single `sl_customization.m` file only, or the software generates an error. This holds true even if you have more than one `sl_customization.m` file on your MATLAB path.
- Except for the *`matlabroot`*`/work` folder, do not place an `sl_customization.m` file in your root MATLAB folder, or any of its subfolders. Otherwise, the software ignores the customizations that the file specifies.

---

**2** Create an `sl_customization` function that takes a single argument. When the software invokes the function, the value of this argument is the Simulink customization manager. In the function:

**a** Create a handle to the code generation objective, using the `ObjectiveCustomizer` constructor.

**b** Register a callback function for the custom objectives, using the `ObjectiveCustomizer.addCallbackObjFcn` method.

c Add a call to execute the callback function, using the `ObjectiveCustomizer.callbackFcn` method.

For example

```
function sl_customization(cm)
%SL_CUSTOMIZATION objective customization callback

objCustomizer = cm.ObjectiveCustomizer;
index = objCustomizer.addCallbackObjFcn(@addObjectives);
objCustomizer.callbackFcn{index}();

end
```

3 Create a callback function which includes M-code to:

- Create code generation objective objects using the `rtw.codegenObjectives.Objective` constructor.
- Add, modify, and remove configuration parameters for each objective using the `addParam`, `modifyInheritedParam`, and `removeInheritedParam` methods.
- Include and exclude checks for each objective using the `addCheck`, `excludeCheck`, and `removeInheritedCheck` methods.
- Register objectives using the `register` method.

The following example shows you how to create an objective, `Reduce RAM Example`. `Reduce RAM Example` includes five parameters and three checks that the Code Generation Advisor reviews:

```
function addObjectives

% Create the custom objective
obj = rtw.codegenObjectives.Objective('ex_ram_1');
setObjectiveName(obj, 'Reduce RAM Example');

% Add parameters to the objective
addParam(obj, 'InlineParams', 'on');
addParam(obj, 'BooleanDataType', 'on');
addParam(obj, 'OptimizeBlockIOStorage', 'on');
addParam(obj, 'EnhancedBackFolding', 'on');
addParam(obj, 'BooleansAsBitfields', 'on');

% Add additional checks to the objective
% The Code Generation Advisor automatically includes 'Check model
% configuration settings against code generation objectives' in every
% objective.
addCheck(obj, 'Identify unconnected lines, input ports, and output ports');
addCheck(obj, 'Check model and local libraries for updates');

%Register the objective
register(obj);

end
```

The following example shows you how to create an objective, `My Traceability Example`, based on the existing Traceability objective. The custom objective modifies, removes, and adds parameters that the Code Generation Advisor reviews. It also adds and removes checks from the Code Generation Advisor:

```
function addObjectives

% Create the custom objective from an existing objective
obj = rtw.codegenObjectives.Objective('ex_my_trace_1', 'Traceability');
setObjectiveName(obj, 'My Traceability Example');

% Modify parameters in the objective
modifyInheritedParam(obj, 'GenerateTraceReportSf', 'Off');
removeInheritedParam(obj, 'ConditionallyExecuteInputs');
addParam(obj, 'MatFileLogging', 'On');

% Modify checks in the objective
addCheck(obj, 'Identify questionable software environment specifications');
removeInheritedCheck(obj, 'com.mathworks.MA.CheckDisableSignalLogging');

%Register the objective
register(obj);

end
```

4 If you previously opened the Code Generation Advisor, close the model from which you opened the Code Generation Advisor.

5 Refresh the customization manager. At the MATLAB command line, enter the `sl_refresh_customizations` command.

6 Open your model and review the new objectives.

# Choosing and Configuring an Embedded Real-Time Target

## Introduction

The first step to configuring a model for Real-Time Workshop code generation is to choose and configure a code generation target. When you select a target, other model configuration parameters change automatically to best serve requirements of the target. For example:

- Code interface parameters
- Build process parameters, such as the template make file
- Target hardware parameters, such as word size and byte ordering

Use the **Browse** button on the **Real-Time Workshop** pane to open the System Target File Browser (See “Selecting a System Target File” on page 15-5). The browser lets you select a preset target configuration consisting of a system target file, template makefile, and `make` command.

If you select a target configuration by using the System Target File Browser, your selection appears in the **System target file** field (`*target*.tlc`).

If you are using a target configuration that does not appear in the System Target File Browser, enter the name of your system target file in the **System target file** field. Click **Apply** or **OK** to configure for that target.

Chapter 15, “Choosing and Configuring an Embedded Real-Time Target” describes the use of the browser and includes a complete list of available target configurations.

You can specify this configuration information for a specific type of target in one step by invoking the System Target File Browser, as explained in “Selecting a System Target File” on page 15-5. The browser lists a variety of ready-to-run configurations.

After selecting a system target, you can modify model configuration parameter settings, if necessary

If you want to switch between different targets in a single workflow for different code generation purposes (for example, rapid prototyping versus product code deployment), set up different configuration sets for the same model and switch the active configuration set for the current operation.

For more information on how to set up configuration sets and change the active configuration set, see "Setting Up Configuration Sets" in the Simulinkdocumentation.

## Selecting an ERT Target

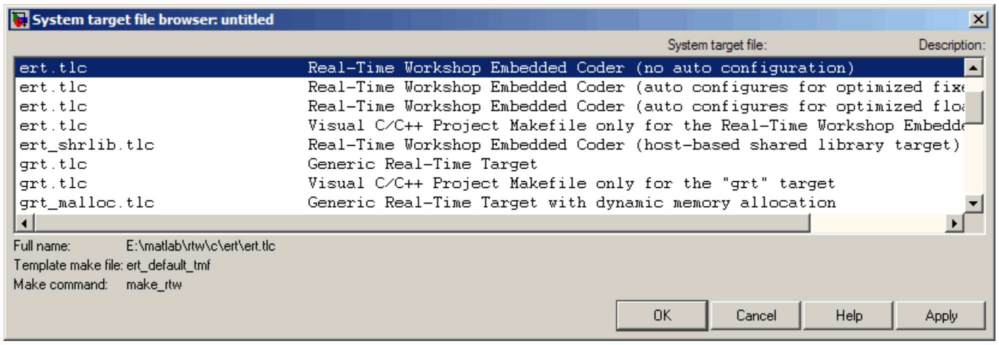
The **Browse** button in the **Target Selection** subpane of the **Real-Time Workshop > General** pane lets you select an ERT target with the System Target File Browser. See "Selecting and Configuring a Target " in the Real-Time Workshop documentation for a general discussion of target selection.

To make it easier for you to generate code that is optimized for your target hardware, the code generator provides three variants of the ERT target that

- Automatically configure parameters that are optimized for fixed-point code generation
- Automatically configure parameters that are optimized for floating-point code generation
- Applies default parameter settings

The discussion throughout this chapter assumes use of the default ERT target.

These targets are based on a common system target file, `ert.tlc`. They are displayed in the System Target File Browser as shown in the figure below.



```
ert.tlc            Real-Time Workshop Embedded Coder (no auto configuration)
ert.tlc            Real-Time Workshop Embedded Coder (auto configures for optimized fixe
ert.tlc            Real-Time Workshop Embedded Coder (auto configures for optimized flo
ert.tlc            Visual C/C++ Project Makefile only for the Real-Time Workshop Embedde
ert_shrlib.tlc     Real-Time Workshop Embedded Coder (host-based shared library target)
grt.tlc            Generic Real-Time Target
grt.tlc            Visual C/C++ Project Makefile only for the "grt" target
grt_malloc.tlc     Generic Real-Time Target with dynamic memory allocation
```

Full name: E:\matlab\rtw\c\ert\ert.tlc
Template make file: ert_default_tmf
Make command: make_rtw

You can use the `ert_shrlib.tlc` target to generate a host-based shared library from your Simulink model. Selecting this target allows you to generate a shared library version of your model code that is appropriate for your host platform, either a Windows dynamic link library (`.dll`) file or a UNIX shared object (`.so`) file. This feature can be used to package your source code securely for easy distribution and shared use. For more information, see "Creating and Using Host-Based Shared Libraries" on page 3-9.

## Selecting a System Target File

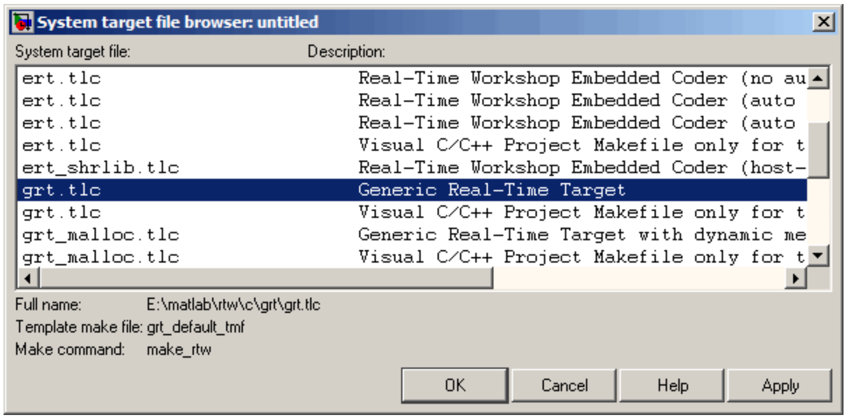
To select a target configuration using the System Target File Browser,

1 Click **Real-Time Workshop** on the Configuration Parameters dialog box. The **Real-Time Workshop** pane appears.

2 Click the **Browse** button next to the **System target file** field. This opens the System Target File Browser. The browser displays a list of all currently available target configurations, including customizations. When you select a target configuration, the Real-Time Workshop software automatically chooses the appropriate system target file, template makefile, and `make` command.

   "Selecting a System Target File" on page 15-5 shows the System Target File Browser with the generic real-time target selected.

3 Click the desired entry in the list of available configurations. The background of the list box turns yellow to indicate an unapplied choice has been made. To apply it, click **Apply** or **OK**.



| System target file: | Description: |
|---|---|
| ert.tlc | Real-Time Workshop Embedded Coder (no au |
| ert.tlc | Real-Time Workshop Embedded Coder (auto |
| ert.tlc | Real-Time Workshop Embedded Coder (auto |
| ert.tlc | Visual C/C++ Project Makefile only for t |
| ert_shrlib.tlc | Real-Time Workshop Embedded Coder (host- |
| grt.tlc | Generic Real-Time Target |
| grt.tlc | Visual C/C++ Project Makefile only for t |
| grt_malloc.tlc | Generic Real-Time Target with dynamic me |
| grt_malloc.tlc | Visual C/C++ Project Makefile only for t |

Full name: E:\matlab\rtw\c\grt\grt.tlc
Template make file: grt_default_tmf
Make command: make_rtw

**System Target File Browser**

When you choose a target configuration, the Real-Time Workshop software automatically chooses the appropriate system target file, template makefile, and `make` command for the selected target, and displays them in the **System target file** field. The description of the target file from the browser is placed below its name in the general **Real-Time Workshop** pane.

## Selecting a System Target File Programmatically

Simulink models store model-wide parameters and target-specific data in *configuration sets*. Every configuration set contains a component that defines the structure of a particular target and the current values of target options. Some of this information is loaded from a system target file when you select a target using the System Target File Browser. You can configure models to generate alternative target code by copying and modifying old or adding new configuration sets and browsing to select a new target. Subsequently, you can interactively select an active configuration from among these sets (only one configuration set can be active at a given time).

Scripts that automate target selection need to emulate this process.

To program target selection

1. Obtain a handle to the active configuration set with a call to the `getActiveConfigSet` function.

2. Define string variables that correspond to the required Real-Time Workshop system target file, template makefile, and `make` command settings. For example, for the ERT target, you would define variables for the strings `'ert.tlc'`, `'ert_default_tmf'`, and `'make_rtw'`.

3. Select the system target file with a call to the `switchTarget` function. In the function call, specify the handle for the active configuration set and the system target file.

4. Set the `TemplateMakefile` and `MakeCommand` configuration parameters to the corresponding variables created in step 2.

For example:

```
cs = getActiveConfigSet(model);
stf = 'ert.tlc';
tmf = 'ert_default_tmf';
mc  = 'make_rtw';
switchTarget(cs,stf,[]);
set_param(cs,'TemplateMakefile',tmf);
set_param(cs,'MakeCommand',mc);
```

# Specifying Code Appearance and Documentation

## Customizing Comments in Generated Code

**In this section...**

### Adding Custom Comments to Generated Code

You can customize the comments in the generated code for ERT targets by setting or clearing several parameters on the **Real-Time Workshop > Comments** pane. These options let you enable or suppress generation of descriptive information in comments for blocks and other objects in the model.

| To... | Select... |
|---|---|
| Include the text specified in the **Description** field of a block's Block Properties dialog box as comments in the code generated for each block | **Simulink block descriptions**. |
| Add a comment that includes the block name at the start of the code for each block | **Simulink block descriptions** |
| Include the text specified in the **Description** field of a Simulink data object (such as a signal, parameter, data type, or bus) in the Simulink Model Explorer as comments in the code generated for each object | **Simulink data object descriptions**. |
| Include comments just above signals and parameter identifiers in the generated code as specified in an M-code or TLC function. | **Custom comments (MPT objects only)**. |

| To... | Select... |
|---|---|
| Include the text specified in the **Description** field of the Properties dialog box for a Stateflow object as comments just above the code generated for each object | **Stateflow object descriptions** . |
| Include requirements assigned to Simulink blocks in the generated code comments (for more information, see "Including Requirements Information with Generated Code" in the Simulink Verification and Validation documentation) | **Requirements in block comments**. |

When you select **Simulink block descriptions**,

- The description text for blocks and Stateflow objects and block names generated as comments can include international (non-US-ASCII) characters. (For details on international character support, see "Support for International (Non-US-ASCII) Characters" in the Real-Time Workshop documentation.)
- The Real-Time Workshop software automatically inserts comments into the generated code for custom blocks. Therefore, it is not necessary to include block comments in the associated TLC file for a custom block.

**Note** If you have existing TLC files with manually inserted comments for block descriptions, the code generation process emits these comments instead of the automatically generated comments. Consider removing existing block comments from your TLC files. Manually inserted comments might be poorly formatted in the generated code and code-to-model traceability might not work.

- For virtual blocks or blocks that have been removed due to block reduction, no comments are generated.

For more information, see "Real-Time Workshop Pane: Comments" in the Real-Time Workshop reference documentation.

## Adding Custom Comments

This procedure allows you to add a comment just above a signal or parameter's identifier in the generated code. This is accomplished using

- A function that you write in M-code or TLC-code and save in a `.m` or `.tlc` file
- The **Custom comments (MPT objects only)** check box on the **Comments** pane of the Configuration Parameters dialog box
- Selecting the `.m` or `.tlc` file in the **Custom comments function** field on the **Comments** pane of the Configuration Parameters dialog box.

You may include at least some or all of the property values for the data object. Each Simulink data object (signal or parameter) has properties, as described in Parameter and Signal Property Values on page 6-2. This example comment contains some of the property values for the data object `MAP` as specified on the Model Explorer:

```
/*     DocUnits:       PSI                                          */
/*     Owner:                                                       */
/*     DefinitionFile: specialDef                                   */
real_T MAP = 0.0;
```

You can type text in the **Description** field on the Model Explorer for a signal or parameter data object. If you do, and if you select the **Simulink data object descriptions** check box on the **Comments** pane of the Configuration Parameters dialog box, this text will appear beside the signal's or parameter's identifier in the generated code as a comment. This is true whether or not you select the **Custom comments (MPT objects only)** check box discussed in this procedure. For example, typing `Manifold Absolute Pressure` in the **Description** field for the data object `MAP` always will result in the following in the generated code:

```
real_T MAP = 0.0;     /* Manifold Absolute Pressure */
```

1. Write a function in M-code or TLC-code that places comments in the generated files as desired. An example `.m` file named `rtwdemo_comments_mptfun.m` is provided in the `matlab/toolbox/rtw/rtwdemos` directory. This file contains instructions.

   The M-code function must have three arguments that correspond to `objectName`, `modelName`, and `request`, respectively. The TLC-code must have three arguments that correspond to `objectRecord`, `modelName`, and `request`, respectively. Note also, in the case of the TLC file, you can use the library function `LibGetSLDataObjectInfo` to get every property value of the data object.

2 Save the function as a `.m` file or a `.tlc` file with the desired filename and place it in any folder in the MATLAB path.

3 Open the model and the Configuration Parameters dialog box.

4 Click **Comments** under **Real-Time Workshop** on the left pane. The **Comments** pane appears on the right.

5 Select the **Custom comments (MPT objects only)** check box.

6 In the **Custom comments function** field, either type the filename of the `.m` file or `.tlc` file you created, or select this filename using the **Browse** button.

7 Click the **Apply** button.

8 Click **Generate Code**.

9 Open the generated files and inspect their content to ensure the comments are what you want.

## Adding Global Comments

- "Introduction" on page 16-5
- "Using a Simulink DocBlock to Add a Comment" on page 16-6
- "Using a Simulink Annotation to Add a Comment" on page 16-7
- "Using a Stateflow Note to Add a Comment" on page 16-8
- "Using Sorted Notes to Add Comments" on page 16-9

### Introduction

The procedures in this section explain how to add a global comment to a Simulink model so that the comment text appears in the generated file or files where desired. This is accomplished by specifying a template symbol name with a Simulink DocBlock, a Simulink annotation, or a Stateflow note, or by using a sorted-notes capability that works with Simulink annotations or Stateflow notes (but not DocBlocks). For more information about template symbols, see "Template Symbols and Rules" on page 16-58.

---

**Note** Template symbol names `Description` and `ModifiedHistory`, referenced below, also are fields in the Model Properties dialog box. If you use one of these symbol names for global comment text, and its Model Properties field has text in it too, both will appear in the generated files.

---

## Using a Simulink DocBlock to Add a Comment

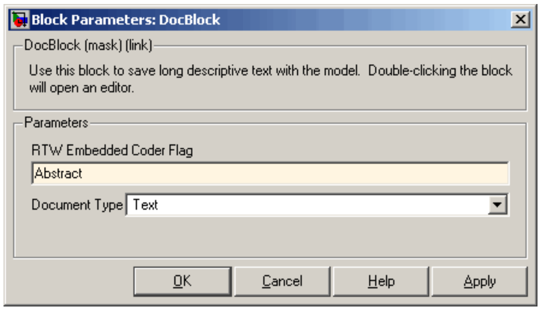
1 With the model open, select **Library Browser** from the **View** menu.

2 Drag the DocBlock from **Model-Wide Utilities** in the Simulink library onto the model.

3 After double-clicking the DocBlock and typing the desired comment in the editor, save and close the editor. See DocBlock in the Simulink documentation for details.

4 Right-click the DocBlock and select **Mask Parameters**. The Block Parameters dialog box appears.

5 Type one of the following Documentation child into the **RTW Embedded Coder Flag** field, illustrated below, and then click **OK**: `Abstract`, `Description`, `History`, `ModifiedHistory`, or `Notes`. Template symbol names are case sensitive.


Block Parameters: DocBlock

DocBlock (mask) (link)

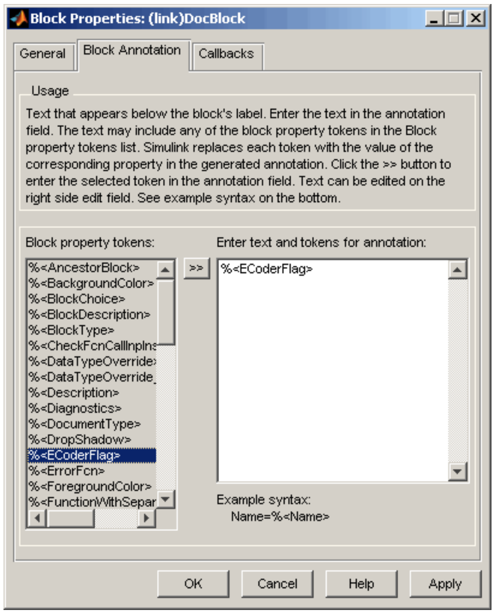
Use this block to save long descriptive text with the model. Double-clicking the block will open an editor.

Parameters

RTW Embedded Coder Flag: Abstract

Document Type: Text

6 In the Block Properties dialog box, **Block Annotation** tab, select `%<ECoderFlag>` as shown in the figure below, and then click **OK**. The symbol name typed in the previous step now appears under the DocBlock on the model.



Text that appears below the block's label. Enter the text in the annotation field. The text may include any of the block property tokens in the Block property tokens list. Simulink replaces each token with the value of the corresponding property in the generated annotation. Click the >> button to enter the selected token in the annotation field. Text can be edited on the right side edit field. See example syntax on the bottom.

Block property tokens:
%<AncestorBlock>
%<BackgroundColor>
%<BlockChoice>
%<BlockDescription>
%<BlockType>
%<CheckFcnCallInpIns
%<DataTypeOverride>
%<DataTypeOverride_
%<Description>
%<Diagnostics>
%<DocumentType>
%<DropShadow>
%<ECoderFlag>
%<ErrorFcn>
%<ForegroundColor>
%<FunctionWithSepar

Enter text and tokens for annotation:
%<ECoderFlag>

Example syntax:
Name=%<Name>

7 Save the model. After you generate code, the code generator places the comment in each generated file whose template has the symbol name you typed. The code generator places the comment in the generated file at the location that corresponds to where the symbol name is located in the template file.

8 To add one or more other comments to the generated files, repeat steps 1 through 7 as desired.

## Using a Simulink Annotation to Add a Comment

1 Double-click the unoccupied area on the model where you want to place the comment. See "Annotating Diagrams" in the Simulink documentation for details.

---

**Note** If you want the code generator to sort multiple comments for the `Notes` symbol name, replace the next step with "Using Sorted Notes to Add Comments" on page 16-9.

---

2. Type `<S:Symbol_name>` followed by the comment, where `Symbol_name` is one of the following Documentation child : `Abstract`, `Description`, `History`, `ModifiedHistory`, or `Notes`. For example, type `<S:Description>This is the description I want.` Template symbol names are case sensitive. (The `"S"` before the colon indicates "symbol.")

3. Click outside the rectangle and save the model. After you generate code, the code generator places the comment in each generated file whose template has the symbol name you typed. The code generator places the comment in the generated file at the location that corresponds to where the symbol name is located in the template file.

4. To add one or more other comments to the generated files, repeat steps 1 through 3 as desired.

### Using a Stateflow Note to Add a Comment

1. Right-click the desired unoccupied area on the Stateflow chart where you want to place the comment. See "Using Notes to Extend Charts" in the Stateflow documentation for details.

2. Select `Add Note` from the drop down menu.

---

**Note** If you want the code generator to sort multiple comments for the `Notes` symbol name, replace the next step with "Using Sorted Notes to Add Comments" on page 16-9.

---

3. Type `<S:Symbol_name>` followed by the comment, where `Symbol_name` is one of the following Documentation child : `Abstract`, `Description`, `History`, `ModifiedHistory`, or `Notes`. For example, type `<S:Description>This is the description I want.` Template symbol names are case sensitive.

4 Click outside the note and save the model. After you generate code, the code generator places the comment in each generated file whose template has the symbol name you typed. The code generator places the comment in the generated file at the location that corresponds to where the symbol name is located in the template file.

5 To add one or more other comments to the generated files, repeat steps 1 through 4 as desired.

### Using Sorted Notes to Add Comments

The sorted-notes capability allows you to add automatically sorted comments to the generated files. The code generator places these comments in each generated file at the location that corresponds to where the `Notes` symbol is located in the template file.

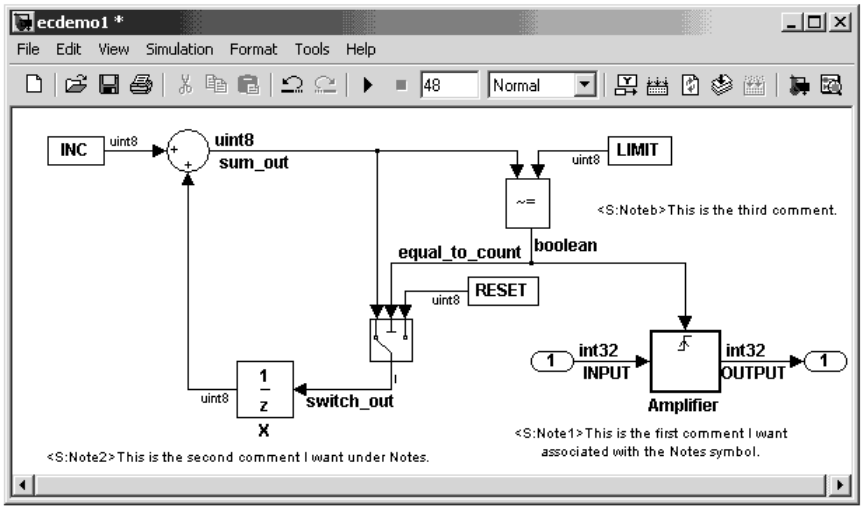
The sorting order the code generator uses is

- Numbers before letters
- Among numbers, 0 is first
- Among letters, uppercase are before lowercase.

You can use sorted notes with a Simulink annotation or a Stateflow note, but not with a DocBlock:

- In the Simulink annotation or the Stateflow note, type `<S:NoteY>` followed by the first comment, where `Y` is a number or letter.
- Repeat for as many additional comments you want, except replace `Y` with a subsequent number or letter.

The figure below illustrates sorted notes on a model, and where the code generator places each in a generated file.



<S:Noteb>This is the third comment.

<S:Note1>This is the first comment I want associated with the Notes symbol.

<S:Note2>This is the second comment I want under Notes.

Here is the relevant fragment from the generated file for the above model:

```
** NOTES

** Note1: This is the first comment I want
associated with the Notes symbol.
Note2: This is the second comment I want under Notes.
Noteb: This is the third comment.

**
```

## Configuring the Appearance of Generated Identifiers

### Customizing Generated Identifiers

Several parameters are available for customizing generated symbols.

| To... | Specify... |
|---|---|
| Define a macro string that specifies whether, and in what order, certain substrings are included within generated identifiers for global variables, global types, field names of global types, subsystem methods, subsystem method arguments, local temporary variables, local block output variables, and constant macros | The macro string with the **Identifier format control** parameter (for details on how to specify formats, see "Specifying Identifier Formats" on page 16-12 and for limitations, see "Identifier Format Control Parameters Limitations" on page 16-19). |
| Specify the minimum number of characters the code generator uses for mangled symbols | Specify an integer value for the **Minimum mangle length** (for details, see "Name Mangling" on page 16-15). |
| Specify the maximum number of characters the code generator can use for function, `typedef`, and variable names (default 31) | Specify an integer value for the **Maximum identifier length**. If you expect your model to generate lengthy identifiers (due to use of long signal or parameter names, for example), or you find that identifiers are being mangled more than expected, you should increase the value of this parameter. |
| Control whether scalar inlined parameter values are expressed in generated code as literal values or macros | The value `Literals` or `Macros` for the **Generate scalar inlined parameters as** parameter<br>.<br>• `Literals`: Parameters are expressed as numeric constants and takes effect if **Inline parameters** is selected.<br>• `Macros`: Parameters are expressed as variables (with `#define` macros). This setting makes code more readable. |

For more information, see “Real-Time Workshop Pane: Symbols” in the Real-Time Workshop reference documentation.

## Configuring Symbols

### Specifying Simulink Data Object Naming Rules

| To Define Rules that Change the Names of a Model’s... | Specify a Naming Rule with the ... |
|---|---|
| Signals | **Signal naming** parameter |
| Parameters | **Parameter naming** parameter |
| Parameters that have a storage class of `Define` | **#define naming** parameter |

For more information on these parameters, see “Specifying Simulink Data Object Naming Rules” on page 11-35 in the Real-Time Workshop Embedded Coder Module Packaging Features document.

### Specifying Identifier Formats

The **Identifier format control** parameters let you customize generated identifiers by entering a macro string that specifies whether, and in what order, certain substrings are included within generated identifiers. For example, you can specify that the root model name be inserted into each identifier.

The macro string can include

- Tokens of the form `$X`, where `X` is a single character. Valid tokens are listed in Identifier Format Tokens on page 16-13. You can use or omit tokens as you want, with the exception of the `$M` token, which is required (see "Name Mangling" on page 16-15) and subject to the use and ordering restrictions noted in Identifier Format Control Parameter Values on page 16-14.
- Any valid C or C++ language identifier characters (`a-z, A-Z, _ , 0-9`).

The build process generates each identifier by expanding tokens (in the order listed in Identifier Format Tokens on page 16-13) and inserting the resultant strings into the identifier. Character strings between tokens are simply inserted directly into the identifier. Contiguous token expansions are separated by the underscore (_) character.

### Identifier Format Tokens

| Token | Description |
|---|---|
| `$M` | Insert name mangling string if required to avoid naming collisions (see "Name Mangling" on page 16-15). **Note:** This token is required. |
| `$F` | Insert method name (for example, `_Update` for update method). This token is available only for subsystem methods. |
| `$N` | Insert name of object (block, signal or signal object, state, parameter or parameter object) for which identifier is being generated. |
| `$R` | Insert root model name into identifier, replacing any unsupported characters with the underscore (_) character. Note that when using model referencing, this token is required in addition to `$M` (see "Model Referencing Considerations" on page 16-18).<br><br>**Note:** This token replaces the **Prefix model name to global identifiers** option used in previous releases. |

**Identifier Format Tokens (Continued)**

| Token | Description |
|---|---|
| `$H` | Insert tag indicating system hierarchy level. For root-level blocks, the tag is the string `root_`. For blocks at the subsystem level, the tag is of the form `sN_`, where `N` is a unique system number assigned by the Simulink software. This token is available only for subsystem methods and field names of global types. **Note:** This token replaces the **Include System Hierarchy Number in Identifiers** option used in previous releases. |
| `$A` | Insert data type acronym (for example, `i32` for long integers) to signal and work vector identifiers. This token is available only for local block output variables and field names of global types. **Note:** This token replaces the **Include data type acronym in identifier** option used in previous releases. |
| `$I` | Insert `u` if the argument is an input or `y` if the argument is an output, (for example, `rtu_` for an input argument and `rty_` for an output argument). This token is available only for subsystem method arguments. |

Identifier Format Control Parameter Values on page 16-14 lists the default macro string, the supported tokens, and the applicable restrictions for each **Identifier format control** parameter.

**Identifier Format Control Parameter Values**

| Parameter | Default Value | Supported Tokens | Restrictions |
|---|---|---|---|
| **Global variables** | `$R$N$M` | `$R`, `$N`, `$M` | `$F`, `$H`, `$A`, and `$I` are disallowed. |
| **Global types** | `$N$R$M` | `$N`, `$R`, `$M` | `$F`, `$H`, `$A`, and `$I` are disallowed. |
| **Field name of global types** | `$N$M` | `$N`, `$M`, `$H`, `$A` | `$R`, `$F`, and `$I` are disallowed. |

**Identifier Format Control Parameter Values (Continued)**

| Parameter | Default Value | Supported Tokens | Restrictions |
|---|---|---|---|
| **Subsystem methods** | `$R$N$M$F` | `$R`, `$N`, `$M`, `$F`, `$H` | `$F` and `$H` are empty for Stateflow functions; `$A` and `$I` are disallowed. |
| **Subsystem method arguments** | `rtu_$N$M` or `rty_$N$M` | `$N`, `$M`, `$I` | `$R`, `$F`, `$H`, and `$A` are disallowed. |
| **Local temporary variables** | `$N$M` | `$N`, `$M`, `$R` | `$F`, `$H`, `$A`, and `$I` are disallowed. |
| **Local block output variables** | `rtb_$N$M` | `$N`, `$M`, `$A` | `$R`, `$F`, `$H`, and `$I` are disallowed. |
| **Constant macros** | `$R$N$M` | `$R`, `$N`, `$M` | `$F`, `$H`, `$A`, and `$I` are disallowed. |

Non-ERT based targets (such as the GRT target) implicitly use a default `$R$N$M` specification. This specifies identifiers consisting of the root model name, followed by the name of the generating object (signal, parameter, state, and so on), followed by a name mangling string (see "Name Mangling" on page 16-15).

For limitations that apply to **Identifier format control** parameters, see "Identifier Format Control Parameters Limitations" on page 16-19.

## Name Mangling

In identifier generation, a circumstance that would cause generation of two or more identical identifiers is called a *name collision*. Name collisions are never permissible. When a potential name collision exists, unique *name mangling* strings are generated and inserted into each of the potentially conflicting identifiers. Each name mangling string is guaranteed to be unique for each generated identifier.

The position of the `$M` token in the **Identifier format control** parameter specification determines the position of the name mangling string in the generated identifiers. For example, if the specification `$R$N$M` is used, the name mangling string is appended (if required) to the end of the identifier.

The **Minimum mangle length** parameter specifies the minimum number of characters used when a name mangling string is generated. The default is `1` character. As described below, the actual length of the generated string may be longer than this minimum.

### Traceability

An important aspect of model based design is the ability to generate identifiers that can easily be traced back to the corresponding entities within the model. To ensure traceability, it is important to make sure that incremental revisions to a model have minimal impact on the identifier names that appear in generated code. There are two ways of achieving this:

1. Choose unique names for Simulink objects (blocks, signals, states, and so on) as much as possible.
2. Make use of name mangling when conflicts cannot be avoided.

When conflicts cannot be avoided (as may be the case in models that use libraries or model reference), name mangling ensures traceability. The position of the name mangling string is specified by the placement of the `$M` token in the **Identifier format control** parameter specification. Mangle characters consist of lower case characters (`a-z`) and numerics (`0-9`), which are chosen with a checksum that is unique to each object. How Name Mangling Strings Are Computed on page 16-16 describes how this checksum is computed for different types of objects.

**How Name Mangling Strings Are Computed**

| Object Type | Source of Mangling String |
|---|---|
| Block diagram | Name of block diagram |
| Simulink block | Full path name of block |

**How Name Mangling Strings Are Computed (Continued)**

| Object Type | Source of Mangling String |
|---|---|
| Simulink parameter | Full name of parameter owner (that is, model or block) and parameter name |
| Simulink signal | Signal name, full name of source block, and port number |
| Stateflow objects | Complete path to Stateflow block and Stateflow computed name (unique within chart) |

The length of the name mangling string is specified by the **Minimum mangle length** parameter. The default value is `1`, but this automatically increases during code generation as a function of the number of collisions.

To minimize disturbance to the generated code during development, specify a larger **Minimum mangle length**. A **Minimum mangle length** of `4` is a conservative and safe value. A value of `4` allows for over 1.5 million collisions for a particular identifier before the mangle length is increased.

## Minimizing Name Mangling

Note that the length of generated identifiers is limited by the **Maximum identifier length** parameter. When a name collision exists, the `$M` token is always expanded to the minimum number of characters required to avoid the collision. Other tokens and character strings are expanded in the order listed in Identifier Format Tokens on page 16-13. If the **Maximum identifier length** is not large enough to accommodate full expansions of the other tokens, partial expansions are used. To avoid this outcome, it is good practice to

- Avoid name collisions in general. One way to do this is to avoid using default block names (for example, `Gain1`, `Gain2...`) when there are many blocks of the same type in the model.
- Where possible, increase the **Maximum identifier length** to accommodate the length of the identifiers you expect to generate.

Set the **Minimum mangle length** parameter to reserve at least three characters for the name mangling string. The length of the name mangling string increases as the number of name collisions increases.

Note that an existing name mangling string increases (or decreases) in length if changes to model create more (or fewer) collisions. If the length of the name mangling string increases, additional characters are appended to the existing string. For example, `'xyz'` might change to `'xyzQ'`. In the inverse case (fewer collisions) `'xyz'` would change to `'xy'`.

### Model Referencing Considerations

Within a model that uses model referencing, there can be no collisions between the names of the constituent models. When generating code from a model that uses model referencing:

- The `$R` token must be included in the **Identifier format control** parameter specifications (in addition to the `$M` token).
- The **Maximum identifier length** must be large enough to accommodate full expansions of the `$R` and `$M` tokens. A code generation error occurs if **Maximum identifier length** is not large enough.

When a name conflict occurs between an identifier within the scope of a higher-level model and an identifier within the scope of a referenced model, the identifier from the referenced model is preserved. Name mangling is performed on the identifier from the higher-level model.

### Exceptions to Identifier Formatting Conventions

There are some exceptions to the identifier formatting conventions described above:

- Type name generation: The above name mangling conventions do not apply to type names (that is, `typedef` statements) generated for global data types. If the `$R` token is included in the **Identifier format control** parameter specification, the model name is included in the `typedef`. The **Maximum identifier length** parameter is not respected when generating type definitions.
- Non-`Auto` storage classes: The **Identifier format control** parameter specification does not affect objects (such as signals and parameters)

that have a storage class other than `Auto` (such as `ImportedExtern` or `ExportedGlobal`).

## Identifier Format Control Parameters Limitations

The following limitations apply to the **Identifier format control** parameters:

- The following autogenerated identifiers currently do not fully comply with the setting of the **Maximum identifier length** parameter on the **Real-Time Workshop/Symbols** pane of the Configuration Parameters dialog box.
  - Model methods
    - The applicable format string is `$R$F`, and the longest `$F` is `_derivatives`, which is 12 characters long. The model name can be up to 19 characters without exceeding the default **Maximum identifier length** of 31.
  - Local functions generated by S-functions or by add-on products such as Signal Processing Blockset™ that rely on S-functions
  - Local variables generated by S-functions or by add-on products such as Signal Processing Blockset that rely on S-functions
  - `DWork` identifiers generated by S-functions in referenced models
  - Fixed-point shared utility macros or shared utility functions
  - Simulink `rtm` macros
    - Most are within the default **Maximum identifier length** of 31, but some exceed the limit. Examples are `RTMSpecAccsGetStopRequestedValStoredAsPtr`, `RTMSpecAccsGetErrorStatusPointer`, and `RTMSpecAccsGetErrorStatusPointerPointer`.
  - Define protection guard macros
    - Header file guards, such as `_RTW_HEADER_$(filename)_h_`, which can exceed the default **Maximum identifier length** of 31 given a filename such as `$R_private.h`.
    - Include file guards, such as `_$R_COMMON_INCLUDES_`.
    - `typedef` guards, such as `_CSCI_$R_CHARTSTRUCT_`.

- In some situations, the following identifiers potentially can conflict with others.
  - Model methods
  - Local functions generated by S-functions or by add-on products such as Signal Processing Blockset that rely on S-functions
  - Local variables generated by S-functions or by add-on products such as Signal Processing Blockset that rely on S-functions
  - Fixed-point shared utility macros or shared utility functions
  - Include header guard macros
- The following external identifiers that are unknown to the Simulink software might conflict with autogenerated identifiers.
  - Identifiers defined in custom code
  - Identifiers defined in custom header files
  - Identifiers introduced through a non-ANSI C standard library
  - Identifiers defined by custom TLC code
- Identifiers generated for simulation targets may exceed the **Maximum identifier length**. Simulation targets include the model reference simulation target, the accelerated simulation target, the RSim target, and the S-function target.

## Controlling Code Style

You can control the following style aspects in generated code:

- Level of parenthesization
- Whether to preserve order of operands in expressions
- Whether to preserve empty primary condition expressions in `if` statements
- Whether to generate code for `if-elseif-else` decision logic as `switch-case` statements
- Whether to include the `extern` keyword in function declarations

For example, C code contains some syntactically required parentheses, and can contain additional parentheses that change semantics by overriding default operator precedence. C code can also contain optional parentheses that have no functional significance, but serve only to increase the readability of the code. Optional C parentheses vary between two stylistic extremes:

- Include the minimum parentheses required by C syntax and any precedence overrides, so that C precedence rules specify all semantics unless overridden by parentheses.
- Include the maximum parentheses that can exist without duplication, so that C precedence rules become irrelevant: parentheses alone completely specify all semantics.

Understanding code with minimum parentheses can require correctly applying nonobvious precedence rules, but maximum parentheses can hinder code reading by belaboring obvious precedence rules. Various parenthesization standards exist that specify one or the other extreme, or define an intermediate style that can be useful to human code readers.

You control the code style options by setting parameters on the **Real-Time Workshop > Code Style** pane. For details on the parameters, see "Real-Time Workshop Pane: Code Style" in the Real-Time Workshop Embedded Coder reference documentation.

## Configuring Templates for Customizing Code Organization and Format

**In this section...**

Customize generated code using code and data templates

| To... | Enter or Select... |
|---|---|
| Specify a template that defines the top-level organization and formatting of generated source code (`.c` or `.cpp`) files | Enter a code generation template (CGT) file for the **Source file (*.c) template** parameter. |
| Specify a template that defines the top-level organization and formatting of generated header (`.h`) files | Enter a CGT file for the **Header file (*.h) template** parameter. This template file can be the same template file that you specify for **Source file (.c) template**. If you use the same template file, source and header files contain identical banners. The default template is *`matlabroot`*`/toolbox/rtw/targets/ecoder/ert_code_template.cgt`. |

| To... | Enter or Select... |
|---|---|
| Specify a template that organizes generated code into sections (such as includes, `typedefs`, functions, and more) | Enter a custom file processing (CFP) template file for the "File customization template" parameter. A CFP template can emit code, directives, or comments into each section. For more information, see "Using Custom File Processing (CFP) Templates" on page 16-30. |
| Generate a model-specific example main program module | Select **Generate an example main program**. For more information, see "Generating a Standalone Program" on page 32-3. |

**Note** Place the template files that you specify on the MATLAB path.

## Overview

This section describes Real-Time Workshop Embedded Coder *custom file processing* (CFP) features. Custom file processing simplifies generation of custom source code. You can:

- Generate any type of source (`.c` or `.cpp`) or header (`.h`) file. Using a *custom file processing template* (CFP template), you can control how code emits to the standard generated model files (for example, *`model`*`.c` or `.cpp`, *`model`*`.h`) or generate files that are independent of model code.
- Organize generated code into sections (such as includes, `typedefs`, functions, and more). Your CFP template can emit code (for example, functions), directives (such as `#define` or `#include` statements), or comments into each section.
- Generate custom *file banners* (comment sections) at the start and end of generated code files and custom *function banners* that precede functions in the generated code.
- Generate code to call model functions, such as *`model`*`_initialize`, *`model`*`_step`, and so on.
- Generate code to read and write model inputs and outputs.
- Generate a main program module.
- Obtain information about the model and the generated files from the model.

## Custom File Processing Components

The custom file processing features are based on the following interrelated components:

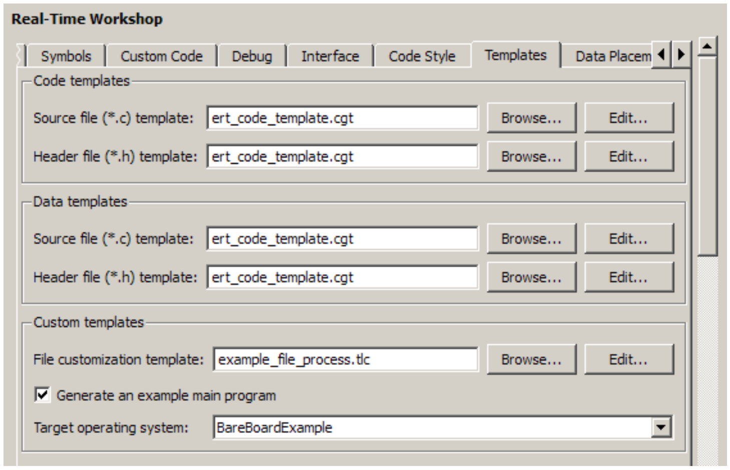
- *Code generation template* (CGT) files: a CGT file defines the top-level organization and formatting of generated code. See "Code Generation Template (CGT) Files" on page 16-26.
- The *code template API*: a high-level Target Language Compiler (TLC) API that provides functions with which you can organize code into named sections and subsections of generated source and header files. The code template API also provides utilities that return information about generated files, generate standard model calls, and perform other functions. See "Code Template API Summary" on page 16-46.
- *Custom file processing (CFP) templates*: a CFP template is a TLC file that manages the process of custom code generation. A CFP template assembles code to be generated into buffers. A CFP template also calls the code template API to emit the buffered code into specified sections of generated source and header files. A CFP template interacts with a CGT file, which defines the ordering of major sections of the generated code. See "Using Custom File Processing (CFP) Templates" on page 16-30.

To use CFP templates, you must understand TLC programming. See the Target Language Compiler document.

## Custom File Processing User Interface Options

To use custom file processing features, create CGT files and CFP templates. These files are based on default templates provided by the Real-Time Workshop Embedded Coder software. Once you have created your templates, you must integrate them into the code generation process.

Select and edit CGT files and CFP templates, and specify their use in the code generation process in the **Real-Time Workshop > Templates** pane of a model configuration set. The following figure shows all options configured for their defaults.



Real-Time Workshop

Code templates

Source file (*.c) template: ert_code_template.cgt

Header file (*.h) template: ert_code_template.cgt

Data templates

Source file (*.c) template: ert_code_template.cgt

Header file (*.h) template: ert_code_template.cgt

Custom templates

File customization template: example_file_process.tlc

☑ Generate an example main program

Target operating system: BareBoardExample

**Real-Time Workshop: Templates Pane**

The options related to custom file processing are:

- The **Source file (.c) template** field in the **Code templates** and **Data templates** sections. This field specifies the name of a CGT file to use when generating source (`.c` or `.cpp`) files. You must place this file on the MATLAB path.
- The **Header file (.h) template** field in the **Code templates** and **Data templates** sections. This field specifies the name of a CGT file to use when generating header (`.h`) files. You must place this file on the MATLAB path.

  By default, the template for both source and header files is `*matlabroot*/toolbox/rtw/targets/ecoder/ert_code_template.cgt`.
- The **File customization template** edit field in the **Custom templates** section. This field specifies the name of a CFP template file to use when generating code files. You must place this file on the MATLAB path. The default CFP template is `*matlabroot*/toolbox/rtw/targets/ecoder/example_file_process.tlc`.

In each of these fields, click **Browse** to navigate to and select an existing CFP template or CGT file. Click **Edit** to open the specified file into the MATLAB editor where you can customize it. You must place this file on the

## Code Generation Template (CGT) Files

CGT files have the following applications:

- Generation of custom banners (comments sections) in code files. See "Generating Custom File and Function Banners" on page 16-49.
- Advanced features, as described in Defining Data Representation and Storage for Code Generation on page 1 that use CGT files.
- Generation of custom code using a CFP template requires a CGT file. To correctly use CFP templates, you must understand the CGT file structure. In many cases, however, you can use the default CGT file without modifying it.

### Default CGT file

The Real-Time Workshop Embedded Coder software provides a default CGT file, `*matlabroot*/toolbox/rtw/targets/ecoder/ert_code_template.cgt`. Base your custom CGT files on the default file.

### CGT File Structure

A CGT file consists of one required section and four optional sections:

**Code Insertion Section.** (Required) This section contains tokens that define an ordered partitioning of the generated code into a number of sections (such as `Includes` and `Defines` sections). Tokens have the form of:

```
%<SectionName>
```

For example,

```
%<Includes>
```

The Real-Time Workshop Embedded Coder software defines a minimal set of required tokens. These tokens generate C or C++ source or header code. They are *built-in* tokens (see "Built-In Tokens and Sections" on page 16-27). You can also define *custom* tokens and add them to the code insertion section (see "Generating a Custom Section" on page 16-41).

Each token functions as a placeholder for a corresponding section of generated code. The ordering of the tokens defines the order in which the corresponding sections appear in the generated code. A token in the CGT file does not guarantee that the corresponding section is generated. To generate code into a given section, explicitly call the code template API from a CFP template, as described in "Using Custom File Processing (CFP) Templates" on page 16-30.

The CGT tokens define the high-level organization of generated code. Using the code template API, you can partition each code section into named subsections, as described in "Subsections" on page 16-29.

In the code insertion section, you can also insert C or C++ comments between tokens. Such comments emit directly into the generated code.

**File Banner Section.** (Optional) This section contains comments and tokens you use in generating a custom file banner. See "Generating Custom File and Function Banners" on page 16-49.

**Function Banner Section.** (Optional) This section contains comments and tokens for use in generating a custom function banner. See"Generating Custom File and Function Banners" on page 16-49.

**Shared Utility Function Banner Section.** (Optional) This section contains comments and tokens for use in generating a custom shared utility function banner. See "Generating Custom File and Function Banners" on page 16-49.

**File Trailer Section.** (Optional) This section contains comments for use in generating a custom trailer banner. See "Generating Custom File and Function Banners" on page 16-49.

## Built-In Tokens and Sections

The following code extract shows the required code insertion section of the default CGT file with the required built-in tokens.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Code insertion section (required)
%%   These are required tokens. You can insert comments and other tokens in
%% between them, but do not change their order or remove them.
%%
%<Includes>
%<Defines>
```

```
%<Types>
%<Enums>
%<Definitions>
%<Declarations>
%<Functions>
```

Note the following requirements for customizing a CGT file:

- Do not remove required built-in tokens.
- Built-in tokens must appear in the order shown because each successive section has dependencies on previous sections.
- Only one token per line.
- Do not repeat tokens.
- You can add custom tokens and comments to the code insertion section as long as you do not violate the previous requirements.

The following table summarizes the built-in tokens and corresponding section names, and describes the code sections.

**Built-In CGT Tokens and Corresponding Code Sections**

| Token and Section Name | Description |
|---|---|
| `Includes` | `#include` directives section |
| `Defines` | `#define` directives section |
| `Types` | `typedef` section. `Typedefs` can depend on any previously defined type |
| `Enums` | Enumerated types section |
| `Definitions` | Data definitions (for example, `double x = 3.0`;) |
| `Declarations` | Data declarations (for example, `extern double x`;) |
| `Functions` | C or C++ functions |

## Subsections

You can define one or more named subsections for any section. Some of the built-in sections have predefined subsections summarized in Subsections Defined for Built-In Sections on page 16-29.

**Note** Sections and subsections emit to the source or header file in the order listed in the CGT file.

Using the custom section feature, you can define additional sections. See "Generating a Custom Section" on page 16-41.

**Subsections Defined for Built-In Sections**

| Section | Subsections | Subsection Description |
|---|---|---|
| `Includes` | N/A | |
| `Defines` | N/A | |
| `Types` | `IntrinsicTypes` | Intrinsic `typedef` section. Intrinsic types depend only on intrinsic C or C++ types. |
| `Types` | `PrimitiveTypedefs` | Primitive `typedef` section. Primitive `typedefs` depend only on intrinsic C or C++ types and on any `typedefs` previously defined in the `IntrinsicTypes` section. |
| `Types` | `UserTop` | You can place any type of code in this section, including code that has dependencies on the previous sections. |
| `Types` | `Typedefs` | `typedef` section. `Typedefs` can depend on any previously defined type |
| `Enums` | N/A | |
| `Definitions` | N/A | |
| `Declarations` | N/A | |
| `Functions` | | C or C++ functions |
| `Functions` | `CompilerErrors` | `#warning` directives |

**Subsections Defined for Built-In Sections (Continued)**

| Section | Subsections | Subsection Description |
|---|---|---|
| `Functions` | `CompilerWarnings` | `#error` directives |
| `Functions` | `Documentation` | Documentation (comment) section |
| `Functions` | `UserBottom` | You can place any code in this section. |

## Using Custom File Processing (CFP) Templates

The files provided to support custom file processing are

- *`matlabroot`*`/rtw/c/tlc/mw/codetemplatelib.tlc`: A TLC function library that implements the code template API. `codetemplatelib.tlc` also provides the comprehensive documentation of the API in the comments headers preceding each function.
- *`matlabroot`*`/toolbox/rtw/targets/ecoder/example_file_process.tlc`: An example custom file processing (CFP) template, which you should use as the starting point for creating your own CFP templates. Guidelines and examples for creating a CFP template are provided in "Generating Source and Header Files with a Custom File Processing (CFP) Template" on page 16-34.
- TLC files supporting generation of single-rate and multirate main program modules (see "Customizing Main Program Module Generation" on page 16-39).

Once you have created a CFP template, you must integrate it into the code generation process, using the **File customization template** edit field (see "Custom File Processing User Interface Options" on page 16-24).

## Custom File Processing (CFP) Template Structure

A custom file processing (CFP) template imposes a simple structure on the code generation process. The template, a code generation template (CGT) file, partitions the code generated for each file into a number of sections. These sections are summarized in Built-In CGT Tokens and Corresponding Code Sections on page 16-28 and Subsections Defined for Built-In Sections on page 16-29.

Code for each section is assembled in buffers and then emitted, in the order listed, to the file being generated.

To generate a file section, your CFP template must first assemble the code to be generated into a buffer. Then, to emit the section, your template calls the TLC function

```
LibSetSourceFileSection(fileH, section, tmpBuf)
```

where

- `fileH` is a file reference to a file being generated.
- `section` is the code section or subsection to which code is to be emitted. section must be one of the section or subsection names listed in Subsections Defined for Built-In Sections on page 16-29.

  Determine the `section` argument as follows:

  - If Subsections Defined for Built-In Sections on page 16-29 defines no subsections for a given section, use the section name as the `section` argument.
  - If Subsections Defined for Built-In Sections on page 16-29 defines one or more subsections for a given section, you can use either the section name or a subsection name as the `section` argument.
  - If you have defined a custom token denoting a custom section, do not call `LibSetSourceFileSection`. Special API calls are provided for custom sections (see “Generating a Custom Section” on page 16-41).
- `tmpBuf` is the buffer containing the code to be emitted.

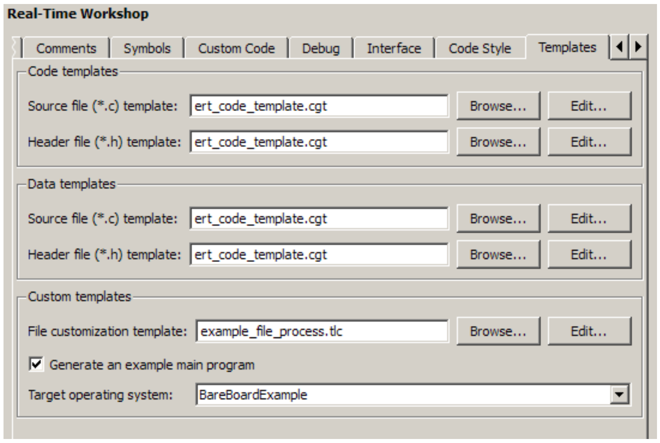
There is no requirement to generate all of the available sections. Your template need only generate the sections you require in a particular file.

Note that no legality or syntax checking is performed on the custom code within each section.

The next section, “Generating Source and Header Files with a Custom File Processing (CFP) Template” on page 16-34, provides typical usage examples.

## Changing the Organization of a Generated File

The files you generated in the previous procedures are organized according to the general Real-Time Workshop Embedded Coder template. This template has the filename `ert_code_template.cgt`, and is specified by default in **Templates** pane of the Configuration Parameters dialog box.



Code templates

Source file (*.c) template: ert_code_template.cgt

Header file (*.h) template: ert_code_template.cgt

Data templates

Source file (*.c) template: ert_code_template.cgt

Header file (*.h) template: ert_code_template.cgt

Custom templates

File customization template: example_file_process.tlc

[✓] Generate an example main program

Target operating system: BareBoardExample

The following fragment shows the `rtwdemo_mpf.c` file header that is generated using this default template:

```
/*
 * File: rtwdemo_mpf.c
 *
 * Real-Time Workshop code generated for Simulink model rtwdemo_mpf.
 *
 * Model version                        : 1.87
 * Real-Time Workshop file version      : 7.3  (R2009a)  20-Nov-2008
 * Real-Time Workshop file generated on : Wed Dec 17 16:27:14 2008
 * TLC version                          : 7.3 (Nov 26 2008)
 * C/C++ source code generated on       : Wed Dec 17 16:27:14 2008
 */
```

You can change the organization of generated files using code templates and data templates. Code templates organize the files that contain functions, primarily. Data templates organize the files that contain identifiers. In this procedure, you organize the generated files, using the supplied MPF code and data templates:

1 Display the active Real-Time Workshop **Templates** configuration parameters.

2 In the **Code templates** section of the **Templates** pane, type `code_c_template.cgt` into the **Source file (*.c) templates** text box.

3 Type `code_h_template.cgt` into the **Header file (*.h) templates** text box.

4 In the **Data templates** section, type `data_c_template.cgt` into the **Source file (*.c) templates** text box.

5 Type `data_h_template.cgt` into the **Header file (*.h) templates** text box, and click **Apply**.

6 Click **Generate code**. Now the files are organized using the templates you specified. For example, the `rtwdemo_mpf.c` file header now is organized like this:

```
/**
 ************************************************************************
 **  FILE INFORMATION:
 **  Filename:           rtwdemo_mpf.c
 **  File Creation Date: 17-Dec-2008
 **
 **  ABSTRACT:
 **
 **
 **  NOTES:
 **
 **
 **  MODEL INFORMATION:
 **  Model Name:         rtwdemo_mpf
 **  Model Description:  Data packaging examples
 **  Model Version:      1.87
 **  Model Author:       The MathWorks Inc. - Mon Mar 01 11:23:00 2004
 **
 **  MODIFICATION HISTORY:
 **  Model at Code Generation: username - Wed Dec 17 16:47:16 2008
 **
 **  Last Saved Modification:  username - Wed Dec 17 15:23:20 2008
 **
 **
 ************************************************************************
 **/
```

## Generating Source and Header Files with a Custom File Processing (CFP) Template

This section walks you through the process of generating a simple source (`.c` or `.cpp`) and header (`.h`) file using the example CFP template. Then, it examines the template and the code generated by the template.

The example CFP template, `*matlabroot*/toolbox/rtw/targets/ecoder/example_file_process.tlc`, demonstrates some of the capabilities of the code template API, including

- Generation of simple source (`.c` or `.cpp`) and header (`.h`) files
- Use of buffers to generate file sections for includes, functions, and so on
- Generation of includes, defines, into the standard generated files (for example, *`model`*`.h`)
- Generation of a main program module

## Generating Code with a CFP Template

This section sets up a CFP template and configures a model to use the template in code generation. The template generates (in addition to the standard model files) a source file (`timestwo.c` or `.cpp`) and a header file (`timestwo.h`).

Follow the steps below to become acquainted with the use of CFP templates:

1. Copy the example CFP template, *`matlabroot`*`/toolbox/rtw/targets/ecoder/example_file_process.tlc`, to a directory outside the MATLAB directory structure (that is, not under *`matlabroot`*). If the directory is not on the MATLAB path or the TLC path, then add it to the MATLAB path. It is good practice to locate the CFP template in the same directory as your system target file, which is guaranteed to be on the TLC path.

2. Rename the copied `example_file_process.tlc` to `test_example_file_process.tlc`.

3. Open `test_example_file_process.tlc` into the MATLAB editor.

4. Uncomment the following line:

   ```
   %%  %assign ERTCustomFileTest = TLC_TRUE
   ```

   It now reads:

   ```
     %assign ERTCustomFileTest = TLC_TRUE
   ```

   If `ERTCustomFileTest` is not assigned as shown, the CFP template is ignored in code generation.

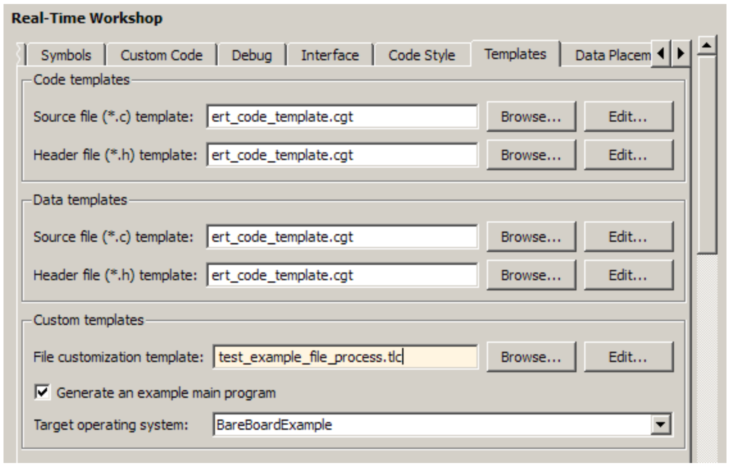
5 Save your changes to the file. Keep `test_example_file_process.tlc` open, so you can refer to it later.

6 Open the `rtwdemo_udt` model.

7 Open the Simulink Model Explorer. Select the active configuration set of the model, and open the **Real-Time Workshop** pane of the active configuration set.

8 Click the **Templates** tab.

9 Configure the **File customization template** field as shown below. The `test_example_file_process.tlc` file, which you previously edited, is now the specified CFP template for your model.



Code templates
Source file (*.c) template: ert_code_template.cgt
Header file (*.h) template: ert_code_template.cgt

Data templates
Source file (*.c) template: ert_code_template.cgt
Header file (*.h) template: ert_code_template.cgt

Custom templates
File customization template: test_example_file_process.tlc
[✓] Generate an example main program
Target operating system: BareBoardExample

10 Select the **Generate code only** option.

11 Click **Apply**.

12 Click **Generate code**. During code generation, notice the following message on the MATLAB command window:

```
Warning:  Overriding example ert_main.c!
```

This message is displayed because `test_example_file_process.tlc` generates the main program module, overriding the default action of the ERT target. This is explained in greater detail below.

**13** The `rtwdemo_udt` model is configured to generate an HTML code generation report. After code generation completes, view the report. Notice that the **Generated Source Files** list contains the files `timestwo.c`, `timestwo.h`, and `ert_main.c`. These files were generated by the CFP template. The next section examines the template to learn how this was done.

**14** Keep the model, the code generation report, and the `test_example_file_process.tlc` file open so you can refer to them in the next section.

### Analysis of the Example CFP Template and Generated Code

This section examines excerpts from `test_example_file_process.tlc` and some of the code it generates. Refer to the comments in *`matlabroot`*`/rtw/c/tlc/mw/codetemplatelib.tlc` while reading the following discussion.

**Generating Code Files.** Source (`.c` or `.cpp`) and header (`.h`) files are created by calling `LibCreateSourceFile`, as in the following excerpts:

```
%assign cFile = LibCreateSourceFile("Source", "Custom", "timestwo")
...
%assign hFile = LibCreateSourceFile("Header", "Custom", "timestwo")
```

Subsequent code refers to the files by the file reference returned from `LibCreateSourceFile`.

**File Sections and Buffers.** The code template API lets you partition the code generated to each file into sections, tagged as `Definitions`, `Includes`, `Functions`, `Banner`, and so on. You can append code to each section as many times as required. This technique gives you a great deal of flexibility in the formatting of your custom code files.

Subsections Defined for Built-In Sections on page 16-29 describes the available file sections and their order in the generated file.

For each section of a generated file, use `%openfile` and `%closefile` to store the text for that section in temporary buffers. Then, to write (append) the buffer contents to a file section, call `LibSetSourceFileSection`, passing in the desired section tag and file reference. For example, the following code uses two buffers (`tmwtypesBuf` and `tmpBuf`) to generate two sections (tagged `"Includes"` and `"Functions"`) of the source file `timestwo.c` or `.cpp` (referenced as `cFile`):

```
 %openfile tmwtypesBuf

 #include "tmwtypes.h"

%closefile tmwtypesBuf

%<LibSetSourceFileSection(cFile,"Includes",tmwtypesBuf)>

 %openfile tmpBuf

 /* Times two function */
 real_T timestwofcn(real_T input) {
   return (input * 2.0);
}

%closefile tmpBuf

%<LibSetSourceFileSection(cFile,"Functions",tmpBuf)>
```

These two sections generate the entire `timestwo.c` or `.cpp` file:

```
#include "tmwtypes.h"

/* Times two function */
FLOAT64 timestwofcn(FLOAT64 input)
{
  return (input * 2.0);
}
```

**Adding Code to Standard Generated Files.** The `timestwo.c` or `.cpp` file generated in the previous example was independent of the standard code files generated from a model (for example, `*model*.c` or `.cpp`, `*model*.h`, and so on). You can use similar techniques to generate custom code within the model files. The code template API includes functions to obtain the names of the standard models files and other model-related information. The following excerpt calls `LibGetMdlPubHdrBaseName` to obtain the correct name for the `*model*.h` file. It then obtains a file reference and generates a definition in the `Defines` section of `*model*.h`:

```
%% Add a #define to the model's public header file model.h

%assign pubName = LibGetMdlPubHdrBaseName()
%assign modelH  = LibCreateSourceFile("Header", "Simulink", pubName)

%openfile tmpBuf

 #define ACCELERATION 9.81

 %closefile tmpBuf

%<LibSetSourceFileSection(modelH,"Defines",tmpBuf)>
```

Examine the generated `rtwdemo_udt.h` file to see the generated `#define` directive.

**Customizing Main Program Module Generation.** Normally, the ERT target determines whether and how to generate an `ert_main.c` or `.cpp` module based on the settings of the **Generate an example main program** and **Target operating system** options on the **Templates** pane of the Configuration Parameters dialog box. You can use a CFP template to override the normal behavior and generate a main program module customized for your target environment.

To support generation of main program modules, two TLC files are provided:

- `bareboard_srmain.tlc`: TLC code to generate an example single-rate main program module for a bareboard target environment. Code is generated by a single TLC function, `FcnSingleTaskingMain`.

- `bareboard_mrmain.tlc`: TLC code to generate a multirate main program module for a bareboard target environment. Code is generated by a single TLC function, `FcnMultiTaskingMain`.

In the example CFP template file *`matlabroot`*`/toolbox/rtw/targets/ecoder/example_file_process.tlc`, the following code generates either a single- or multitasking `ert_main.c` or `.cpp` module. The logic depends on information obtained from the code template API calls `LibIsSingleRateModel` and `LibIsSingleTasking`:

```
%% Create a simple main.  Files are located in MATLAB/rtw/c/tlc/mw.

 %if LibIsSingleRateModel() || LibIsSingleTasking()
   %include "bareboard_srmain.tlc"
   %<FcnSingleTaskingMain()>
 %else
   %include "bareboard_mrmain.tlc"
   %<FcnMultiTaskingMain()>
 %endif
```

Note that `bareboard_srmain.tlc` and `bareboard_mrmain.tlc` use the code template API to generate `ert_main.c` or `.cpp`.

When generating your own main program module, you disable the default generation of `ert_main.c` or `.cpp`. The TLC variable `GenerateSampleERTMain` controls generation of `ert_main.c` or `.cpp`. You can directly force this variable to `TLC_FALSE`. The examples `bareboard_mrmain.tlc` and `bareboard_srmain.tlc` use this technique, as shown in the following excerpt from `bareboard_srmain.tlc`.

```
%if GenerateSampleERTMain
    %assign CompiledModel.GenerateSampleERTMain = TLC_FALSE
    %warning Overriding example ert_main.c!
%endif
```

Alternatively, you can implement a `SelectCallback` function for your target. A `SelectCallback` function is an M-function that is triggered during model loading, and also when the user selects a target with the System Target File browser. Your `SelectCallback` function should deselect and disable the **Generate an example main program** option. This prevents the TLC variable `GenerateSampleERTMain` from being set to TLC_TRUE.

See the “rtwgensettings Structure” section of the Developing Embedded Targets document for information on creating a `SelectCallback` function.

The following code illustrates how to deselect and disable the **Generate an example main program** option in the context of a `SelectCallback` function.

```
slConfigUISetVal(hDlg, hSrc, 'GenerateSampleERTMain', 'off');
slConfigUISetEnabled(hDlg, hSrc, 'GenerateSampleERTMain',0);
```

---

**Note** Creation of a main program for your target environment requires some customization; for example, in a bareboard environment you need to attach `rt_OneStep` to a timer interrupt. It is expected that you will customize either the generated code, the generating TLC code, or both. See “Guidelines for Modifying the Main Program” on page 32-5 and “Guidelines for Modifying rt_OneStep” on page 32-12 for further information.

---

## Generating a Custom Section

You can define custom tokens in a CGT file and direct generated code into an associated built-in section. This feature gives you additional control over the formatting of code within each built-in section. For example, you could add subsections to built-in sections that do not already define any subsections. All custom sections must be associated with one of the built-in sections: `Includes`, `Defines`, `Types`, `Enums`, `Definitions`, `Declarations`, or `Functions`. To create custom sections, you must

- Add a custom token to the code insertion section of your CGT file.
- In your CFP file:
  - Assemble code to be generated to the custom section into a buffer.
  - Declare an association between the custom section and a built-in section, with the code template API function `LibAddSourceFileCustomSection`.
  - Emit code to the custom section with the code template API function `LibSetSourceFileCustomSection`.

The following code examples illustrate the addition of a custom token, `Myincludes`, to a CGT file, and the subsequent association of the custom section `Myincludes` with the built-in section `Includes` in a CFP file.

---

**Note** If you have not already created custom CGT and CFP files for your model, copy the default template files *`matlabroot`*`/toolbox/rtw/targets/ecoder/ert_code_template.cgt` and *`matlabroot`*`/toolbox/rtw/targets/ecoder/example_file_process.tlc` to a work directory that is outside the MATLAB directory structure but on the MATLAB or TLC path, rename them (for example, add the prefix `test_` to each file), and update the **Templates** pane of the Configuration Parameters dialog box to correctly reference them.

---

First, add the token `Myincludes` to the code insertion section of your CGT file. For example:

```
%<Includes>
%<Myincludes>
%<Defines>
%<Types>
%<Enums>
%<Definitions>
%<Declarations>
%<Functions>
```

Next, in the CFP file, add code to generate `include` directives into a buffer. For example, in your copy of the example CFP file, you could insert the following section between the `Includes` section and the `Create a simple main` section:

```
%% Add a custom section to the model's C file model.c

%openfile tmpBuf
#include "moretables1.h"
#include "moretables2.h"
%closefile tmpBuf

%<LibAddSourceFileCustomSection(modelC,"Includes","Myincludes")>
%<LibSetSourceFileCustomSection(modelC,"Myincludes",tmpBuf)>
```

The `LibAddSourceFileCustomSection` function call declares an association between the built-in section `Includes` and the custom section `Myincludes`. In effect, `Myincludes` is a subsection of `Includes`.

The `LibSetSourceFileCustomSection` function call directs the code in the `tmpBuf` buffer to the `Myincludes` section of the generated file. `LibSetSourceFileCustomSection` is syntactically identical to `LibSetSourceFileSection`.

In the generated code, the include directives generated to the custom section appear after other code directed to `Includes`.

```
#include "rtwdemo_udt.h"
#include "rtwdemo_udt_private.h"

/* #include "mytables.h" */
#include "moretables1.h"
#include "moretables2.h"
```

---

**Note** The placement of the custom token in this example CGT file is arbitrary. By locating `%<Myincludes>` after `%<Includes>`, the CGT file ensures only that the `Myincludes` code appears after `Includes` code.

---

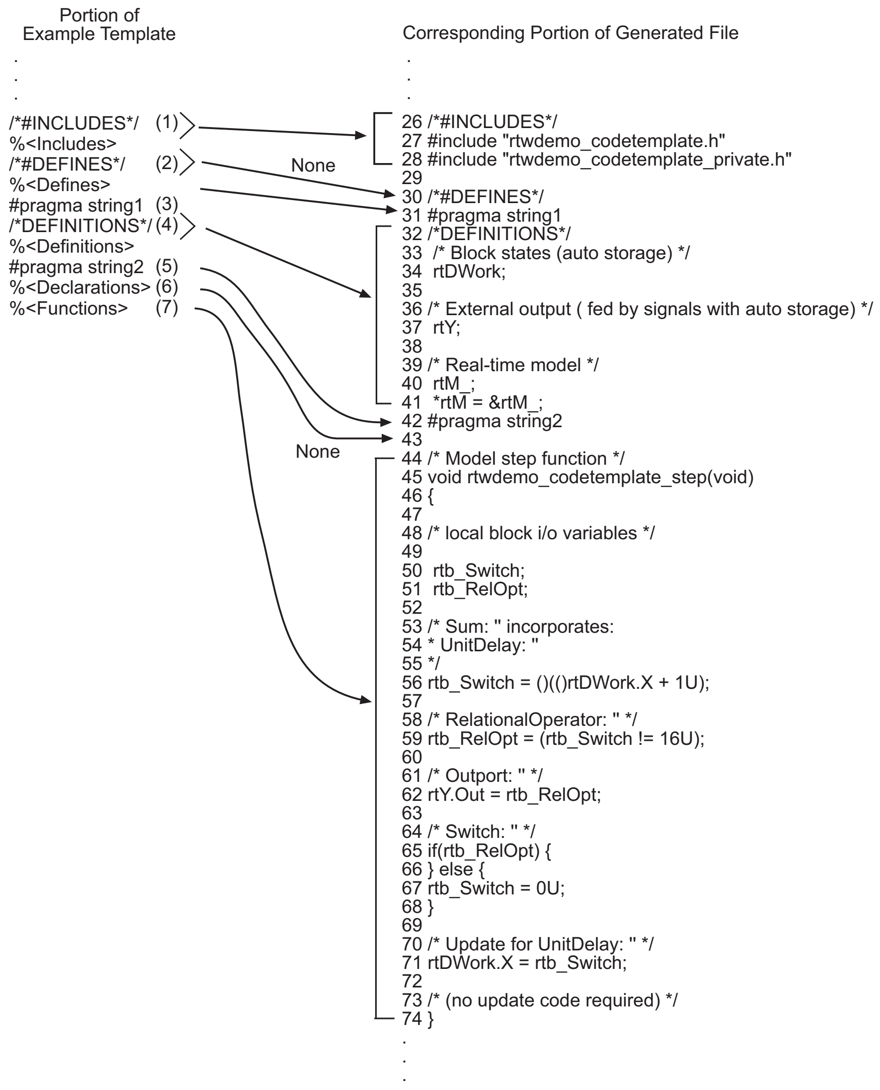
## Comparison of a Template and Its Generated File

The next figure shows part of a user-modified MPF template and the resulting Real-Time Workshop Embedded Coder generated code. This figure illustrates how you can use a template to

- Define what code the Real-Time Workshop Embedded Coder software should add to the generated file
- Control the location of code in the file
- Optionally insert comments in the generated file

Notice `%<Includes>`, for example, on the template. The term `Includes` is a symbol name. A percent sign and brackets (`%< >`) must enclose every symbol name. You can add the desired symbol name (within the `%< >` delimiter) at a particular location in the template. This is how you control where the code generator places an item in the generated file.

## Template and Generated File


Portion of Example Template
Corresponding Portion of Generated File
None
None

```
.
.
.
/*#INCLUDES*/      (1)
%<Includes>
/*#DEFINES*/       (2)
%<Defines>
#pragma string1    (3)
/*DEFINITIONS*/    (4)
%<Definitions>
#pragma string2    (5)
%<Declarations>    (6)
%<Functions>       (7)
```

```
.
.
.
/*#INCLUDES*/
#include "rtwdemo_codetemplate.h"
#include "rtwdemo_codetemplate_private.h"

/*#DEFINES*/
#pragma string1
/*DEFINITIONS*/
 /* Block states (auto storage) */
 rtDWork;

/* External output ( fed by signals with auto storage) */
 rtY;

/* Real-time model */
 rtM_;
 *rtM = &rtM_;
#pragma string2

/* Model step function */
void rtwdemo_codetemplate_step(void)
{

/* local block i/o variables */

 rtb_Switch;
 rtb_RelOpt;

/* Sum: '' incorporates:
* UnitDelay: ''
*/
rtb_Switch = ()(()rtDWork.X + 1U);

/* RelationalOperator: '' */
rtb_RelOpt = (rtb_Switch != 16U);

/* Outport: '' */
rtY.Out = rtb_RelOpt;

/* Switch: '' */
if(rtb_RelOpt) {
} else {
rtb_Switch = 0U;
}

/* Update for UnitDelay: '' */
rtDWork.X = rtb_Switch;

/* (no update code required) */
}
.
.
.
```

### How the Template Affects Code Generation

| This part of the template... | | Generates in the file... | | Explanation |
|---|---|---|---|---|
| | | Line | Description | |
| (1) | `/*#INCLUDES*/`<br>`%<Includes>` | 26–28 | An `/*#INCLUDES*/` comment, followed by `#include` statements | The code generator adds the C/C++ comment as a header, and then interprets the `%<Includes>` template symbol to list all the necessary `#include` statements in the file. This code is first in this section of the file because the template entries are first. |
| (2) | `/*DEFINES*/`<br>`%<Defines>` | 30 | A `*/DEFINES*/` comment, but no `#define` statements | Next, the code generator places the comment as a header for `#define` statements, but the file does not need `#define`. No code is added. |
| (3) | `#pragma string1` | 31 | `#pragma` statements | While the code generator requires `%<>` delimiters for template symbols, it can also interpret C/C++ statements in the template without delimiters. In this case, the generator adds the specified statements to the code, following the order in which the statements appear in the template. |
| (5) | `#pragma string2` | 42 | | |
| (4) | `/#DEFINITIONS*/`<br>`%<Definitions>` | 32–41 | `/*#DEFINITIONS*/` comment, followed by definitions | The code generator places the comment and definitions needed in the file between the `#pragma` statements, according to the order in the template. It also inserts comments (lines 33 and 36) that are preset in the model's Configuration Parameters dialog box. |

**How the Template Affects Code Generation (Continued)**

| This part of the template... | | Generates in the file... | | Explanation |
|---|---|---|---|---|
| | | Line | Description | |
| (6) | `%<Declarations>` | 43 | No declarations | The file needs no declarations, so the code generator does not generate any for this file. The template has no comment to provide a header. Line 43 is left blank. |
| (7) | `%<Functions>` | 44–74 | Functions | Finally, the code generator adds functions from the model, plus comments that are preset in the Configuration Parameters dialog box. But it adds no comments as a header for the functions, because the template does not have one. This code is last because the template entry is last. |

For a list of template symbols and the rules for using them, see “Template Symbol Groups” on page 16-58, “Template Symbols” on page 16-60, and “Rules for Modifying or Creating a Template” on page 16-65. To set comment options, from the **Simulation** menu, select **Configuration Parameters**. On the Configuration Parameters dialog box, select the **Real-Time Workshop > Comments** pane. For details, see “Configuring a Model for Code Generation” in the Real-Time Workshop documentation.

## Code Template API Summary

Code Template API Functions on page 16-47 summarizes the code template API. See the source code in `*matlabroot*/rtw/c/tlc/mw/codetemplatelib.tlc` for detailed information on the arguments, return values, and operation of these calls.

## Code Template API Functions

| Function | Description |
|---|---|
| `LibGetNumSourceFiles` | Returns the number of created source files (`.c` or `.cpp` and `.h`). |
| `LibGetSourceFileTag` | Returns `<filename>_h` and `<filename>_c` for header and source files, respectively, where `filename` is the name of the model file. |
| `LibCreateSourceFile` | Creates a new C or C++ file and returns its reference. If the file already exists, simply returns its reference. |
| `LibGetSourceFileFromIdx` | Returns a model file reference based on its index. This is useful for a common operation on all files, such as to set the leading file banner of all files. |
| `LibSetSourceFileSection` | Adds to the contents of a specified section within a specified file (see also “Custom File Processing (CFP) Template Structure” on page 16-30). |
| `LibIndentSourceFile` | Indents a file with the Real-Time Workshop `c_indent` utility (from within the TLC environment). |
| `LibCallModelInitialize` | Returns code for calling the model’s *`model`*`_initialize` function (valid for ERT only). |
| `LibCallModelStep` | Returns code for calling the model’s *`model`*`_step` function (valid for ERT only). |
| `LibCallModelTerminate` | Returns code for calling the model’s *`model`*`_terminate` function (valid for ERT only). |
| `LibCallSetEventForThisBaseStep` | Returns code for calling the model’s set events function (valid for ERT only). |

**Code Template API Functions (Continued)**

| Function | Description |
|---|---|
| `LibWriteModelData` | Returns data for the model (valid for ERT only). |
| `LibSetRTModelErrorStatus` | Returns the code to set the model error status. |
| `LibGetRTModelErrorStatus` | Returns the code to get the model error status. |
| `LibIsSingleRateModel` | Returns true if model is single rate and false otherwise. |
| `LibGetModelName` | Returns name of the model (no extension). |
| `LibGetMdlSrcBaseName` | Returns the name of model's main source file (for example, *`model`*`.c` or `.cpp`). |
| `LibGetMdlPubHdrBaseName` | Returns the name of model's public header file (for example, *`model`*`.h`). |
| `LibGetMdlPrvHdrBaseName` | Returns the name of the model's private header file (for example, *`model`*`_private.h`). |
| `LibIsSingleTasking` | Returns `true` if the model is configured for single-tasking execution. |
| `LibWriteModelInput` | Returns the code to write to a particular root input (that is, a model inport block). (valid for ERT only). |
| `LibWriteModelOutput` | Returns the code to write to a particular root output (that is, a model outport block). (valid for ERT only). |
| `LibWriteModelInputs` | Returns the code to write to root inputs (that is, all model inport blocks). (valid for ERT only) |
| `LibWriteModelOutputs` | Returns the code to write to root outputs (that is, all model outport blocks). (valid for ERT only). |

**Code Template API Functions (Continued)**

| Function | Description |
|---|---|
| `LibNumDiscreteSampleTimes` | Returns the number of discrete sample times in the model. |
| `LibSetSourceFileCodeTemplate` | Set the code template to be used for generating a specified source file. |
| `LibSetSourceFileOutputDirectory` | Set the directory into which a specified source file is to be generated. |
| `LibAddSourceFileCustomSection` | Add a custom section to a source file. The custom section must be associated with one of the built-in (required) sections: `Includes`, `Defines`, `Types`, `Enums`, `Definitions`, `Declarations`, or `Functions`. |
| `LibSetSourceFileCustomSection` | Adds to the contents of a specified custom section within a specified file. The custom section must have been previously created with `LibAddSourceFileCustomSection`. |
| `LibGetSourceFileCustomSection` | Returns the contents of a specified custom section within a specified file. |
| `LibSetCodeTemplateComplianceLevel` | This function must be called from your CFP template before any other code template API functions are called. Pass in `2` as the `level` argument. |

## Generating Custom File and Function Banners

Using code generation template (CGT) files, you can specify custom file banners and function banners for the generated code files. File banners are comment sections in the header and trailer sections of a generated file. Function banners are comment sections for each function in the generated code. Use these banners to add a company copyright statement, specify a special version symbol for your configuration management system, remove time stamps, and for many other purposes. These banners can contain characters, which propagate to the generated code.

To specify banners, create a custom CGT file with customized banner sections. The build process creates an executable TLC file from the CGT file. The code generation process then invokes the TLC file.

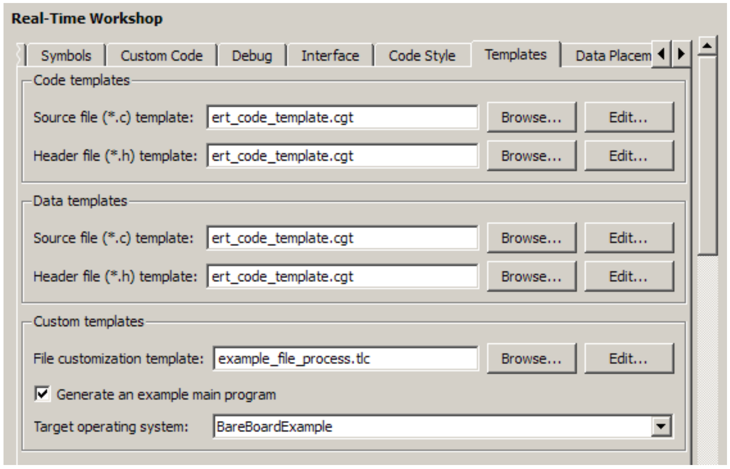
You do not need to be familiar with TLC programming to generate custom banners. You can modify example files that are supplied with the ERT target.

---

**Note** Prior releases supported direct use of customized TLC files as banner templates. You specified these with the **Source file (.c) banner template** and **Header file (.h) banner template** options of the ERT target. You can still use a custom TLC file banner templates, however, you can now use CGT files instead.

---

ERT template options on the **Real-Time Workshop > Templates** pane of a configuration set, in the **Code templates** section, support banner generation.



Code templates

Source file (*.c) template: ert_code_template.cgt

Header file (*.h) template: ert_code_template.cgt

Data templates

Source file (*.c) template: ert_code_template.cgt

Header file (*.h) template: ert_code_template.cgt

Custom templates

File customization template: example_file_process.tlc

☑ Generate an example main program

Target operating system: BareBoardExample

**Real-Time Workshop: Templates Pane**

The options for function and file banner generation are:

- "Code templates: Source file (*.c) template": CGT file to use when generating source (`.c` or `.cpp`) files. Place this file on the MATLAB path.

- “Code templates: Header file (*.h) template”: CGT file to use when generating header (`.h`) files. You must place this file on the MATLAB path. This file can be the same template specified in the **Code templates: Source file (*.c) template** field, in which case identical banners are generated in source and header files.

  By default, the template for both source and header files is `*matlabroot*/toolbox/rtw/targets/ecoder/ert_code_template.cgt`.

- In each of these fields, click **Browse** to navigate to and select an existing CGT file for use as a template. Click **Edit** to open the specified file into the MATLAB editor, where you can customize it.

## Creating a Custom File and Function Banner Template

To customize a CGT file for custom banner generation, make a local copy of the default code template and edit it, as follows:

1. Activate the configuration set you that want to work with.
2. Open the **Real-Time Workshop** pane of the active configuration set.
3. Click the **Templates** tab.
4. By default, the code template specified in the **Code templates: Source file (*.c) template** and **Code templates: Header file (*.h) template** fields is `*matlabroot*/toolbox/rtw/targets/ecoder/ert_code_template.cgt`.
5. If you want to use a different template as your starting point, click **Browse** to locate and select a CGT file.
6. Click **Edit** button to open the CGT file into the MATLAB editor.
7. Save a local copy of the CGT file. Store the copy in a directory that is outside of the MATLAB directory structure, but on the MATLAB path. If necessary, add the directory to the MATLAB path.
8. If you intend to use the CGT file with a custom target, locate the CGT file in a folder under your target root directory.
9. Rename your local copy of the CGT file. When you rename the CGT file, update the associated **Code templates: Source file (*.c) template** or **Code templates: Header file (*.h) template** field to match the new file name.
10. Edit and customize the local copy of the CGT file for banner generation, using the information provided in "Customizing a Code Generation Template (CGT) File for File and Function Banner Generation" on page 16-53.
11. Save your changes to the CGT file.
12. Click **Apply** to update the configuration set.
13. Save your model.

**14** Generate code. Examine the generated source and header files to confirm that they contain the banners specified by the template or templates.

### Customizing a Code Generation Template (CGT) File for File and Function Banner Generation

This section describes how to edit a CGT file for custom file and function banner generation. For a description of CGT files, see "Code Generation Template (CGT) Files" on page 16-26.

**Components of the File and Function Banner Sections in the CGT file.** In a CGT file, you can modify the following sections: file banner, function banner, shared utility function banner, and file trailer. Each section is defined by open and close tags. The tags specific to each section are shown in the following table.

| CGT File Section | Open Tag | Close Tag |
|---|---|---|
| "File Banner" on page 16-55 | `<FileBanner>` | `</FileBanner>` |
| "Function Banner" on page 16-56 | `<FunctionBanner>` | `</FunctionBanner>` |
| "Shared Utility Function Banner" on page 16-57 | `<SharedUtilityBanner>` | `</SharedUtilityBanner>` |
| "File Trailer" on page 16-57 | `<FileTrailer>` | `</FileTrailer>` |

You can customize your banners by including tokens and comments between the open and close tag for each section. Tokens are typically TLC variables, for example `<ModelVersion>`, which are replaced with values in the generated code.

**Note** Including C comment indicators, '/*' or a '*/', in the contents of your banner might introduce an error in the generated code.

The open tag can include a tag attribute called style, which specifies the boundary for the file or function banner comments in the generated code. Enclose the value of the style attribute in single or double quotes. The open tag syntax is:

```
<OpenTag style = “StyleValue”>
```

You can choose from several built-in styles.

| **Style value** | **Example** |
|---|---|
| `classic` style | `/* single line comments */`<br>`/*`<br>` * Multi-line comments`<br>` * Second line`<br>` */` |
| `classic_cpp` | `// single line comments`<br>`//`<br>`// multiple line contents`<br>`// second line`<br>`//` |
| `box` | `/***************************************************************/`<br>`/* banner contents                                           */`<br>`/***************************************************************/` |
| `box_cpp` | `/////////////////////////////////////////////////////////////////`<br>`// banner contents                                           //`<br>`/////////////////////////////////////////////////////////////////` |
| `open_box` | `/***************************************************************`<br>` * banner contents`<br>` ***************************************************************/` |
| `open_box_cpp` | `/////////////////////////////////////////////////////////////////`<br>`// banner contents`<br>`/////////////////////////////////////////////////////////////////` |

**File Banner.** This section contains comments and tokens for use in generating a custom file banner. The file banner precedes any C or C++ code generated by the model. If you omit the file banner section from the CGT file, then no file banner emits to the generated code. The following section is the file banner section provided with the default CGT file, *matlabroot*/toolbox/rtw/targets/ecoder/ert_code_template.cgt.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Custom file banner section (optional)
%%
<FileBanner style="classic">
File: %<FileName>

Real-Time Workshop code generated for Simulink model %<ModelName>.

Model version                       : %<ModelVersion>
Real-Time Workshop file version     : %<RTWFileVersion>
Real-Time Workshop file generated on : %<RTWFileGeneratedOn>
TLC version                         : %<TLCVersion>
C/C++ source code generated on      : %<SourceGeneratedOn>
%<CodeGenSettings>
</FileBanner>
```

### Summary of Tokens for File Banner Generation

| | |
|---|---|
| FileName | Name of the generated file (for example, "rtwdemo_udt.c"). |
| FileType | Either "source" or "header". Designates whether generated file is a .c or .cpp file or an .h file. |
| FileTag | Given file names file.c or .cpp and file.h; the file tags are "file_c" and "file_h", respectively. |
| ModelName | Name of generating model. |
| ModelVersion | Version number of model. |
| RTWFileVersion | Version number of *model*.rtw file. |
| RTWFileGeneratedOn | Timestamp of *model*.rtw file. |

**Summary of Tokens for File Banner Generation (Continued)**

| | |
|---|---|
| `TLCVersion` | Version of Target Language Compiler. |
| `SourceGeneratedOn` | Timestamp of generated file. |
| `CodeGenSettings` | Code generation settings for model: target language, target selection, embedded hardware selection, emulation hardware selection, code generation objectives (in priority order), and Code Generation Advisor validation result. |

**Function Banner.** This section contains comments and tokens for use in generating a custom function banner. The function banner precedes any C or C++ function generated during the build process. If you omit the function banner section from the CGT file, the default function banner emits to the generated code. The following section is the default function banner section provided with the default CGT file, *`matlabroot`*`/toolbox/rtw/targets/ecoder/ert_code_template.cgt`.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Custom function banner section (optional)
%%   Customize function banners by using the following predefined tokens:
%% %<ModelName>, %<FunctionName>, %<FunctionDescription>, %<Arguments>,
%% %<ReturnType>, %<GeneratedFor>, %<BlockDescription>.
%%
<FunctionBanner style="classic">
%<FunctionDescription>
%<BlockDescription>
</FunctionBanner>
```

**Summary of Tokens for Function Banner Generation**

| | |
|---|---|
| `FunctionName` | Name of function |
| `Arguments` | List of function arguments |
| `ReturnType` | Return type of function |
| `ModelName` | Name of generating model |
| `FunctionDescription` | Short abstract about the function |

**Summary of Tokens for Function Banner Generation (Continued)**

| | |
|---|---|
| `Generated For` | Full block path for the generated function |
| `BlockDescription` | User input block description |

**Shared Utility Function Banner.** The shared utility function banner section contains comments and tokens for use in generating a custom shared utility function banner. The shared utility function banner precedes any C or C++ shared utility function generated during the build process. If you omit the shared utility function banner section from the CGT file, the default shared utility function banner emits to the generated code. The following section is the default shared utility function banner section provided with the default CGT file, *`matlabroot`*`/toolbox/rtw/targets/ecoder/ert_code_template.cgt`.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Custom shared utility function banner section (optional)
%%   Customize banners for functions generated in shared location by using the
%% following predefined tokens: %<FunctionName>, %<FunctionDescription>,
%% %<Arguments>, %<ReturnType>.
%%
<SharedUtilityBanner style="classic">
%<FunctionDescription>
</SharedUtilityBanner>
```

**Summary of Tokens for Shared Utility Function Banner Generation**

| | |
|---|---|
| `FunctionName` | Name of function |
| `Arguments` | List of function arguments |
| `ReturnType` | Return type of function |
| `FunctionDescription` | Short abstract about function |

**File Trailer.** The file trailer section contains comments for generating a custom file trailer. The file trailer follows any C or C++ code generated from the model. If you omit the file trailer section from the CGT file, no file trailer emits to the generated code. The following section is the default file trailer provided in the default CGT file.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%% Custom file trailer section (optional)
%%
<FileTrailer style="classic">
File trailer for Real-Time Workshop generated code.

[EOF]
</FileTrailer>
```

All of the tokens available for the file banner are available for the file trailer. See Summary of Tokens for File Banner Generation on page 16-55.

## Template Symbols and Rules

### Introduction

"Template Symbol Groups" on page 16-58 and "Template Symbols" on page 16-60 describe MPF template symbols and rules for using them. The location of a symbol in one of the supplied template files (`code_c_template.cgt`, `code_h_template.cgt`, `data_c_template.cgt`, or `data_h_template.cgt`) determines where the items associated with that symbol are located in the corresponding generated file. "Template Symbol Groups" on page 16-58 identifies the symbol groups, starting with the parent ("Base") group, followed by the children of each parent. "Template Symbols" on page 16-60 lists the symbols alphabetically.

### Template Symbol Groups

| Symbol Group | Symbol Names in This Group |
|---|---|
| Base (Parents) | `Declarations`<br>`Defines`<br>`Definitions`<br>`Documentation`<br>`Enums`<br>`Functions`<br>`Includes` |

| Symbol Group | Symbol Names in This Group |
|---|---|
| | `Types` |
| Declarations | `ExternalCalibrationLookup1D`<br>`ExternalCalibrationLookup2D`<br>`ExternalCalibrationScalar`<br>`ExternalVariableScalar` |
| Defines | `LocalDefines`<br>`LocalMacros` |
| Definitions | `FilescopeCalibrationLookup1D`<br>`FilescopeCalibrationLookup2D`<br>`FilescopeCalibrationScalar`<br>`FilescopeVariableScalar`<br>`GlobalCalibrationLookup1D`<br>`GlobalCalibrationLookup2D`<br>`GlobalCalibrationScalar`<br>`GlobalVariableScalar` |
| Documentation | `Abstract`<br>`Banner`<br>`Created`<br>`Creator`<br>`Date`<br>`Description`<br>`FileName`<br>`History`<br>`LastModifiedDate`<br>`LastModifiedBy`<br>`ModelName` |

| Symbol Group | Symbol Names in This Group |
|---|---|
| | `ModelVersion`<br>`ModifiedBy`<br>`ModifiedComment`<br>`ModifiedDate`<br>`ModifiedHistory` |
| | `Notes`<br>`ToolVersion` |
| Functions | `CFunctionCode` |
| Types | This parent has no children. |

### Template Symbols

| Symbol Name* | Symbol Group | Symbol Scope | Symbol Description (What the symbol puts in the generated file) |
|---|---|---|---|
| `Abstract` | Documentation | N/A | User-supplied description of the model or file. Placed in the generated file based on the Stateflow note, Simulink annotation, or DocBlock on the model.** |
| `Banner` | Documentation | N/A | Comments located near top of the file. Contains information that includes model and Real-Time Workshop versions, and date file was generated. |
| `CFunctionCode` | Functions | File | All of the C/C++ functions. Must be at the bottom of the template. |

| Symbol Name* | Symbol Group | Symbol Scope | Symbol Description (What the symbol puts in the generated file) |
|---|---|---|---|
| `Created` | Documentation | N/A | Date when model was created. From **Created on** field on Model Properties dialog box. |
| `Creator` | Documentation | N/A | User who created model. From **Created by** field on Model Properties dialog box. |
| `Date` | Documentation | N/A | Date file was generated. Taken from computer clock. |
| `Declarations` | Base | | Data declaration of any signal or parameter. For example, `extern real_T globalvar;`. |
| `Defines` | Base | File | Any necessary `#defines` of `.h` files. |
| `Definitions` | Base | File | Data definition of any signal or parameter. |
| `Description` | Documentation | N/A | Description of model. From **Model description** field on Model Properties dialog box.** |
| `Documentation` | Base | N/A | Comments about how to interpret the Real-Time Workshop generated files. |
| `Enums` | Base | File | Enumerated data type definitions. |
| `ExternalCalibrationLookup1D` | Declarations | External | *** |
| `ExternalCalibrationLookup2D` | Declarations | External | *** |
| `ExternalCalibrationScalar` | Declarations | External | *** |
| `ExternalVariableScalar` | Declarations | External | *** |
| `FileName` | Documentation | N/A | Name of the generated file. |
| `FilescopeCalibrationLookup1D` | Definitions | File | *** |

| Symbol Name* | Symbol Group | Symbol Scope | Symbol Description (What the symbol puts in the generated file) |
|---|---|---|---|
| `FilescopeCalibrationLookup2D` | Definitions | File | *** |
| `FilescopeCalibrationScalar` | Definitions | File | *** |
| `FilescopeVariableScalar` | Definitions | File | *** |
| `Functions` | Base | File | Generated function code. |
| `GlobalCalibrationLookup1D` | Definitions | Global | *** |
| `GlobalCalibrationLookup2D` | Definitions | Global | *** |
| `GlobalCalibrationScalar` | Definitions | Global | *** |
| `GlobalVariableScalar` | Definitions | Global | *** |
| `History` | Documentation | N/A | User-supplied revision history of the generated files. Placed in the generated file based on the Stateflow note, Simulink annotation, or DocBlock on the model.** |
| `Includes` | Base | File | `#include` preprocessor directives. |
| `LastModifiedDate` | Documentation | N/A | Date when model was last saved. From **Last saved on** field on Model Properties dialog box. |
| `LastModifiedBy` | Documentation | N/A | User who last saved model. From **Last saved by** field on Model Properties dialog box. |
| `LocalDefines` | Defines | File | `#define` preprocessor directives from code-generation data dictionary. |
| `LocalMacros` | Defines | File | C/C++ macros local to the file. |
| `ModelName` | Documentation | N/A | Name of the model. |

| Symbol Name* | Symbol Group | Symbol Scope | Symbol Description (What the symbol puts in the generated file) |
|---|---|---|---|
| `ModelVersion` | Documentation | N/A | Version number of the Simulink model. |
| `ModifiedBy` | Documentation | N/A | Name of user who last modified the model. From **Model version** field on Model Properties dialog box. |
| `ModifiedComment` | Documentation | N/A | Comment user enters in the **Modified Comment** field on the Log Change dialog box. See "Creating a Model Change History" in the Simulink documentation. |
| `ModifiedDate` | Documentation | N/A | Date model was last modified before code was generated. |
| `ModifiedHistory` | Documentation | N/A | Text from **Modified history** field on Model Properties dialog box.** |
| `Notes` | Documentation | N/A | User-supplied miscellaneous notes about the model or generated files. Placed in the generated file based on the Stateflow note, Simulink annotation, or DocBlock on the model.** |
| `ToolVersion` | Documentation | N/A | A list of the versions of the toolboxes used in generating the code. |
| `Types` | Base | | Data types of generated code. |

* All symbol names must be enclosed between `%< >`. For example, `%<Functions>`.

** This symbol can be used to add a comment to the generated files. See "Adding Global Comments" on page 16-5. The code generator places the comment in each generated file whose template has this symbol name. The code generator places the comment at the location that corresponds to where the symbol name is located in the template file.

*** The description can be deduced from the symbol name. For example, `GlobalCalibrationScalar` is a symbol that identifies a scalar. It contains data of global scope that you can calibrate .

### Rules for Modifying or Creating a Template

The following are the rules for creating any MPF template. "Comparison of a Template and Its Generated File" on page 16-43 illustrates several of these rules.

1 Place a symbol on a template within the `%< >` delimiter. For example, the symbol named `Includes` should look like this on a template: `%<Includes>`. *Note that symbol names are case sensitive.*

2 Place a symbol on a template where desired. Its location on the template determines where the item associated with this symbol is located in the generated file. If no item is associated with it, the symbol is ignored.

3 Place a C/C++ statement outside of the `%< >` delimiter, and on a different line than a `%< >` delimiter, for that statement to appear in the generated file. For example, `#pragma message ("my text")` in the template results in `#pragma message ("my text")` at the corresponding location in the generated file. Note that the statement must be compatible with your C/C++ compiler.

4 Use the `.cgt` extension for every template filename. ("`cgt`" stands for *c*ode *g*eneration *t*emplate.)

5 Note that `%% $Revision:  1.1.4.10.4.1 $` appears at the top of the MathWorks supplied templates. This is for internal MathWorks use only. It does not need to be placed on a user-defined template and does not show in a generated file.

6 Place a comment on the template between `/* */` as in standard ANSI C[4]. This results in `/*comment*/` on the generated file.

7 Each MPF template must have all of the Base group symbols, in predefined order. They are listed in "Template Symbol Groups" on page 16-58. Each symbol in the Base group is a parent. For example, `Declarations` is a parent symbol.

8 Each symbol in a non-Base group is a child. For example, `LocalMacros` is a child.

4. ANSI® is a registered trademark of the American National Standards Institute, Inc.

9 Except for Documentation children, all children must be placed after their parent, before the next parent, and before the `Functions` symbol.

10 Documentation children can be located before or after their parent in any order anywhere in the template.

11 If a non-Documentation child is missing from the template, the code generator places the information associated with this child at its parent location in the generated file.

12 If a Documentation child is missing from the template, the code generator omits the information associated with that child from the generated file.

## Configuring the Placement of Data in Generated Code

| To... | Select or Enter... |
|---|---|
| Specify whether data is to be defined in the generated source file or in a single separate header file | Select **Auto**, **Data defined in source file**, or **Data defined in single separate source file** for the **Data definition** parameter. |
| Specify whether data is to be declared in the generated source file or in a single separate header file | Select **Auto**, **Data defined in source file**, or **Data defined in single separate source file** for the **Data declaration** parameter. |
| Specify the `#include` file delimiter to be used in generated files that contain the `#include` preprocessor directive for `mpt` data objects | Select **Auto**, **Data defined in source file**, or **Data defined in single separate source file** for the **#include file delimiter** parameter. |
| Name the generated module using the same name as the model or a user-specified name | Select **Not specified**, **Same as model**, or **User specified** for the **Module naming** parameter. |
| Control whether signal data objects are to be declared as global data in the generated code | Enter an integer value for the **Signal display level** parameter. |
| Declare a parameter data object as tunable global data in the generated code | Enter an integer value for the **Parameter tune level** parameter. |

For details about data placement, see Chapter 12, "Managing Placement of Data Definitions and Declarations".

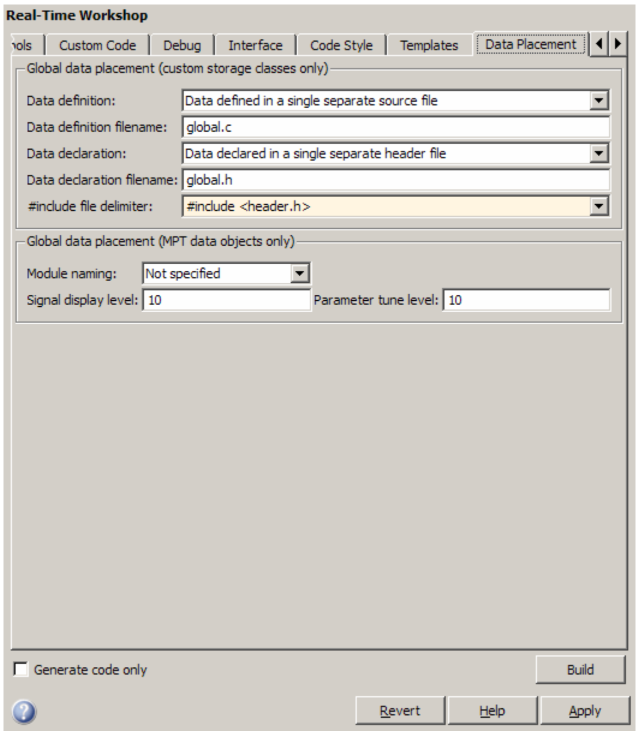
## Ensuring Delimiter Is Specified for All #Includes

Understanding the purpose of this procedure requires understanding the `Header file` property of a data object, described in Parameter and Signal Property Values on page 6-2, and applied in “Creating mpt Data Objects with Data Object Wizard” on page 11-12. For a particular data object, you can specify as the `Header file` property value a `.h` filename where that data object will be declared. Then, in the `IncludeFile` section of the generated file, this `.h` file is indicated in a `#include` preprocessor directive.

Further, when specifying the filename as the `Header file` property value, you may or may not place it within the double-quote or angle-bracket delimiter. That is, you can specify it as `filename.h`, `"filename.h"`, or `<filename.h>`. The code generator finds every data object for which you specified a filename as its `Header file` property value *without* a delimiter. By default, it assigns to each of these the double-quote delimiter.

This procedure allows you to specify the angle-bracket delimiter for these instead of the default double-quote delimiter. See the figure below.

1. In the **#include file delimiter** field on the **Data Placement** pane of the Configuration Parameters dialog box, select `#include <header.h>` instead of the default `#include "header.h"`.
2. Click **Apply**.



Global data placement (custom storage classes only)

| | |
|---|---|
| Data definition: | Data defined in a single separate source file |
| Data definition filename: | global.c |
| Data declaration: | Data declared in a single separate header file |
| Data declaration filename: | global.h |
| #include file delimiter: | #include <header.h> |

Global data placement (MPT data objects only)

| | | | |
|---|---|---|---|
| Module naming: | Not specified | | |
| Signal display level: | 10 | Parameter tune level: | 10 |

☐ Generate code only

# Defining Model Configuration Variations

## Introduction

This chapter explains how to use the Embedded Real-Time (ERT) target code generation options to configure models for production code generation. The discussion also includes other options that are not specific to the ERT target, but which affect ERT code generation.

Every model contains one or more named configuration sets that specify model parameters such as solver options, code generation options, and other choices. A model can contain multiple configuration sets, but only one configuration set is active at any time. A configuration set includes code generation options that affect Real-Time Workshop code generation in general, and options that are specific to a given target, such as the ERT target.

Configuration sets can be particularly useful in embedded systems development. By defining multiple configuration sets in a model, you can easily retarget code generation from that model. For example, one configuration set might specify the default ERT target with external mode support enabled for rapid prototyping, while another configuration set might specify the ERT-based target for Visual C++ to generate production code for deployment of the application. Activation of either configuration set fully reconfigures the model for the appropriate type of code generation.

Before you work with the ERT target options, you should become familiar with

- Configuration sets and how to view and edit them in the Configuration Parameters dialog box. The *Simulink User's Guide* document contains detailed information on these topics.
- Real-Time Workshop code generation options and the use of the System Target File Browser. The Real-Time Workshop documentation contains detailed information on these topics.

For descriptions of the Embedded Real-Time (ERT) target code generation options, see "Configuration Parameters" in the Real-Time Workshop Embedded Coder reference documentation.

## Viewing ERT Target Options in the Configuration Parameters Dialog Box or Model Explorer

The Configuration Parameters dialog box and Model Explorer provide the quickest routes to a model's active configuration set. Illustrations throughout this chapter and "Configuration Parameters" in the Real-Time Workshop Embedded Coder reference documentation show the Configuration Parameters dialog box view of model parameters (unless otherwise noted).

# Generating Code and Building Executables

18

# Generating Code Modules

# Code Modules

**In this section...**

## Introduction

This section summarizes the code modules and header files that make up a Real-Time Workshop Embedded Coder program, and describes where to find them.

Note that in most cases, the easiest way to locate and examine the generated code files is to use the Real-Time Workshop Embedded Coder code generation report. The code generation report provides a table of hyperlinks that let you view the generated code in the MATLAB Help browser. See Chapter 19, "Generating Reports for Code Reviews and Traceability Analysis" for more information.

## Generated Code Modules

The Real-Time Workshop Embedded Coder software creates a build directory in your working directory to store generated source code. The build directory also contains object files, a makefile, and other files created during the code generation process. The default name of the build directory is `model_ert_rtw`.

Real-Time Workshop® Embedded Coder™ File Packaging on page 18-3 summarizes the structure of source code generated by the Real-Time Workshop Embedded Coder software.

---

**Note** The Real-Time Workshop Embedded Coder file packaging differs slightly (but significantly) from the file packaging employed by the GRT, GRT malloc, and other nonembedded targets. See the Real-Time Workshop documentation for further information.

---

**Real-Time Workshop Embedded Coder File Packaging**

| File | Description |
|---|---|
| *`model`*`.c` or `.cpp` | Contains entry points for code implementing the model algorithm (for example, *`model`*`_step`, *`model`*`_initialize`, and *`model`*`_terminate`). |
| *`model`*`_private.h` | Contains local macros and local data that are required by the model and subsystems. This file is included by the generated source files in the model. You do not need to include *`model`*`_private.h` when interfacing hand-written code to a model. |
| *`model`*`.h` | Declares model data structures and a public interface to the model entry points and data structures. Also provides an interface to the real-time model data structure (*`model`*`_M`) with accessor macros. *`model`*`.h` is included by subsystem `.c` or `.cpp` files in the model.<br><br>If you are interfacing your hand-written code to generated code for one or more models, you should include *`model`*`.h` for each model to which you want to interface. |
| *`model`*`_data.c` or `.cpp` (conditional) | *`model`*`_data.c` or `.cpp` is conditionally generated. It contains the declarations for the parameters data structure, the constant block I/O data structure, and any zero representations used for the model's structure data types. If these data structures and zero representations are not used in the model, *`model`*`_data.c` or `.cpp` is not generated. Note that these structures and zero representations are declared `extern` in *`model`*`.h`. |
| *`model`*`_types.h` | Provides forward declarations for the real-time model data structure and the parameters data structure. These may be needed by function declarations of reusable functions. Also provides type definitions for user-defined types used by the model. |
| `rtwtypes.h` | Defines data types, structures and macros required by Real-Time Workshop Embedded Coder generated code. Most other generated code modules require these definitions. |
| `ert_main.c` or `.cpp` (optional) | This file is generated only if the **Generate an example main program** option is on. (This option is on by default.) See "Generate an example main program". |

**Real-Time Workshop Embedded Coder File Packaging (Continued)**

| File | Description |
|---|---|
| `autobuild.h` (optional) | This file is generated only if the **Generate an example main program** option is off. (See "Generate an example main program".) `autobuild.h` contains `#include` directives required by the static version of the `ert_main.c` main program module. Since the static `ert_main.c` is not created at code generation time, it includes `autobuild.h` to access model-specific data structures and entry points. See "Static Main Program Module" on page 32-16 for further information. |
| *`model`*`_capi.c` or `.cpp` *`model`*`_capi.h` (optional) | Provides data structures that enable a running program to access model parameters and signals without use of external mode. To learn how to generate and use the *`model`*`_capi.c` or `.cpp` and `.h` files, see the "Monitoring Signals With the C API" chapter in the Real-Time Workshop documentation. |

You can also customize the generated set of files in several ways:

- Nonvirtual subsystem code generation: You can instruct the Real-Time Workshop software to generate separate functions, within separate code files, for any nonvirtual subsystems. You can control the names of the functions and of the code files. For further information, see "Creating Subsystems" in the Real-Time Workshop documentation.
- Custom storage classes: You can use custom storage classes to partition generated data structures into different files based on file names you specify. For further information, see Chapter 7, "Creating and Using Custom Storage Classes".
- Module Packaging Features (MPF) also lets you direct the generated code into a required set of `.c` or `.cpp` and `.h` files, and control the internal organization of the generated files. For details, see Defining Data Representation and Storage for Code Generation on page 1.

## User-Written Code Modules

Code that you write to interface with generated model code usually includes a customized main module (based on a main program provided by the Real-Time Workshop software), and may also include interrupt handlers, device driver blocks and other S-functions, and other supervisory or supporting code.

You should establish a working directory for your own code modules. Your working directory should be on the MATLAB path. Minimally, you must also modify the ERT template makefile and system target file so that the build process can find your source and object files. More extensive modifications to the ERT target files are needed if you want to generate code for a particular microprocessor or development board, and to deploy the code on target hardware with a cross-development system.

See the Developing Embedded Targets document for information on how to customize the ERT target for your production requirements.

# Generating Reports for Code Reviews and Traceability Analysis

## About HTML Code Generation Report Extensions

The Real-Time Workshop Embedded Coder code generation report is an enhanced version of the HTML code generation report normally generated by the Real-Time Workshop build process. In the report:

- The **Summary** section lists version, date, and code generation objectives information. The **Configuration settings at the time of code generation** link opens a noneditable view of the Configuration Parameters dialog box that shows the Simulink model settings, including TLC options, at the time of code generation.
- The **Subsystem Report** section contains information on nonvirtual subsystems in the model.
- The **Code Interface Report** section provides information about the generated code interface, including model entry point functions and input/output data.
- The **Traceability Report** section allows you to account for **Eliminated / Virtual Blocks** that are untraceable, versus the listed **Traceable Simulink Blocks / Stateflow Objects / Embedded MATLAB Scripts**, providing a complete mapping between model elements and code.

In the **Generated Source Files** section of the **Contents** pane, you can click the names of source code files generated from your model to view their contents in a MATLAB Web browser window. In the displayed source code:

- The summary information is included as the code header.
- Global variable instances are hyperlinked to their definitions.
- If you selected the traceability option **Code-to-model**, hyperlinks within the displayed source code let you view the blocks or subsystems from which the code was generated. Click the hyperlinks to view the relevant blocks or subsystems in the Simulink model window. For more information about tracing code to blocks, see "Tracing Code To Model Objects Using Hyperlinks" on page 35-2.
- If you selected the traceability option **Model-to-code**, you can view the generated code for any block in the model. To highlight the generated code for a block in the HTML report, right-click the block and select **Real-Time Workshop > Navigate to Code**. For more information about tracking

blocks to generated code, see “Tracing Blocks to Generated Code” on page 35-4

For a complete discussion on using traceability to verify generated code, see Chapter 35, “Verifying Generated Code”

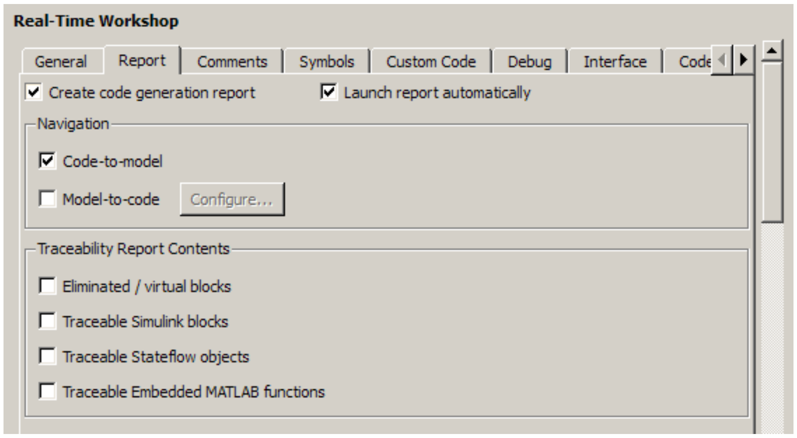
## Generating an HTML Code Generation Report

To generate a Real-Time Workshop Embedded Coder code generation report,

1. With your ERT-based model open, open the Configuration Parameters dialog box or Model Explorer and navigate to the **Real-Time Workshop > Report** pane.

2. Select **Create code generation report** if it is not already selected. By default, **Launch report automatically** and **Code-to-model** also are selected, and **Model-to-code** is cleared, as shown in the figure below.

   You can select or clear any of these options.



Real-Time Workshop

[✓] Create code generation report
[✓] Launch report automatically

Navigation
[✓] Code-to-model
[ ] Model-to-code

Traceability Report Contents
[ ] Eliminated / virtual blocks
[ ] Traceable Simulink blocks
[ ] Traceable Stateflow objects
[ ] Traceable Embedded MATLAB functions

3. Generate code from your model or subsystem (for example, for a model, by clicking **Build** on the **Real-Time Workshop** pane of the Configuration Parameters dialog box).

4. The Real-Time Workshop build process writes the code generation report files in the `html` subdirectory of the build directory. The top-level HTML report file is named *`model`*`_codegen_rpt.html` or *`subsystem`*`_codegen_rpt.html`.

5. If you selected **Launch report automatically**, the Real-Time Workshop build process automatically opens a MATLAB Web browser window and displays the code generation report.

If you did not select **Launch report automatically**, you can open the code generation report (`*model*_codegen_rpt.html` or `*subsystem*_codegen_rpt.html`) manually into a MATLAB Web browser window, or into another Web browser.

6 If you selected **Code-to-model**, hyperlinks to blocks in the generating model are created in the report files. When you view the report files in a MATLAB Web browser, clicking on these hyperlinks displays and highlights the referenced blocks in the model. For more information, see "Tracing Code To Model Objects Using Hyperlinks" on page 35-2.

7 If you selected **Model-to-code**, model-to-code highlighting support is included in the generated HTML report. To highlight the generated code for a block in your Simulink model, right-click the block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the generated code for the block in the HTML code generation report. For more information, see "Tracing Blocks to Generated Code" on page 35-4 and "Customizing Traceability Reports" on page 35-7.

**Notes**

- For large models (containing over 1000 blocks), you may find that HTML report generation takes longer than you want. In this case, consider clearing the **Code-to-model** and **Model-to-code** check boxes. The report will be generated faster.
- You can also view the HTML report files, as well as the generated code files, in the Simulink Model Explorer. See "Viewing Generated Code in the Model Explorer Code Viewer" in the Real-Time Workshop documentation for details.

## Using the Code Interface Report to Analyze the Generated Code Interface

**In this section...**

### Code Interface Report Overview

When you select the **Create code generation report** option for an ERT-based model, a **Code Interface Report** section is automatically included in the generated HTML report. The **Code Interface Report** section provides documentation of the generated code interface, including model entry point functions and interface data, for consumers of the generated code. The information in the report can help facilitate code review and code integration.

The code interface report includes the following subsections

- **Entry Point Functions** — interface information about each model entry point function, including `model_initialize`, `model_step`, and (if applicable) `model_terminate`
- **Inports** and **Outports** — interface information about each model inport and outport
- **Interface Parameters** — interface information about tunable parameters that are associated with the model
- **Data Stores** — interface information about global data stores and data stores with non-`auto` storage that are associated with the model

For limitations that apply to code interface reports, see "Code Interface Report Limitations" on page 19-18

---

**Note** This section uses the following demo models for illustration purposes:

- `rtwdemo_basicsc` (with the **ExportedGlobal Storage Class** button selected in the demo model window) for examples of report subsections
- `rtwdemo_mrmtbb` for examples of timing information
- `rtwdemo_fcnprotoctrl` for examples of function argument and return value information

---

## Generating a Code Interface Report

To generate a code interface report for your model, perform the following steps.

1. Open your model, go to the **Real-Time Workshop** pane of the Configuration Parameters dialog box, and select `ert.tlc` or an ERT-based **System target file**, if one is not already selected.

2. Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the option **Create code generation report**, if it is not already selected. The `rtwdemo_basicsc`, `rtwdemo_mrmtbb`, and `rtwdemo_fcnprotoctrl` demo models used in this section select every **Report** pane option by default, but selecting **Create code generation report** alone is sufficient to generate a **Code Interface Report** section in the HTML report.

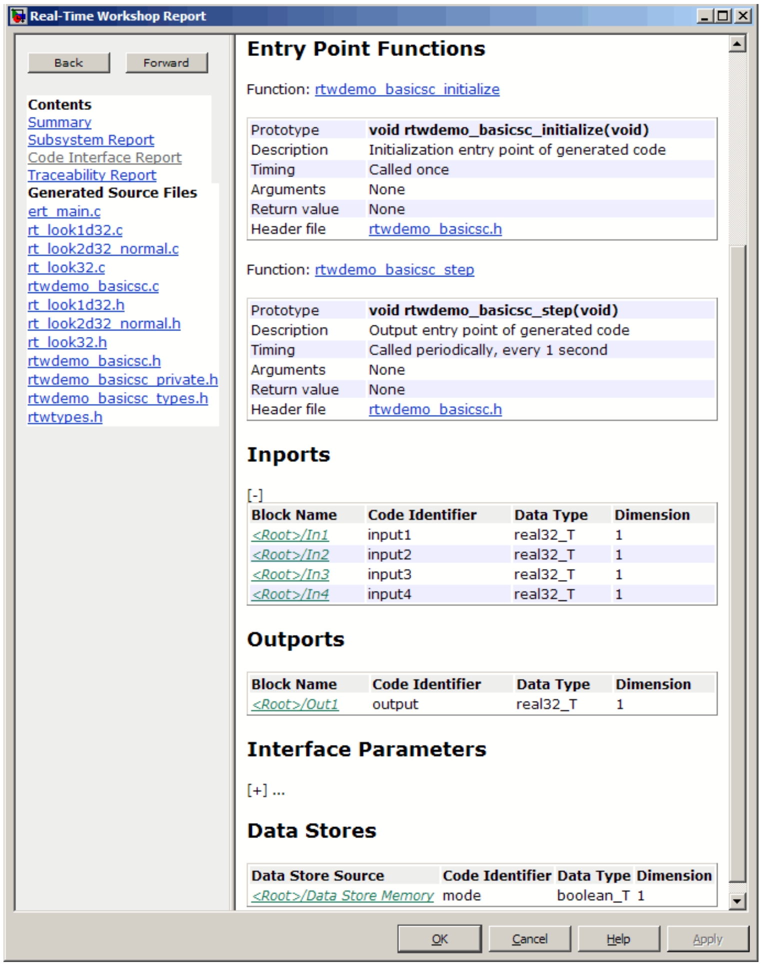
   Alternatively, you can programmatically select the option by issuing the following MATLAB command:

   ```
   set_param(bdroot, 'GenerateReport', 'on')
   ```

   If the **Report** pane option **Code-to-model** is selected, the generated report will contain hyperlinks to the model. You should leave this value selected unless you plan to use the report outside the MATLAB environment.

3 Build the model. If you selected the **Report** pane option **Launch report automatically**, the code generation report opens automatically after the build process completes. (Otherwise, you can launch it manually from within the model build directory.)

4 To display the code interface report for your model, go to the **Contents** pane of the HTML report and click the **Code Interface Report** link. For example, here is the generated code interface report for the demo model `rtwdemo_basicsc` (with the **ExportedGlobal Storage Class** button selected in the demo model window).


Real-Time Workshop Report

Back Forward

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Subsystem Report
Code Interface Report
Traceability Report

**Generated Source Files**
ert_main.c
rt_look1d32.c
rt_look2d32_normal.c
rt_look32.c
rtwdemo_basicsc.c
rt_look1d32.h
rt_look2d32_normal.h
rt_look32.h
rtwdemo_basicsc.h
rtwdemo_basicsc_private.h
rtwdemo_basicsc_types.h
rtwtypes.h

**Entry Point Functions**

Function: rtwdemo_basicsc_initialize

| | |
|---|---|
| Prototype | **void rtwdemo_basicsc_initialize(void)** |
| Description | Initialization entry point of generated code |
| Timing | Called once |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_basicsc.h |

Function: rtwdemo_basicsc_step

| | |
|---|---|
| Prototype | **void rtwdemo_basicsc_step(void)** |
| Description | Output entry point of generated code |
| Timing | Called periodically, every 1 second |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_basicsc.h |

**Inports**

[-]

| Block Name | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| <Root>/In1 | input1 | real32_T | 1 |
| <Root>/In2 | input2 | real32_T | 1 |
| <Root>/In3 | input3 | real32_T | 1 |
| <Root>/In4 | input4 | real32_T | 1 |

**Outports**

| Block Name | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| <Root>/Out1 | output | real32_T | 1 |

**Interface Parameters**

[+] ...

**Data Stores**

| Data Store Source | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| <Root>/Data Store Memory | mode | boolean_T | 1 |

For help navigating the content of the code interface report subsections, see "Navigating Code Interface Report Subsections" on page 19-10. For help interpreting the content of the code interface report subsections, see the sections beginning with "Interpreting the Entry Point Functions Subsection" on page 19-10.

## Navigating Code Interface Report Subsections

To help you navigate code interface descriptions, the code interface report provides collapse/expand tokens and hyperlinks, as follows:

- For any lengthy subsection, the report provides `[-]` and `[+]` symbols that allow you to collapse or expand that section. In the example in the previous section, the symbols are provided for the **Inports** and **Interface Parameters** sections.
- Several forms of hyperlink navigation are provided in the code interface report. For example,
  - The **Table of Contents** located at the top of the code interface report provides links to each subsection.
  - You can click on each function name to go to its declaration in *`model`*`.c`.
  - You can click on each function's header file name to go to the header file source listing.
  - If you selected the **Report** pane option **Code-to-model** for your model, you can click hyperlinks for any of the following to go to the corresponding location in the model display:
    - Function argument
    - Function return value
    - Inport
    - Outport
    - Interface parameter (if the parameter source is a block)
    - Data store (if the data store source is a Data Store Memory block)

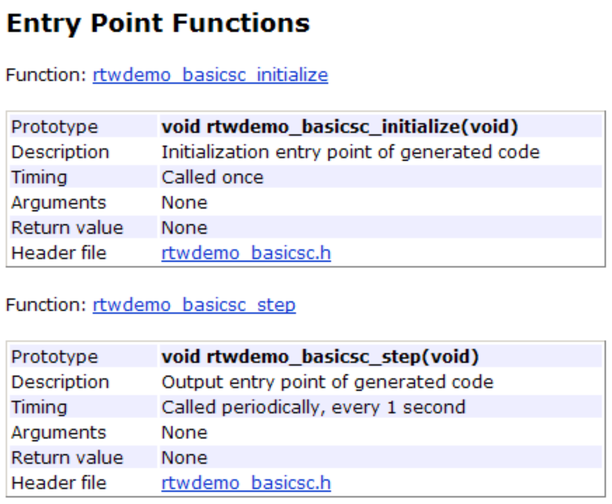
For general backward and forward navigation within the HTML code generation report, use the **Back** and **Forward** buttons above the **Contents** section in the upper left corner of the report.

## Interpreting the Entry Point Functions Subsection

The **Entry Point Functions** subsection of the code interface report provides the following interface information about each model entry point function, including `model_initialize`, `model_step`, and (if applicable) `model_terminate`.

| Field | Description |
|---|---|
| **Function:** | Lists the function name. You can click on the function name to go to its declaration in *`model`*`.c`. |
| **Prototype** | Displays the function prototype, including the function return value, name, and arguments. |
| **Description** | Provides a text description of the function's purpose in the application. |
| **Timing** | Describes the timing characteristics of the function, such as how many times the function is called, or if it is called periodically, at what time interval. For a multirate timing example, see the `rtwdemo_mrmtbb` report excerpt below. |
| **Arguments** | If the function has arguments, displays the number, name, data type, and Simulink description for each argument. If you selected the **Report** pane option **Code-to-model** for your model, you can click the hyperlink in the description to go to the block corresponding to the argument in the model display. For argument examples, see the `rtwdemo_fcnprotoctrl` report excerpt below. |
| **Return value** | If the function has a return value, displays the return value data type and Simulink description. If you selected the **Report** pane option **Code-to-model** for your model, you can click the hyperlink in the description to go to the block corresponding to the return value in the model display. For a return value example, see the `rtwdemo_fcnprotoctrl` report excerpt below. |
| **Header file** | Lists the name of the header file for the function. You can click on the header file name to go to the header file source listing. |

For example, here is the **Entry Point Functions** subsection for the demo model `rtwdemo_basicsc`.



## Entry Point Functions

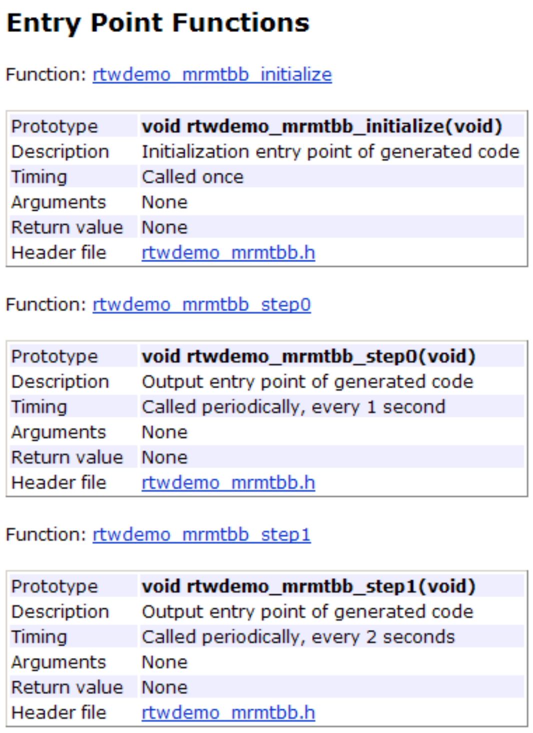
Function: rtwdemo_basicsc_initialize

| | |
|---|---|
| Prototype | **void rtwdemo_basicsc_initialize(void)** |
| Description | Initialization entry point of generated code |
| Timing | Called once |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_basicsc.h |

Function: rtwdemo_basicsc_step

| | |
|---|---|
| Prototype | **void rtwdemo_basicsc_step(void)** |
| Description | Output entry point of generated code |
| Timing | Called periodically, every 1 second |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_basicsc.h |

To illustrate how timing information might be listed for a multirate model, here are the **Entry Point Functions** and **Inports** subsections for the demo model `rtwdemo_mrmtbb`. This multirate, discrete-time, multitasking model contains Inport blocks 1 and 2, which specify 1-second and 2-second sample times, respectively. The sample times are constrained to the specified times by the **Periodic sample time constraint** option on the **Solver** pane of the Configuration Parameters dialog box.



**Entry Point Functions**

Function: rtwdemo_mrmtbb_initialize

| | |
|---|---|
| Prototype | **void rtwdemo_mrmtbb_initialize(void)** |
| Description | Initialization entry point of generated code |
| Timing | Called once |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_mrmtbb.h |

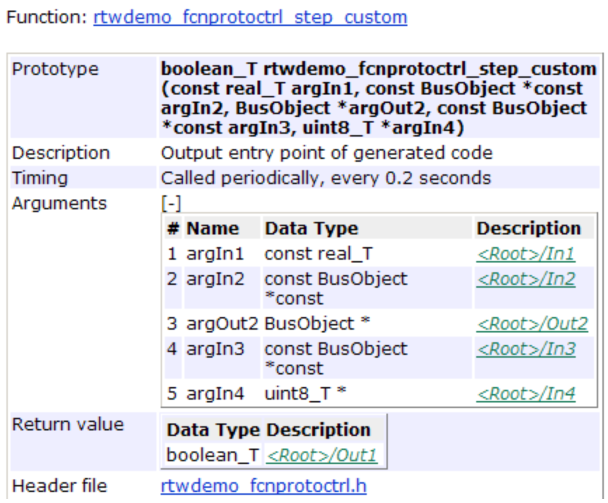
Function: rtwdemo_mrmtbb_step0

| | |
|---|---|
| Prototype | **void rtwdemo_mrmtbb_step0(void)** |
| Description | Output entry point of generated code |
| Timing | Called periodically, every 1 second |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_mrmtbb.h |

Function: rtwdemo_mrmtbb_step1

| | |
|---|---|
| Prototype | **void rtwdemo_mrmtbb_step1(void)** |
| Description | Output entry point of generated code |
| Timing | Called periodically, every 2 seconds |
| Arguments | None |
| Return value | None |
| Header file | rtwdemo_mrmtbb.h |

To illustrate how function arguments and return values are displayed in the report, here is the **Entry Point Functions** description of the model step function for the demo model `rtwdemo_fcnprotoctrl`.



Function: rtwdemo_fcnprotoctrl_step_custom

| | |
|---|---|
| Prototype | **boolean_T rtwdemo_fcnprotoctrl_step_custom (const real_T argIn1, const BusObject *const argIn2, BusObject *argOut2, const BusObject *const argIn3, uint8_T *argIn4)** |
| Description | Output entry point of generated code |
| Timing | Called periodically, every 0.2 seconds |
| Arguments | [-] |

| # | Name | Data Type | Description |
|---|---|---|---|
| 1 | argIn1 | const real_T | <Root>/In1 |
| 2 | argIn2 | const BusObject *const | <Root>/In2 |
| 3 | argOut2 | BusObject * | <Root>/Out2 |
| 4 | argIn3 | const BusObject *const | <Root>/In3 |
| 5 | argIn4 | uint8_T * | <Root>/In4 |

Return value

| Data Type | Description |
|---|---|
| boolean_T | <Root>/Out1 |

Header file: rtwdemo_fcnprotoctrl.h

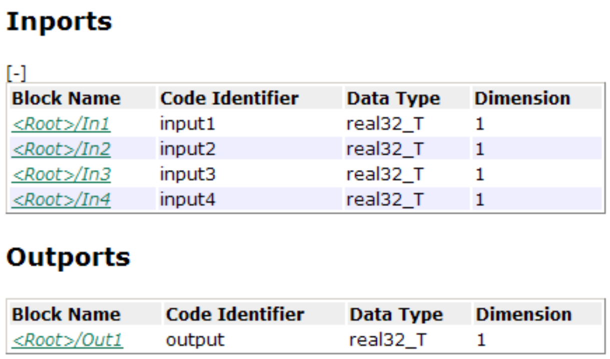
## Interpreting the Inports and Outports Subsections

The **Inports** and **Outports** subsections of the code interface report provide the following interface information about each inport and outport in the model.

| Field | Description |
|---|---|
| **Block Name** | Displays the Simulink block name of the inport or outport. If you selected the **Report** pane option **Code-to-model** for your model, you can click on each inport or outport **Block Name** value to go to its location in the model display. |
| **Code Identifier** | Lists the identifier associated with the inport or outport data in the generated code, as follows:<br><br>• If the data is defined in the generated code, the field displays the identifier string.<br>• If the data is declared but not defined in the generated code — for example, if the data is resolved with an imported storage class — the field displays the identifier string prefixed with the label '`Imported data:`'. |

| Field | Description |
|---|---|
| | • If the data is neither defined nor declared in the generated code — for example, if the option **Generate reusable code** is selected for the model — the field displays the string '`Defined externally`'. |
| **Data Type** | Lists the data type of the inport or outport. |
| **Dimension** | Lists the dimensions of the inport or outport (for example, `1` or `[4, 5]`). |

For example, here are the **Inports** and **Outports** subsections for the demo model `rtwdemo_basicsc`.



**Inports**

[-]

| Block Name | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| <Root>/In1 | input1 | real32_T | 1 |
| <Root>/In2 | input2 | real32_T | 1 |
| <Root>/In3 | input3 | real32_T | 1 |
| <Root>/In4 | input4 | real32_T | 1 |

**Outports**

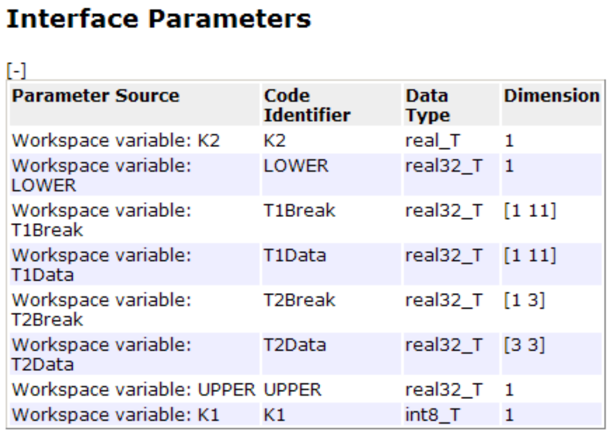
| Block Name | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| <Root>/Out1 | output | real32_T | 1 |

## Interpreting the Interface Parameters Subsection

The **Interface Parameters** subsection of the code interface report provides the following interface information about tunable parameters that are associated with the model.

| Field | Description |
|---|---|
| **Parameter Source** | Lists the source of the parameter value, as follows:<br><br>• If the source of the parameter value is a block, the field displays the block name, such as `<Root>/Gain2` or `<S1>/Lookup1`. If you selected the **Report** pane option **Code-to-model** for your model, you can click on the **Parameter Source** value to go to the parameter's location in the model display.<br>• If the source of the parameter value is a workspace variable, the field displays the name of the workspace variable prefixed with the label '`Workspace variable:`'; for example, `Workspace variable:  K2`. |
| **Code Identifier** | Lists the identifier associated with the tunable parameter data in the generated code, as follows:<br><br>• If the data is defined in the generated code, the field displays the identifier string.<br>• If the data is declared but not defined in the generated code — for example, if the data is resolved with an imported storage class — the field displays the identifier string prefixed with the label '`Imported data:`'.<br>• If the data is neither defined nor declared in the generated code — for example, if the option **Generate reusable code** is selected for the model — the field displays the string '`Defined externally`'. |
| **Data Type** | Lists the data type of the tunable parameter. |
| **Dimension** | Lists the dimensions of the tunable parameter (for example, `1` or `[4, 5, 6]`). |

For example, here is the **Interface Parameters** subsection for the demo model `rtwdemo_basicsc` (with the **ExportedGlobal Storage Class** button selected in the demo model window).



**Interface Parameters**

[-]

| Parameter Source | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| Workspace variable: K2 | K2 | real_T | 1 |
| Workspace variable: LOWER | LOWER | real32_T | 1 |
| Workspace variable: T1Break | T1Break | real32_T | [1 11] |
| Workspace variable: T1Data | T1Data | real32_T | [1 11] |
| Workspace variable: T2Break | T2Break | real32_T | [1 3] |
| Workspace variable: T2Data | T2Data | real32_T | [3 3] |
| Workspace variable: UPPER | UPPER | real32_T | 1 |
| Workspace variable: K1 | K1 | int8_T | 1 |

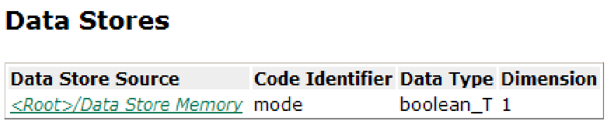
## Interpreting the Data Stores Subsection

The **Data Stores** subsection of the code interface report provides the following interface information about global data stores and data stores with non-`auto` storage that are associated with the model.

| Field | Description |
|---|---|
| **Data Store Source** | Lists the source of the data store memory, as follows:<br>• If the data store is defined using a Data Store Memory block, the field displays the block name, such as `<Root>/DS1`. If you selected the **Report** pane option **Code-to-model** for your model, you can click on the **Data Store Source** value to go to the data store's location in the model display.<br>• If the data store is defined using a `Simulink.Signal` object, the field displays the name of the `Simulink.Signal` object prefixed with the label '`Global:`'. |
| **Code Identifier** | Lists the identifier associated with the data store data in the generated code, as follows:<br>• If the data is defined in the generated code, the field displays the identifier string. |

| Field | Description |
|---|---|
| | • If the data is declared but not defined in the generated code — for example, if the data is resolved with an imported storage class — the field displays the identifier string prefixed with the label '`Imported data:`'. • If the data is neither defined nor declared in the generated code — for example, if the option **Generate reusable code** is selected for the model — the field displays the string '`Defined externally`'. |
| **Data Type** | Lists the data type of the data store. |
| **Dimension** | Lists the dimensions of the data store (for example, `1` or `[1, 2]`). |

For example, here is the **Data Stores** subsection for the demo model `rtwdemo_basicsc` (with the **ExportedGlobal Storage Class** button selected in the demo model window).



**Data Stores**

| Data Store Source | Code Identifier | Data Type | Dimension |
|---|---|---|---|
| <Root>/Data Store Memory | mode | boolean_T | 1 |

## Code Interface Report Limitations

The following limitations apply to code interface section of the HTML code generation reports.

- The code interface report does not support the GRT interface with an ERT target or the **C++ (Encapsulated)** language option. For these configurations, the code interface report will not be generated and will not appear in the HTML code generation report **Contents** pane.
- The code interface report supports data resolved with most custom storage classes (CSCs), except when the CSC properties are set in any of the following ways:

  - The CSC property **Type** is set to `FlatStructure`. For example, the `BitField` and `Struct` CSCs in the Simulink package have **Type** set to `FlatStructure` and are not supported by the code interface report.
  - The CSC property **Type** is set to `Other`. For example, the `GetSet` CSC in the Simulink package has **Type** set to `Other` and is not supported by the code interface report.
  - The CSC property **Data access** is set to `Pointer`, indicating that imported symbols are declared as pointer variables rather than simple variables. This property is accessible only when the CSC property **Data scope** is set to `Imported` or `Instance-specific`.

  In these cases, the report displays empty **Data Type** and **Dimension** fields.

- For outports, the code interface report cannot describe the associated memory (data type and dimensions) if the memory is optimized. In these cases, the report displays empty **Data Type** and **Dimension** fields.
- The code interface report does not support data type replacement using the **Real-Time Workshop > Data Type Replacement** pane of the Configuration Parameters dialog box. The data types listed in the report will link to built-in data types rather than their specified replacement data types.

# Optimizing Generated Code

## Configuring Production Code Optimizations

| To... | Select or Specify... |
|---|---|
| Control whether parameter data for reusable subsystems is generated in a separate header file for each subsystem or in a single parameter data structure | Select `Hierarchical` or `NonHierarchical` for **Parameter structure**. |
| Generate initialization code for root-level inports and outports with a value of zero | Select **Remove root level I/O zero initialization**. |
| Generate additional code to set float and double storage explicitly to value `0.0` | Select **Use memset to initialize floats and doubles to 0.0** When you set this parameter, the `memset` function clears internal storage (regardless of type) to the integer bit pattern `0` (that is, all bits are off). The additional code generated when the option is off, is slightly less efficient.If the representation of floating-point zero used by your compiler and target CPU is identical to the integer bit pattern `0`, you can gain efficiency by setting this parameter. |
| Suppress the generation of code that initializes internal work structures (for example, block states and block outputs) to zero | Select **Remove internal state zero initialization**. |
| Generate run-time initialization code for a block that has states only if the block is in a system that can reset its states, such as an enabled subsystem | Select **Optimize initialization code for model reference** This results in more efficient code, but requires that you not refer to the model from a Model block that resides in a system that resets its states. Such nesting results in an error. Turn this option off only if your application requires you refer to the model from Model blocks in systems that can reset their states. |

| To... | Select or Specify... |
|---|---|
| Remove code that ensures that execution of the generated code produces the same results as simulation when out-of-range conversions occur | Select **Remove code from floating-point to integer conversions that wraps out-of-range values**. This reduces the size and increases the speed of the generated code at the cost of potentially producing results that do not match simulation in the case of out-of-range values. |
| Suppress generation of code that guards against fixed-point division by zero | Select **Remove code that protects against division arithmetic exceptions**. When you select this parameter, simulation results and results from generated code may no longer be in bit-for-bit agreement. |
| To minimize the amount of memory allocated for absolute and elapsed time counters | Specify an integer value for **Application lifespan (days)** For more information on the allocation and operation of absolute and elapsed timers, see “Using Timers”, “Using Timers in Asynchronous Tasks”, and “Controlling Memory Allocation for Time Counters” in the Real-Time Workshop documentation. |

## Optimization Dependencies

Several parameters available on the **Optimization** pane have dependencies on settings of other options. The following table summarizes the dependencies.

| Option | Dependencies? | Dependency Details |
|---|---|---|
| **Block reduction** | No | |
| **Conditional input branch execution** | No | |
| **Implement logic signals as Boolean data (versus double)** | Yes | Disable for models created with a Simulink version that supports only signals of type `double` |
| **Signal storage reuse** | No | |
| **Inline parameters** | Yes | Disable for referenced models in a model reference hierarchy |
| **Application lifespan (days)** | No | |
| **Parameter structure** (ERT targets only) | Yes | Enabled by **Inline parameters** |
| **Enable local block outputs** | Yes | Enabled by **Signal storage reuse** |
| **Reuse block outputs** | Yes | Enabled by **Signal storage reuse** |
| **Inline invariant signals** | Yes | Enabled by **Inline parameters** |
| **Eliminate superfluous local variables (Expression folding)** | Yes | Enabled by **Signal storage reuse** |
| **Pack Boolean data into bitfields** (ERT targets only) | No | |
| **Minimize data copies between local and global variables** | Yes | Enabled by **Signal storage reuse** |
| **Simplify array indexing** (ERT targets only) | No | |
| **Loop unrolling threshold** | No | |
| **Use memcpy for vector assignment** | No | |

| Option | Dependencies? | Dependency Details |
|---|---|---|
| **Memcpy threshold (bytes)** | Yes | Enabled by **Use memcpy for vector assignment** |
| **Pass reusable subsystem output as** (ERT targets only) | No | |
| **Remove root level I/O zero initialization** (ERT targets only) | No | |
| **Use memset to initialize floats and doubles to 0.0** | No | |
| **Remove internal data zero initialization** (ERT targets only) | No | |
| **Optimize initialization code for model reference** (ERT targets only) | Yes | Disable if model includes an enabled subsystem *and* the model is referred to from another model with a Model block |
| **Remove code from floating-point to integer conversions that wrap out-of-range values** | No | |
| **Remove code from floating-point to integer conversions with saturation that maps NaN to zero** | Yes (ERT targets) No (GRT targets) | For ERT targets, enabled by **Support floating-point numbers** and **Support non-finite numbers** in the **Real-Time Workshop > Interface** pane |
| **Remove code that protects against division arithmetic exceptions** (ERT targets only) | No | |

## Optimizing Your Model with Configuration Wizard Blocks and Scripts

**In this section...**

### Overview

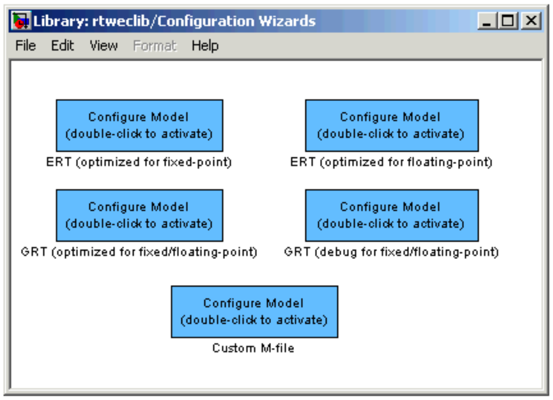
The Real-Time Workshop Embedded Coder software provides a library of *Configuration Wizard* blocks and scripts to help you configure and optimize code generation from your models quickly and easily.

The library provides a Configuration Wizard block you can customize, and four preset Configuration Wizard blocks.

| Block | Description |
|---|---|
| Custom M-file | Automatically update active configuration parameters of parent model using custom M-file |
| ERT (optimized for fixed-point) | Automatically update active configuration parameters of parent model for ERT fixed-point code generation |
| ERT (optimized for floating-point) | Automatically update active configuration parameters of parent model for ERT floating-point code generation |

| Block | Description |
|---|---|
| GRT (debug for fixed/floating-point) | Automatically update active configuration parameters of parent model for GRT fixed- or floating-point code generation with debugging enabled |
| GRT (optimized for fixed/floating-point) | Automatically update active configuration parameters of parent model for GRT fixed- or floating-point code generation |

These are shown in the figure below.


Library: rtweclib/Configuration Wizards
File Edit View Format Help
Configure Model (double-click to activate)
ERT (optimized for fixed-point)
Configure Model (double-click to activate)
ERT (optimized for floating-point)
Configure Model (double-click to activate)
GRT (optimized for fixed/floating-point)
Configure Model (double-click to activate)
GRT (debug for fixed/floating-point)
Configure Model (double-click to activate)
Custom M-file

When you add one of the preset Configuration Wizard blocks to your model and double-click it, a predefined M-file script executes and configures all parameters of the model's active configuration set without manual intervention. The preset blocks configure the options optimally for one of the following cases:

- Fixed-point code generation with the ERT target
- Floating-point code generation with the ERT target
- Fixed/floating-point code generation with TLC debugging options enabled, with the GRT target.

- Fixed/floating-point code generation with the GRT target

The Custom block is associated with an example M-file script that you can adapt to your requirements.

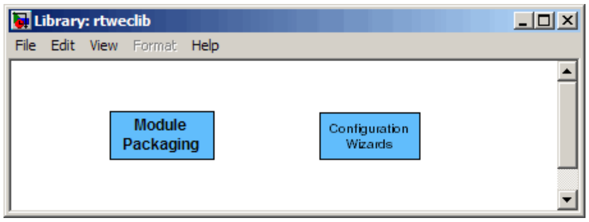
You can also set up the Configuration Wizard blocks to invoke the build process after configuring the model.

## Adding a Configuration Wizard Block to Your Model

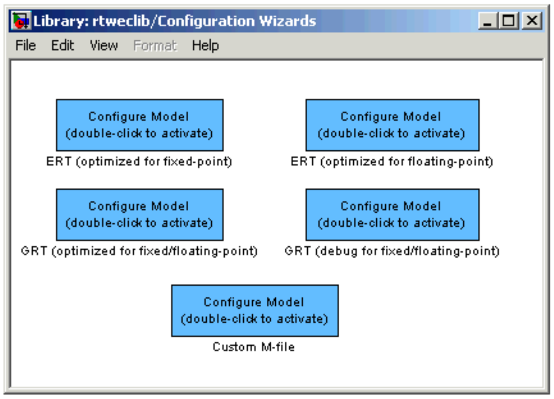
This section describes how to add one of the preset Configuration Wizard blocks to a model.

The Configuration Wizard blocks are available in the Real-Time Workshop Embedded Coder block library. To use a Configuration Wizard block:

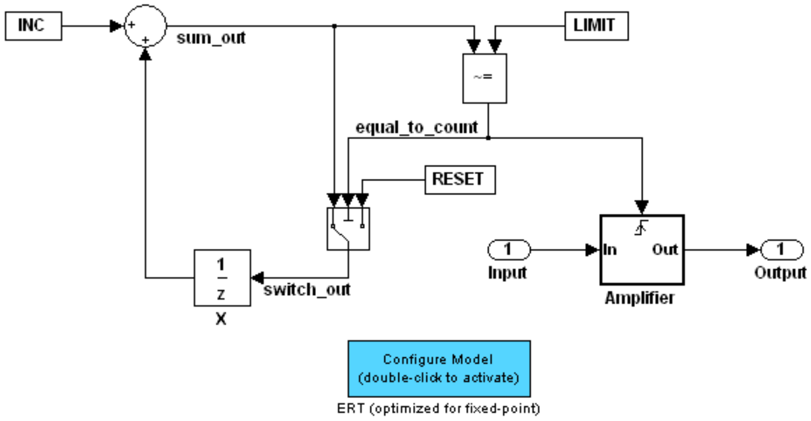
1. Open the model that you want to configure.
2. Open the Real-Time Workshop Embedded Coder library by typing the command `rtweclib`.
3. The top level of the library is shown below.



4. Double-click the Configuration Wizards icon. The Configuration Wizards sublibrary opens, as shown below.

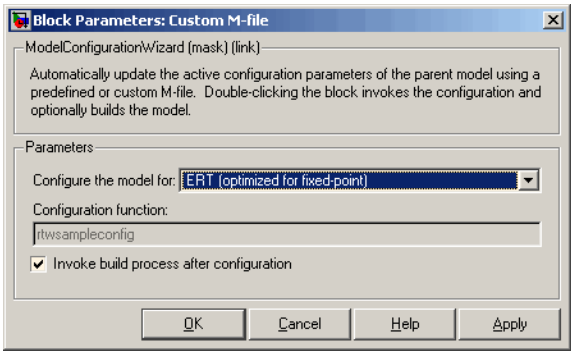

Library: rtweclib/Configuration Wizards
File
Edit
View
Format
Help
Configure Model (double-click to activate)
ERT (optimized for fixed-point)
Configure Model (double-click to activate)
ERT (optimized for floating-point)
Configure Model (double-click to activate)
GRT (optimized for fixed/floating-point)
Configure Model (double-click to activate)
GRT (debug for fixed/floating-point)
Configure Model (double-click to activate)
Custom M-file

5 Select the Configuration Wizard block you want to use and drag and drop it into your model. In the figure below, the `ERT (optimized for fixed-point)` Configuration Wizard block has been added to the model.



6 You can set up the Configuration Wizard block to invoke the build process after executing its configuration script. If you do not want to use this feature, skip to the next step.

If you want the Configuration Wizard block to invoke the build process, right-click on the Configuration Wizard block in your model, and select **Mask Parameters...** from the context menu. Then, select the **Invoke build process after configuration** option, as shown below.



ModelConfigurationWizard (mask) (link)

Automatically update the active configuration parameters of the parent model using a predefined or custom M-file. Double-clicking the block invokes the configuration and optionally builds the model.

Parameters

Configure the model for: ERT (optimized for fixed-point)

Configuration function:
rtwsampleconfig

✓ Invoke build process after configuration

7 Click **Apply**, and close the Mask Parameters dialog box.

---

**Note** You should not change the **Configure the model for** option, unless you want to create a custom block and script. In that case, see "Creating a Custom Configuration Wizard Block" on page 20-11.

---

8 Save the model.

9 You can now use the Configuration Wizard block to configure the model, as described in the next section.

## Using Configuration Wizard Blocks

Once you have added a Configuration Wizard block to your model, just double-click the block. The script associated with the block automatically sets all parameters of the active configuration set that are relevant to code generation (including selection of the appropriate target). You can verify that the options have changed by opening the Configuration Parameters dialog box and examining the settings.

If the **Invoke build process after configuration** option for the block was selected, the script also initiates the code generation and build process.

---

**Note** You can add more than one Configuration Wizard block to your model. This provides a quick way to switch between configurations.

---

## Creating a Custom Configuration Wizard Block

The Custom Configuration Wizard block is shipped with an associated M-file script, `rtwsampleconfig.m`. The script is located in the directory *`matlabroot`*`/toolbox/rtw/rtw`.

Both the block and the script are intended to provide a starting point for customization. This section describes:

- How to create a custom Configuration Wizard block linked to a custom script.

- Operation of the example script, and programming conventions and requirements for a customized script.
- How to run a configuration script from the MATLAB command line (without a block).

## Setting Up a Configuration Wizard Block

This section describes how to set up a custom Configuration Wizard block and link it to a script. If you want to use the block in more than one mode, it is advisable to create a Simulink library to contain the block.

To begin, make a copy of the example script for later customization:

1. Create a directory to store your custom script. This directory should not be anywhere inside the MATLAB directory structure (that is, it should not be under `matlabroot`).

   The discussion below refers to this directory as `/my_wizards`.

2. Add the directory to the MATLAB path. Save the path for future sessions.

3. Copy the example script (`matlabroot/toolbox/rtw/rtw/rtwsampleconfig.m`) to the `/my_wizards` directory you created in the previous steps. Then, rename the script as desired. The discussion below uses the name `my_configscript.m`.

4. Open the example script into the MATLAB editor. Scroll to the end of the file and enter the following line of code:

   ```
   disp('Custom Configuration Wizard Script completed.');
   ```

   This statement is used later as a test to verify that your custom block has executed the script.

5. Save your script and close the MATLAB editor.

The next step is to create a Simulink library and add a custom block to it. Do this as follows:

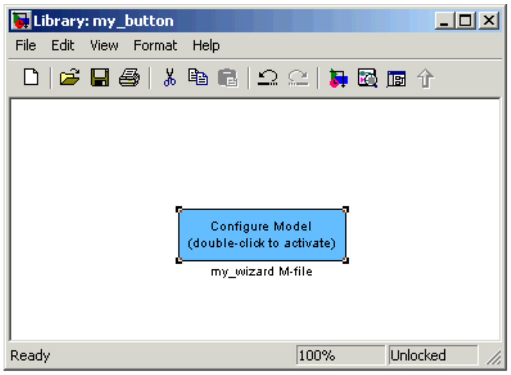
1 Open the Real-Time Workshop Embedded Coder library and the Configuration Wizards sublibrary, as described in "Adding a Configuration Wizard Block to Your Model" on page 20-8.

2 Select **New Library** from the **File** menu of the Configuration Wizards sublibrary window. An empty library window opens.

3 Select the `Custom M-file` block from the Configuration Wizards sublibrary and drag and drop it into the empty library window.

4 To distinguish your custom block from the original, edit the `Custom M-file` label under the block as desired.

5 Select **Save as** from the **File** menu of the new library window; save the library to the `/my_wizards` directory, under your library name of choice. In the figure below, the library has been saved as `my_button`, and the block has been labeled `my_wizard M-file`.

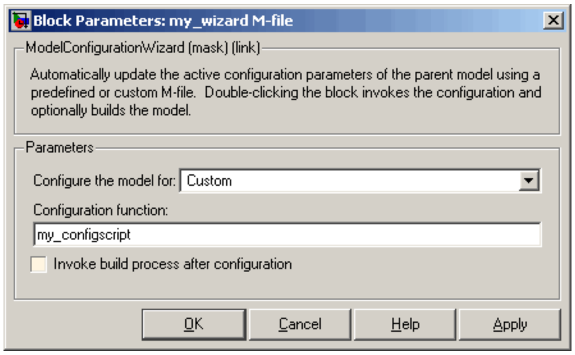


The next step is to link the custom block to the custom script:

1 Right-click on the block in your model, and select **Mask Parameters** from the context menu. Notice that the **Configure the model for** menu set to `Custom`. When `Custom` is selected, the **Configuration function** edit field is enabled, so you can enter the name of a custom script.

2 Enter the name of your custom script into the **Configuration function** field. (Do not enter the `.m` filename extension, which is implicit.) In the figure below, the script name `my_configscript` has been entered into the

**Configuration function** field. This establishes the linkage between the block and script.



Block Parameters: my_wizard M-file

ModelConfigurationWizard (mask) (link)

Automatically update the active configuration parameters of the parent model using a predefined or custom M-file. Double-clicking the block invokes the configuration and optionally builds the model.

Parameters

Configure the model for: Custom

Configuration function:

my_configscript

Invoke build process after configuration

3. Note that by default, the **Invoke build process after configuration** option is deselected. You can change the default for your custom block by selecting this option. For now, leave this option deselected.

4. Click **Apply** and close the Mask Parameters dialog box.

5. Save the library.

6. Close the Real-Time Workshop Embedded Coder library and the Configuration Wizards sublibrary. Leave your custom library open for use in the next step.

Now, test your block and script in a model. Do this as follows:

1. Open the `vdp` demo model by typing the command:

   ```
   vdp
   ```

2. Open the Configuration Parameters dialog box and view the Real-Time Workshop options by clicking on the **Real-Time Workshop** entry in the list in the left pane of the dialog box.

3. Observe that the `vdp` demo is configured, by default, for the GRT target. Close the Configuration Parameters dialog box.

4. Select your custom block from your custom library. Drag and drop the block into the `vdp` model.

5. In the `vdp` model, double-click your custom block.

6. In the MATLAB window, you should see the test message you previously added to your script:

   ```
   Custom Configuration Wizard Script completed.
   ```

   This indicates that the custom block successfully executed the script.

7. Reopen the Configuration Parameters dialog box and view the **Real-Time Workshop** pane again. You should now see that the model is configured for the ERT target.

Before applying further edits to your custom script, proceed to the next section to learn about the operation and conventions of Configuration Wizard scripts.

### Creating a Configuration Wizard Script

You should create your custom Configuration Wizard script by copying and modifying the example script, `rtwsampleconfig.m`. This section provides guidelines for modification.

**The Configuration Function.** The example script implements a single function without a return value. The function takes a single argument `cs`:

```
function rtwsampleconfig(cs)
```

The argument `cs` is a handle to a proprietary object that contains information about the model's active configuration set. The Simulink software obtains this handle and passes it in to the configuration function when the user double-clicks a Configuration Wizard block.

Your custom script should conform to this prototype. Your code should use `cs` as a "black box" object that transmits information to and from the active configuration set, using the accessor functions described below.

**Accessing Configuration Set Options.** To set options or obtain option values, use the Simulink `set_param` and `get_param` functions (if you are unfamiliar with these functions, see the Simulink Reference document).

Option names are passed in to `set_param` and `get_param` as strings specifying an *internal option name*. The internal option name is not always the same as the corresponding option label on the GUI (for example, the Configuration Parameters dialog box). The example configuration accompanies each `set_param` and `get_param` call with a comment that correlates internal option names to GUI option labels. For example:

```
set_param(cs,'LifeSpan','1'); % Application lifespan (days)
```

To obtain the current setting of an option in the active configuration set, call `get_param`. Pass in the `cs` object as the first argument, followed by the internal option name. For example, the following code excerpt tests the setting of the **Create code generation report** option:

```
if strcmp(get_param(cs, 'GenerateReport'), 'on')
    ...
```

To set an option in the active configuration set, call `set_param`. Pass in the `cs` object as the first argument, followed by one or more parameter/value pairs that specify the internal option name and its value. For example, the following code excerpt turns off the **Support absolute time** option:

```
set_param(cs,'SupportAbsoluteTime','off');
```

**Selecting a Target.** A Configuration Wizard script must select a target configuration. The example script uses the ERT target as a default. The script first stores string variables that correspond to the required **System target file**, **Template makefile**, and **Make command** settings:

```
stf = 'ert.tlc';
tmf = 'ert_default_tmf';
mc  = 'make_rtw';
```

The system target file is selected by passing the `cs` object and the `stf` string to the `switchTarget` function:

```
switchTarget(cs,stf,[]);
```

The template makefile and make command options are set by `set_param` calls:

```
set_param(cs,'TemplateMakefile',tmf);
set_param(cs,'MakeCommand',mc);
```

To select a target, your custom script needs only to set up the string variables `stf`, `tmf`, and `mc` and pass them to the appropriate calls, as above.

**Obtaining Target and Configuration Set Information.** The following utility functions and properties are provided so that your code can obtain information about the current target and configuration set, with the `cs` object:

- `isValidParam(cs, 'option')`: The `option` argument is an internal option name. `isValidParam` returns true if `option` is a valid option in the context of the active configuration set.
- `getPropEnabled(cs, 'option')`: The `option` argument is an internal option name. Returns true if this `option` is enabled (that is, writable).
- `IsERTTarget` property: Your code can detect whether or not the currently selected target is derived from the ERT target is selected by checking the `IsERTTarget` property, as follows:

```
isERT = strcmp(get_param(cs,'IsERTTarget'),'on');
```

This information can be used to determine whether or not the script should configure ERT-specific options, for example:

```
if isERT
  set_param(cs,'ZeroExternalMemoryAtStartup','off');
  set_param(cs,'ZeroInternalMemoryAtStartup','off');
  set_param(cs,'InitFltsAndDblsToZero','off');
  set_param(cs,'InlinedParameterPlacement',...
                 'NonHierarchical');
     set_param(cs,'NoFixptDivByZeroProtection','on')
end
```

## Invoking a Configuration Wizard Script from the MATLAB Command Prompt

Like any other M-file, Configuration Wizard scripts can be run from the MATLAB command prompt. (The Configuration Wizard blocks are provided as a graphical convenience, but are not essential.)

Before invoking the script, you must open a model and instantiate a `cs` object to pass in as an argument to the script. After running the script, you can invoke the build process with the `rtwbuild` command. The following example opens, configures, and builds a model.

```
open my_model;
cs = getActiveConfigSet ('my_model');
rtwsampleconfig(cs);
rtwbuild('my_model');
```

## Tips for Optimizing the Generated Code

**In this section...**

### Introduction

The Real-Time Workshop Embedded Coder software features a number of code generation options that can help you further optimize the generated code. This section highlights code generation options you can use to improve performance and reduce code size.

Most of the tips in this section apply specifically to the ERT target. See also the "Optimizing Generated Code" section of the Real-Time Workshop documentation for optimization techniques that are common to all target configurations.

### Using Configuration Wizard Blocks

the Real-Time Workshop Embedded Coder software provides a library of *Configuration Wizard* blocks and scripts to help you configure and optimize code generation from your models quickly and easily.

When you add one of the preset Configuration Wizard blocks to your model and double-click it, an M-file script executes and configures all parameters of the model's active configuration set without user intervention. The preset blocks configure the options optimally for common fixed- and floating-point code generation scenarios.

You can also create custom Configuration Wizard scripts and blocks.

See "Optimizing Your Model with Configuration Wizard Blocks and Scripts" on page 20-6 for detailed information.

## Setting Hardware Implementation Parameters Correctly

Correct specification of target-specific characteristics of generated code (such as word sizes for `char`, `short`, `int`, and `long` data types, or desired rounding behaviors in integer operations) can be critical in embedded systems development. The **Hardware Implementation** category of options in a configuration set provides a simple and flexible way to control such characteristics in both simulation and code generation.

Before generating and deploying code, you should become familiar with the options on the **Hardware Implementation** pane of the Configuration Parameters dialog box. See "Hardware Implementation Pane" in the Simulink documentation and "Configuring the Hardware Implementation" in the Real-Time Workshop documentation for full details on the **Hardware Implementation** pane.

By configuring the **Hardware Implementation** properties of your model's active configuration set to match the behaviors of your compiler and hardware, you can generate more efficient code. For example, if you specify the **Byte ordering** property, you can avoid generation of extra code that tests the byte ordering of the target CPU.

You can use the `rtwdemo_targetsettings` demo model to determine some implementation-dependent characteristics of your C or C++ compiler, as well as characteristics of your target hardware. By using this model in conjunction with your target development system and debugger, you can observe the behavior of the code as it executes on the target. You can then use this information to configure the **Hardware Implementation** parameters of your model.

To use this model, type the command

```
rtwdemo_targetsettings
```

Follow the instructions in the model window.

## Removing Unnecessary Initialization Code

Consider selecting the **Remove internal state zero initialization** and **Remove root level I/O zero initialization** options on the **Optimization** pane.

These options (both off by default) control whether internal data (block states and block outputs) and external data (root inports and outports whose value is zero) are initialized. Initializing the internal and external data whose value is zero is a precaution and may not be necessary for your application. Many embedded application environments initialize all RAM to zero at startup, making generation of initialization code redundant.

However, be aware that if you select **Remove internal state zero initialization**, it is not guaranteed that memory is in a known state each time the generated code begins execution. If you turn the option on, running a model (or a generated S-function) multiple times can result in different answers for each run.

This behavior is sometimes desirable. For example, you can turn on **Remove internal state zero initialization** if you want to test the behavior of your design during a warm boot (that is, a restart without full system reinitialization).

In cases where you have turned on **Remove internal state zero initialization** but still want to get the same answer on every run from a S-function generated by the Real-Time Workshop Embedded Coder software, you can use either of the following MATLAB commands before each run:

```
clear SFcnName
```

where *SFcnName* is the name of the S-function, or

```
clear mex
```

A related option, **Use memset to initialize floats and doubles**, lets you control the representation of zero used during initialization. See "Use memset to initialize floats and doubles to 0.0" in the Simulink reference documentation.

Note that the code still initializes data structures whose value is not zero when **Remove internal state zero initialization** and **Remove root level I/O zero initialization** are selected.

Note also that data of `ImportedExtern` or `ImportedExternPointer` storage classes is never initialized, regardless of the settings of these options.

## Generating Pure Integer Code If Possible

If your application uses only integer arithmetic, deselect the **Support floating-point numbers** option in the **Software environment** section of the **Interface** pane to ensure that generated code contains no floating-point data or operations. When this option is deselected, an error is raised if any noninteger data or expressions are encountered during code generation. The error message reports the offending blocks and parameters.

## Disabling MAT-File Logging

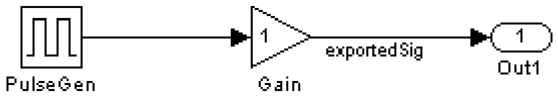
Clear the **MAT-file logging** option in the **Verification** section of the **Interface** pane. This setting is the default, and is recommended for embedded applications because it eliminates the extra code and memory usage required to initialize, update, and clean up logging variables. In addition to these efficiencies, clearing the **MAT-file logging** option lets you exploit further efficiencies under certain conditions. See "Using Virtualized Output Ports Optimization" on page 20-24 for information.

Note also that code generated to support MAT-file logging invokes `malloc`, which may be undesirable for your application.

## Using Virtualized Output Ports Optimization

The *virtualized output ports* optimization lets you store the signal entering the root output port as a global variable. This eliminates code and data storage associated with root output ports when the **MAT-file logging** option is cleared and the TLC variable `FullRootOutputVector` equals `0`, both of which are defaults for Real-Time Workshop Embedded Coder targets.

To illustrate this feature, consider the model shown in the following block diagram. Assume that the signal `exportedSig` has `exportedGlobal` storage class.



In the default case, the output of the Gain block is written to the signal storage location, `exportedSig`. No code or data is generated for the `Out1` block, which has become, in effect, a virtual block. This is shown in the following code fragment.

```
/* Gain Block: <Root>/Gain */
  exportedSig = rtb_PulseGen * VirtOutPortLogOFF_P.Gain_Gain;
```

In cases where either the **MAT-file logging** option is enabled, or `FullRootOutputVector = 1`, the generated code represents root output ports as members of an external outputs vector.

The following code fragment was generated from the same model shown in the previous example, but with **MAT-file logging** enabled. The output port is represented as a member of the external outputs vector `VirtOutPortLogON_Y`. The Gain block output value is copied to both `exportedSig` and to the external outputs vector.

```
/* Gain Block: <Root>/Gain */
  exportedSig = rtb_PulseGen * VirtOutPortLogON_P.Gain_Gain;

/* Outport Block: <Root>/Out1 */
  VirtOutPortLogON_Y.Out1 = exportedSig;
```

The overhead incurred by maintenance of data in the external outputs vector can be significant for smaller models being used to perform benchmarks.

Note that you can force root output ports to be stored in the external outputs vector (regardless of the setting of **MAT-file logging**) by setting the TLC variable `FullRootOutputVector` to `1`. You can do this by adding the statement

```
%assign FullRootOutputVector = 1
```

to the Real-Time Workshop Embedded Coder system target file. Alternatively, you can enter the assignment with **TLC options** on the **Real-Time Workshop** pane of the Configuration Parameters dialog box.

For more information on how to control signal storage in generated code, see the "Defining Data Representation and Storage for Code Generation" section of the Real-Time Workshop documentation.

## Using Stack Space Allocation Options

the Real-Time Workshop software offers a number of options that let you control how signals in your model are stored and represented in the generated code. This section discusses options that

- Let you control whether signal storage is declared in global memory space, or locally in functions (that is, in stack variables).
- Control the allocation of stack space when using local storage.

For a complete discussion of signal storage options, see the "Defining Data Representation and Storage for Code Generation" section of the Real-Time Workshop documentation.

If you want to store signals in stack space, you must turn the **Enable local block outputs** option on. To do this

1. Select the **Optimization** pane of the Configuration Parameters dialog box. Make sure that **Signal storage reuse** is selected. If **Signal storage reuse** is cleared, **Enable local block outputs** is not available.
2. Select the **Enable local block outputs** option. Click **Apply** if necessary.

Your embedded application may be constrained by limited stack space. When the **Enable local block outputs** option is on, you can limit the use of stack space by using the following TLC variables:

- `MaxStackSize`: The total allocation size of local variables that are declared by all block outputs in this model cannot exceed `MaxStackSize` (in bytes). `MaxStackSize` can be any positive integer. If the total size of local block output variables exceeds this maximum, the remaining block output variables are allocated in global, rather than local, memory. The default value for `MaxStackSize` is `rtInf`, that is, unlimited stack size.

  **Note** Local variables in the generated code from sources other than local block outputs and stack usage from sources such as function calls and context switching are not included in the `MaxStackSize` calculation. For overall executable stack usage metrics, you should do a target-specific measurement, such as using runtime (empirical) analysis or static (code path) analysis with object code.

- `MaxStackVariableSize`: Limits the size of any local block output variable declared in the code to `N` bytes, where `N>0`. A variable whose size exceeds `MaxStackVariableSize` is allocated in global, rather than local, memory. The default is 4096.

To set either of these variables, use `assign` statements in the system target file (`ert.tlc`), as in the following example.

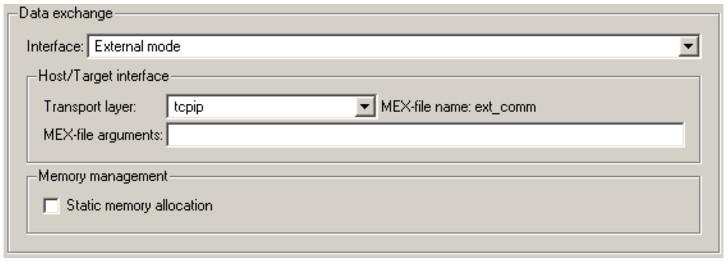
```
%assign MaxStackSize = 4096
```

You should write your `%assign` statements in the `Configure RTW code generation settings` section of the system target file. The `%assign` statement is described in the Target Language Compiler document.

## Using External Mode with the ERT Target

Selecting the **External mode** option turns on generation of code to support external mode communication between host (Simulink) and target systems. The Real-Time Workshop Embedded Coder software supports all features of Simulink external mode, as described in the "Communicating With Code Executing on a Target System Using Simulink External Mode" section of the Real-Time Workshop documentation.

This section discusses external mode options that may be of special interest to embedded systems designers. The next figure shows the **Data Exchange** subpane of the Configuration Parameters dialog box, **Interface** pane, with `External mode` selected.



Data exchange
Interface: External mode
Host/Target interface
Transport layer: tcpip
MEX-file name: ext_comm
MEX-file arguments:
Memory management
☐ Static memory allocation

### Memory Management

Consider the **Memory management** option **Static memory allocation** before generating external mode code for an embedded target. Static memory allocation is generally desirable, as it reduces overhead and promotes deterministic performance.

When you select the **Static memory allocation** option, static external mode communication buffers are allocated in the target application. When **Static memory allocation** is deselected, communication buffers are allocated dynamically (with `malloc`) at run time.

## Generation of Pure Integer Code with External Mode

The Real-Time Workshop Embedded Coder software supports generation of pure integer code when external mode code is generated. To do this, select the **External mode** option, and deselect the **Support floating-point numbers** option in the **Software environment** section of the **Interface** pane.

This enhancement lets you generate external mode code that is free of any storage definitions of double or float data type, and allows your code to run on integer-only processors

If you intend to generate pure integer code with **External mode** on, note the following requirements:

- All trigger signals must be of data type `int32`. Use a Data Type Conversion block if needed.
- When pure integer code is generated, the simulation stop time specified in the **Solver** options is ignored. To specify a stop time, run your target application from the MATLAB command line and use the `-tf` option. (See "Running the External Program" in the "External Mode" section of the Real-Time Workshop documentation.) If you do not specify this option, the application executes indefinitely (as if the stop time were `inf`).

  When executing pure integer target applications, the stop time specified by the `-tf` command line option is interpreted as the number of base rate ticks to execute, rather than as an elapsed time in seconds. The number of ticks is computed as

  ```
  stop time in seconds / base rate step size in seconds
  ```

# Developing Models and Code That Comply with Industry Standards and Guidelines

## What Are the Standards and Guidelines?

If your application has mission-critical development and certification goals, your models or subsystems and the code generated for them might need to comply with one or more of the standards and guidelines listed in the following table.

| Standard or Guidelines | Organization | For More Information, See... |
|---|---|---|
| Guidelines: Use of MATLAB, Simulink, and Stateflow software for control algorithm modeling – MathWorks Automotive Advisory Board (MAAB) Guidelines | MAAB | • Control Algorithm Modeling Guidelines Using MATLAB, Simulink, and Stateflow Software: PDF, Word<br>• “Developing Models and Code That Comply with MAAB Guidelines” on page 21-4 |
| Guidelines: Use of the C Language in Critical Systems (MISRA C[5]) | Motor Industry Software Reliability Association (MISRA) | • MISRA C Web site<br>• Technical Solution 1-1IFP0W on the MathWorks Web site<br>• “Developing Models and Code That Comply with MISRA C Guidelines” on page 21-5 |
| Standard: AUTomotive Open System ARchitecture (AUTOSAR) | AUTOSAR Development Partnership | • Publications and specifications available from the AUTOSAR Web site<br>• Technical Solution 1-2WFS27 on the MathWorks Web site<br>• Chapter 22, “Generating Code for AUTOSAR Software Components” |

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| Standard or Guidelines | Organization | For More Information, See... |
|---|---|---|
| Standard: IEC 61508, Functional safety of electrical/electronic/ programmable electronic safety-related systems | International Electrotechnical Commission | • IEC functional safety zone Web site<br>• Model-Based Design for IEC 61508 (Excerpts) — For the complete document, see Technical Solution 1-32COJP on the MathWorks Web site.<br>• "Developing Models and Code That Comply with the IEC 61508 Standard" on page 21-6 |
| Standard: DO-178B, Software Considerations in Airborne Systems and Equipment Certification | Radio Technical Commission for Aeronautics (RTCA) | • Model-Based Design for DO-178B (Excerpts) — For the complete document, see Technical Solution 1-1ZLDDE on the MathWorks Web site.<br>• "Developing Models and Code That Comply with the DO-178B Standard" on page 21-9 |

For information on whether Real-Time Workshop technology is certified or qualified and whether safety-critical software has been developed with MathWorks tools, see Real-Time Workshop Embedded Coder — Code Certification with MathWorks Tools.

## Developing Models and Code That Comply with MAAB Guidelines

The MathWorks Automotive Advisory Board (MAAB) involves major automotive OEMs and suppliers in the process of evolving MathWorks controls, simulation, and code generation products, including Simulink, Stateflow, and Real-Time Workshop. An important result of the MAAB has been the MAAB Guidelines.

If you have a Simulink Verification and Validation product license, you can

- Gain access to the guidelines
- Check that your Simulink model or subsystem and the code that you generate from it complies with MAAB guidelines by running the Simulink Model Advisor on MathWorks Automotive Advisory Board checks

1. Open your model or subsystem.
2. Start the Model Advisor.
3. In the **Task Hierarchy**, expand **By Product > Simulink Verification and Validation > Modeling Standards > MathWorks Automotive Advisory Board Checks**.
4. Select the checks that you want to enable. To generate an HTML report that shows the check results, also select **Show report after run**.
5. Click **Run Selected Checks**. The Model Advisor processes the checks and displays the results.
6. In the Model Advisor window, review the check results and make any necessary changes. To see detailed results for a specific check, select the check in the **Task Hierarchy**. The results appear in the right pane.

For more information on using the Model Advisor, see “Consulting the Model Advisor” in the Simulink documentation.

## Developing Models and Code That Comply with MISRA C Guidelines

The Motor Industry Software Reliability Association (MISRA[6]) has established “Guidelines for the Use of the C Language in Critical Systems” (MISRA C). For general information about MISRA C, see `www.misra-c.com`.

For information about using Real-Time Workshop Embedded Coder software within MISRA C guidelines, see Technical Solution 1-1IFP0W on the MathWorks Web site.

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## Developing Models and Code That Comply with the IEC 61508 Standard

**In this section...**

### Applying Simulink and Real-Time Workshop Technology to the IEC 61508 Standard

Applying Model-Based Design successfully to a safety-critical system requires extra consideration and rigor to ensure the system adheres to defined safety standards. IEC 61508, Functional safety of electrical/electronic/programmable electronic safety related systems, is such a standard. Because the standard was published when most software was coded by hand, the standard needs to be mapped to Model-Based Design technologies. Model-Based Design for IEC 61508 (Excerpts) provides a sampling of information available from a document that offers recommendations on how to apply Simulink, Real-Time Workshop, and third-party products for Model-Based Design to IEC 61508 measures and techniques. For the complete version of Model-Based Design for IEC 61508, see Technical Solution 1-32COJP on the MathWorks Web site.

### Checking for IEC 61508 Standard Compliance Using the Model Advisor

If you have a Simulink Verification and Validation product license, you can check that your Simulink model or subsystem and the code that you generate from it complies with selected aspects of the IEC 61508 standard by running the Simulink Model Advisor on IEC 61508 checks.

1 Open your model or subsystem.

2 Start the Model Advisor.

3. In the **Task Hierarchy**, expand **By Product > Simulink Verification and Validation > Modeling Standards > IEC 61508 Checks** or **By Task > Modeling Standards for IEC 61508**.

4. Select the checks that you want to enable.

5. Select **Show report after run** if you want to display an HTML report that shows the check results. Alternatively, later you can click the report link in the **Last Report** section of the results pane. In either case, you can save and print the resulting report for review or archiving purposes.

6. Click **Run Selected Checks**. The Model Advisor processes the checks and displays the results.

7. In the Model Advisor window, review the check results and make any necessary changes. To see detailed results for a specific check, select the check in the **Task Hierarchy**. The results appear in the right pane.

---

**Note** If your model uses model referencing, apply Model Advisor checks to all referenced models before applying them to the parent model.

---

For more information on using the Model Advisor, see "Consulting the Model Advisor" in the Simulink documentation.

## Validating Traceability

Typically, applications that require certification require some level of traceability between requirements, models, and corresponding code.

| To... | Use... |
|---|---|
| Associate requirements documents with objects in Simulink models | The Requirements Management Interface (RMI) that is available if you have a Simulink Verification and Validation license. |
| Trace model blocks and subsystems to generated code | The **Model-to-code** traceability option when generating an HTML report during the code generation or build process. |
| Trace generated code to model blocks and subsystems | The **Code-to-model** traceability option when generating an HTML report during the code generation or build process. |

## Developing Models and Code That Comply with the DO-178B Standard

**In this section...**

### Applying Simulink and Real-Time Workshop Technology to the DO-178B Standard

Applying Model-Based Design successfully to a safety-critical system, requires extra consideration and rigor to ensure the system adheres to defined safety standards. DO-178B, Software Considerations in Airborne Systems and Equipment Certification, is such a standard. Because the standard was published when most software was coded by hand, the standard needs to be mapped to Model-Based Design technologies. Model-Based Design for DO-178B (Excerpts) provides a sampling of information available from a document that offers recommendations on how to apply Simulink, Real-Time Workshop, and third-party products for Model-Based Design to DO-178B measures and techniques. For the complete version of Model-Based Design for DO-178B, see Technical Solution 1-1ZLDDE on the MathWorks Web site.

### Checking for Standard Compliance Using the Model Advisor

If you have a Simulink Verification and Validation product license, you can check that your Simulink model or subsystem and the code that you generate from it complies with selected aspects of the DO-178B standard by running the Simulink Model Advisor on DO-178B checks.

**1** Open your model or subsystem.

**2** Start the Model Advisor.

3. In the **Task Hierarchy**, expand **By Product > Simulink Verification and Validation > Modeling Standards > DO-178B Checks** or **By Task > Modeling Standards for DO-178B**.

4. Select the checks that you want to enable.

5. Select **Show report after run** if you want to display an HTML report that shows the check results. Alternatively, later you can click the report link in the **Last Report** section of the results pane. In either case, you can save and print the resulting report for review or archiving purposes.

6. Click **Run Selected Checks**. The Model Advisor processes the checks and displays the results.

7. In the Model Advisor window, review the check results and make any necessary changes. To see detailed results for a specific check, select the check in the **Task Hierarchy**. The results appear in the right pane.

---

**Note** If your model uses model referencing, apply Model Advisor checks to all referenced models before applying them to the parent model.

---

For more information on using the Model Advisor, see "Consulting the Model Advisor" in the Simulink documentation.

## Validating Traceability

Typically, applications that require certification require some level of traceability between requirements, models, and corresponding code.

| To... | Use... |
|---|---|
| Associate requirements documents with objects in Simulink models | The Requirements Management Interface (RMI) that is available if you have a Simulink Verification and Validation license. |
| Trace model blocks and subsystems to generated code | The **Model-to-code** traceability option when generating an HTML report during the code generation or build process. |
| Trace generated code to model blocks and subsystems | The **Code-to-model** traceability option when generating an HTML report during the code generation or build process. |

# Generating Code for AUTOSAR Software Components

## Overview of AUTOSAR Support

Real-Time Workshop Embedded Coder software supports AUTOSAR (*AUTomotive Open System ARchitecture*), an open and standardized automotive software architecture. AUTOSAR is developed jointly by automobile manufacturers, suppliers, and tool developers.

The AUTOSAR standard addresses:

- Architecture – Three layers, *Application*, *Runtime Environment (RTE)*, and *Basic Software*, enable decoupling of AUTOSAR Software Components from the execution platform. Standard interfaces between AUTOSAR Software Components and the Runtime Environment allow reuse or relocation of components within the Electronic Control Unit (ECU) topology of a vehicle.
- Methodology – Specification of code formats and description file templates, for example.
- Application Interfaces – Specification of interfaces for typical automotive applications.

For details on the AUTOSAR standard, go to www.autosar.org.

In Simulink, you can model AUTOSAR Software Components and related concepts. See "Simulink Modeling Patterns for AUTOSAR" on page 22-3.

Using Real-Time Workshop Embedded Coder software, you can generate AUTOSAR-compliant code and description files. See "Workflow for AUTOSAR " on page 22-27.

## Simulink Modeling Patterns for AUTOSAR

**In this section...**

This section describes how you model AUTOSAR Software Components and related concepts in Simulink.

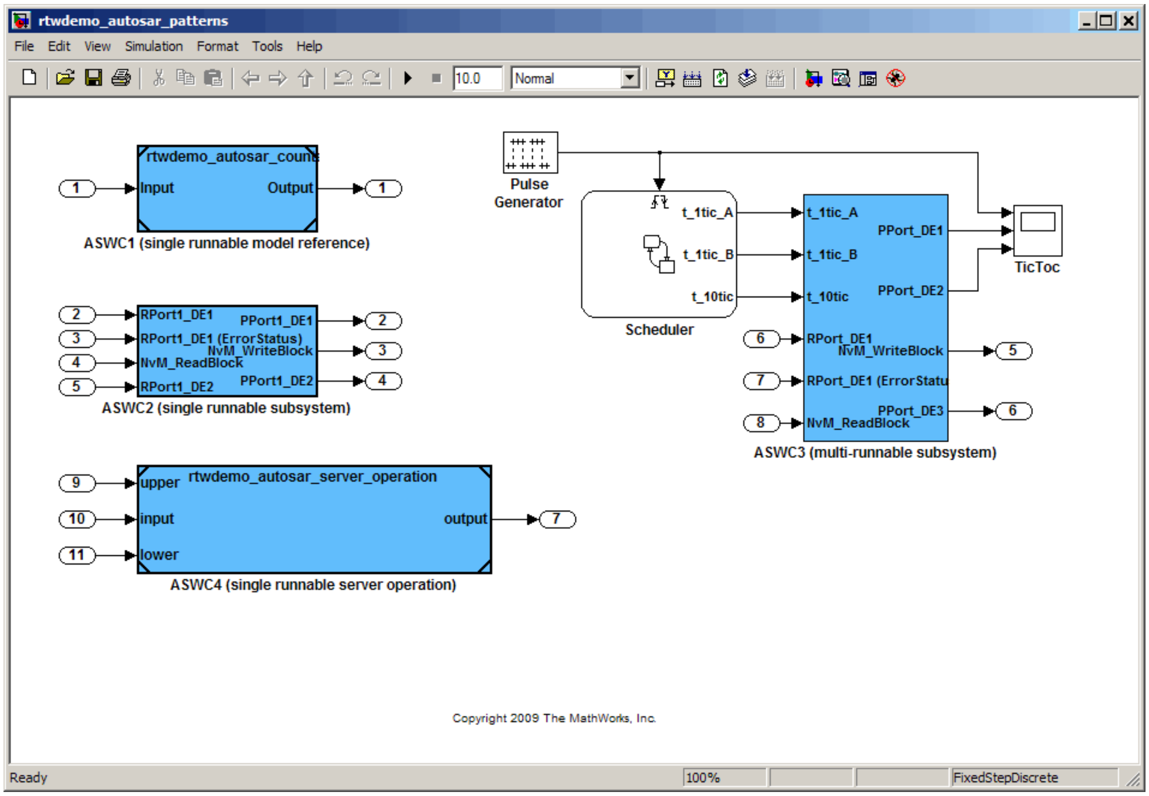
### AUTOSAR Software Components

In AUTOSAR, application software consists of separate units, *AUTOSAR Software Components*.

**Note** An AUTOSAR Software Component is sometimes referred to as *atomic* because it is never split across more than one Electronic Control Unit (ECU). Do not confuse *atomic* in this context with the concept of Simulink atomic subsystems.

The behavior of an AUTOSAR Software Component is implemented by a single or multiple *runnable entities* (runnables), which expose well-defined connection points, *ports*.

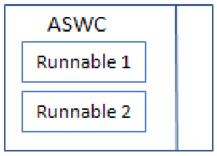
In Simulink, you can represent an AUTOSAR Software Component using a model or a subsystem. For example, the following figure shows modeling patterns for AUTOSAR Software Components (ASWC) labeled `ASWC1`, `ASWC2`, `ASWC3`, and `ASWC4`.



## Runnables

AUTOSAR Software Components contain runnables that are directly or indirectly scheduled by the underlying AUTOSAR operating system.

The following figure shows an AUTOSAR Software Component with two runnables, `Runnable 1` and `Runnable 2`. Each runnable is triggered by RTEEvents, events generated by the AUTOSAR Runtime Environment (RTE). For example, TimingEvent is an RTEEvent that is generated periodically.



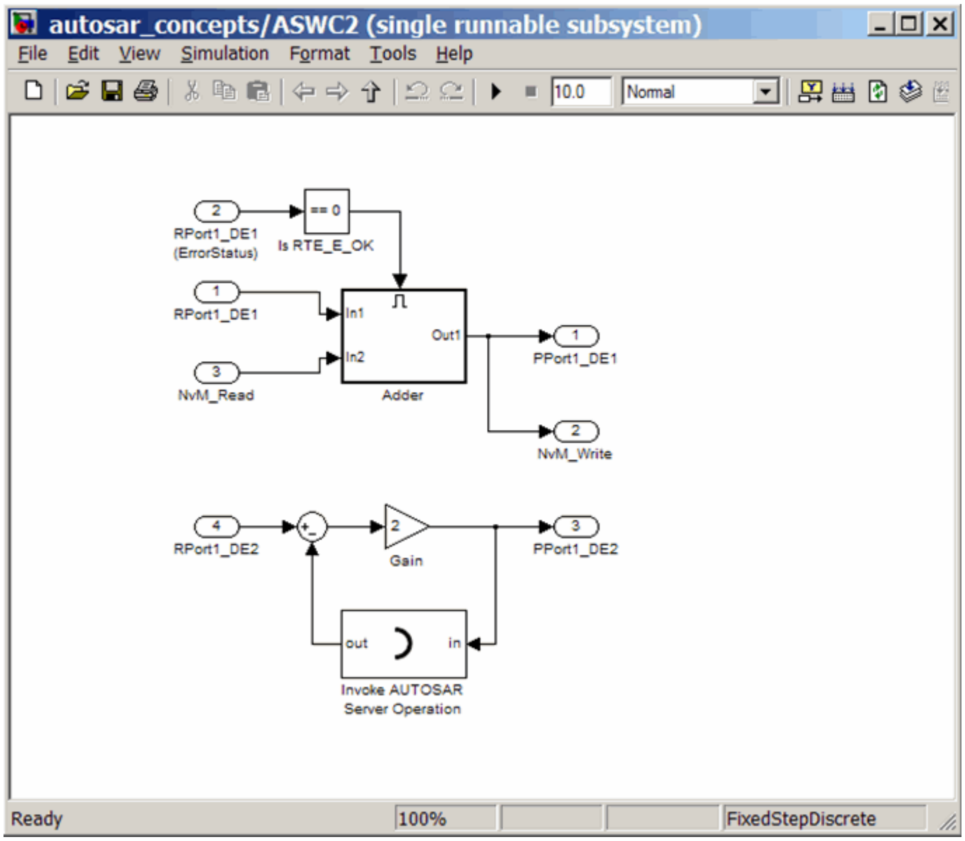
The components ASWC1, ASWC2 and ASWC4 contain single runnables. These components are represented by a subsystem or a model, and can be single- or multirate. However, the software implements each component as a single-tasking operation. A single-tasking operation uses a single-step function while a multitasking operation can have a separate step function for each rate or task.

---

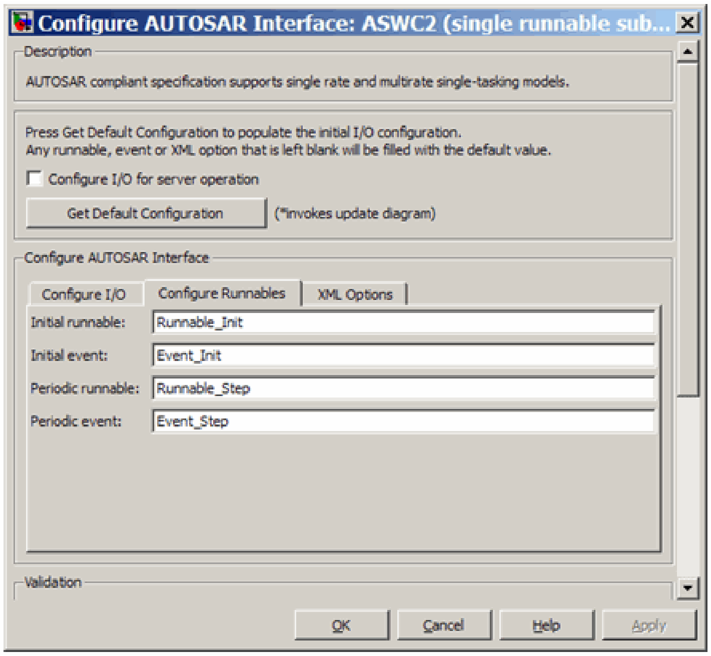
**Note** The software generates an additional runnable for the initialization function regardless of the modeling pattern.

---

ASWC2 is modeled as a single-rate, single-tasking atomic subsystem.



You can generate the ASWC2 runnable, which corresponds to the step function of the subsystem. Use the Configure AUTOSAR Interface dialog box to specify the names of the initial and periodic runnables, as shown by the following figure.


Configure AUTOSAR Interface: ASWC2 (single runnable sub...

Description

AUTOSAR compliant specification supports single rate and multirate single-tasking models.

Press Get Default Configuration to populate the initial I/O configuration.
Any runnable, event or XML option that is left blank will be filled with the default value.

☐ Configure I/O for server operation

Get Default Configuration (*invokes update diagram)

Configure AUTOSAR Interface

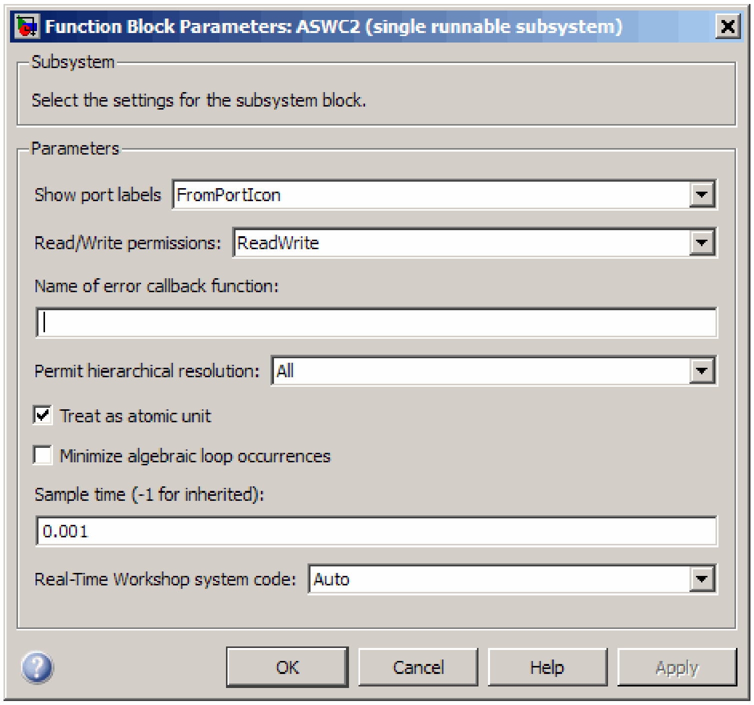
Configure I/O | Configure Runnables | XML Options

| | |
|---|---|
| Initial runnable: | Runnable_Init |
| Initial event: | Event_Init |
| Periodic runnable: | Runnable_Step |
| Periodic event: | Event_Step |

Validation

The software generates TimingEvents for the runnables, with the following periods:

- 0 for initial runnable.
- Fundamental sample time of model or atomic subsystem for periodic runnable. You specify this sample time in the **Sample time (-1 for inherited)** field in the Subsystem Parameters dialog box, as shown by the following figure.


Function Block Parameters: ASWC2 (single runnable subsystem)
OK
Cancel
Help
Apply

Subsystem

Select the settings for the subsystem block.

Parameters

Show port labels: FromPortIcon

Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

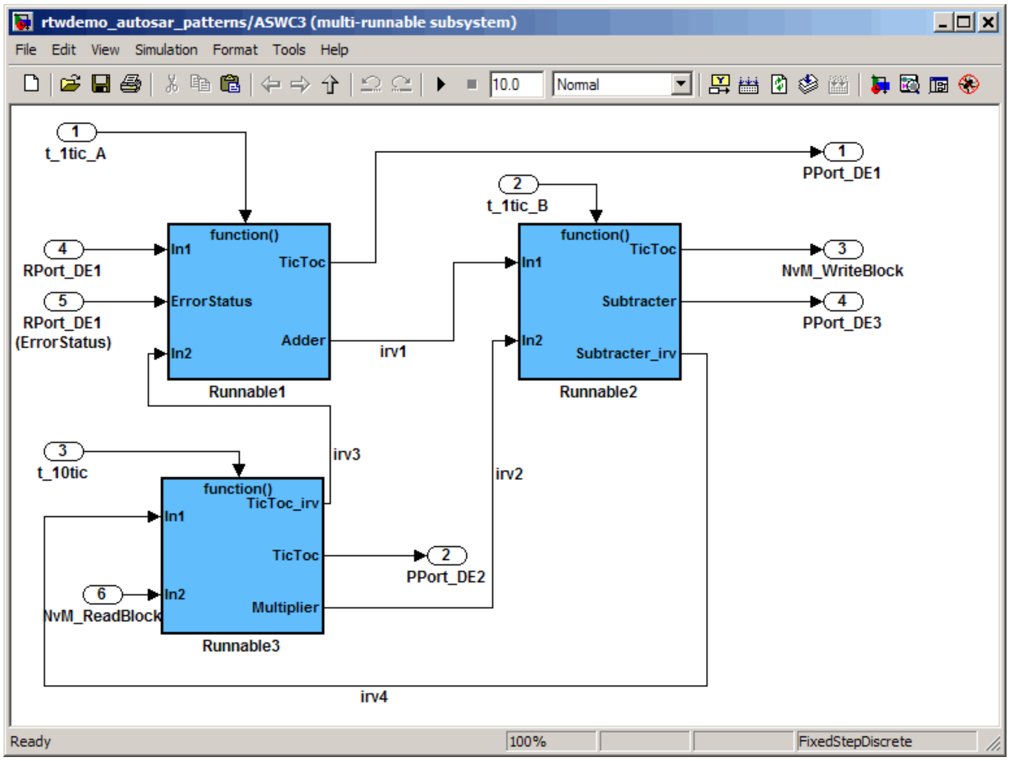
[✓] Treat as atomic unit

[ ] Minimize algebraic loop occurrences

Sample time (-1 for inherited): 0.001

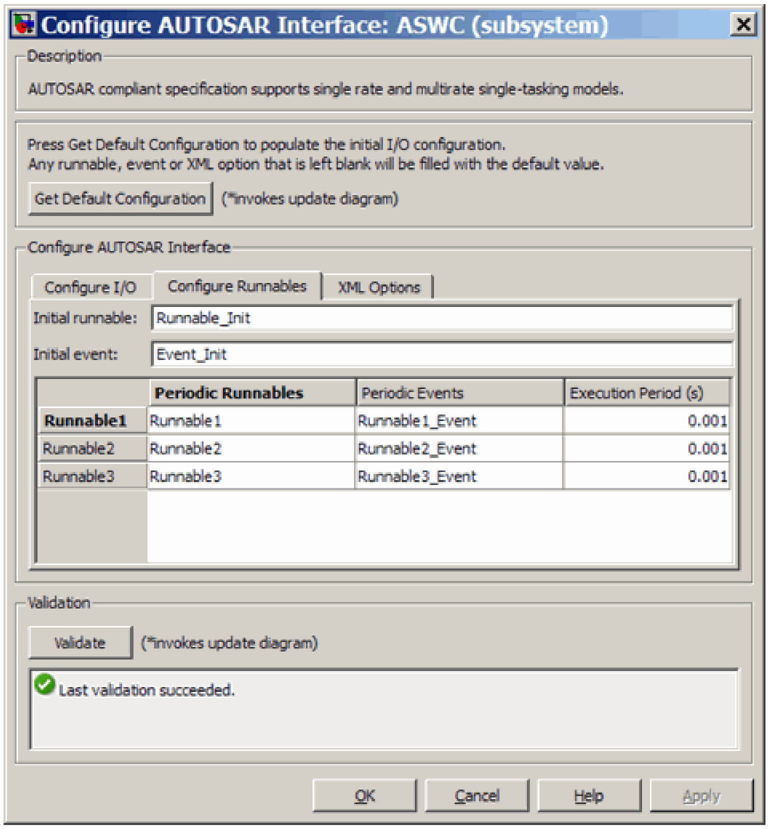
Real-Time Workshop system code: Auto

The component `ASWC3` contains multiple runnables.



You can use the Export Functions feature to map the runnables to Simulink function-call subsystems. See “Configuring Multiple Runnables” on page 22-48. The software also generates an initialization runnable for the initialization function.

Use the Configure AUTOSAR Interface dialog box to specify the names of the multiple runnables and the periods of Timing Events.


Configure AUTOSAR Interface: ASWC (subsystem)

Description

AUTOSAR compliant specification supports single rate and multirate single-tasking models.

Press Get Default Configuration to populate the initial I/O configuration.
Any runnable, event or XML option that is left blank will be filled with the default value.

Get Default Configuration (*invokes update diagram)

Configure AUTOSAR Interface

Configure I/O | Configure Runnables | XML Options

Initial runnable: Runnable_Init

Initial event: Event_Init

| | Periodic Runnables | Periodic Events | Execution Period (s) |
|---|---|---|---|
| Runnable1 | Runnable1 | Runnable1_Event | 0.001 |
| Runnable2 | Runnable2 | Runnable2_Event | 0.001 |
| Runnable3 | Runnable3 | Runnable3_Event | 0.001 |

Validation

Validate (*invokes update diagram)

✓ Last validation succeeded.

OK Cancel Help Apply

## Multiple Instantiation

AUTOSAR supports multiple instantiations of software components; the use of reentrant code. To generate reentrant code in Simulink, on the **Real-Time Workshop Interface** pane, select the **Generate reusable code** check box. You do not have to change the Simulink model. However, current software support for this feature is restricted to models that you configure as servers. See “Configuring a Server Operation” on page 22-38

## AUTOSAR Communication

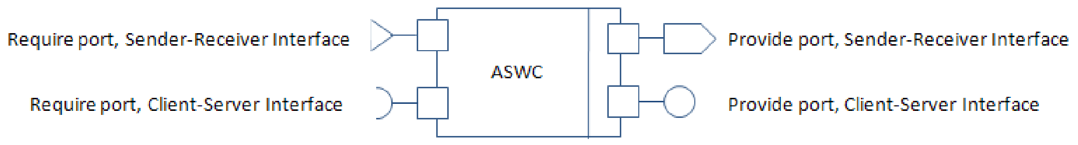
AUTOSAR Software Components provide well-defined connection points, ports. There are two types of AUTOSAR ports:

- `Require`
- `Provide`

In addition, these AUTOSAR ports can reference two kinds of interfaces:

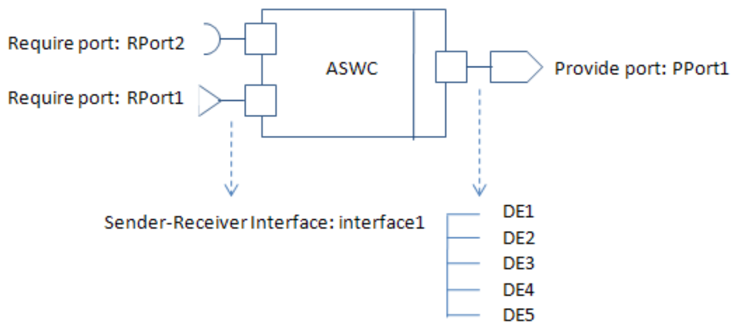
- Sender-Receiver
- Client-Server

The following figure shows an AUTOSAR Software Component with four ports representing all port and interface combinations.


Require port, Sender-Receiver Interface
Require port, Client-Server Interface
ASWC
Provide port, Sender-Receiver Interface
Provide port, Client-Server Interface

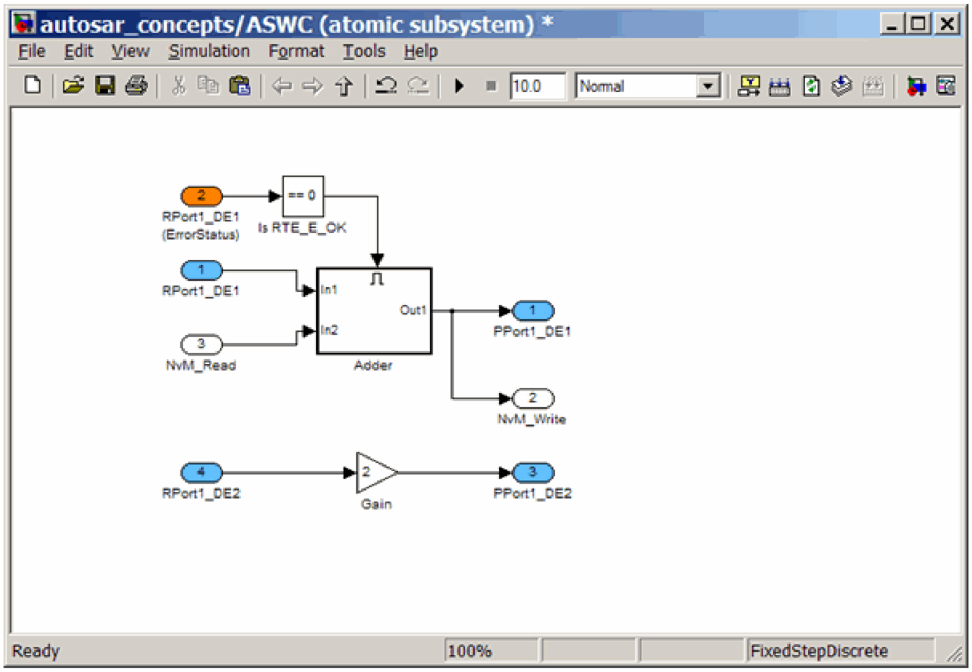
## Sender-Receiver Interface

A Sender-Receiver Interface consists of one or more data elements with each data element referencing a particular data type. Although a `Require` or `Provide` port may reference a Sender-Receiver Interface, the AUTOSAR Software Component does not necessarily access all the data elements. For example, consider the following figure.



The AUTOSAR Software Component has a `Require` and `Provide` port that references the same Sender-Receiver Interface, `interface1`. Although this interface contains data elements `DE1`, `DE2`, `DE3`, `DE4`, and `DE5`, the component does not utilize all the data elements.

The following figure is an example of how you model, in Simulink, an AUTOSAR Software Component that accesses data elements.

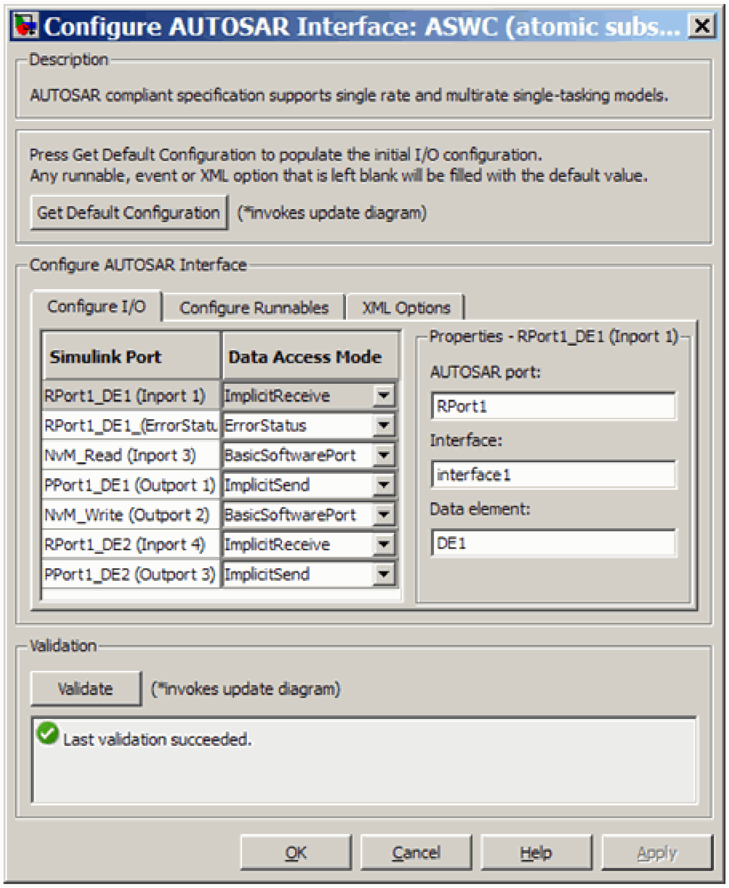


`ASWC` accesses data elements `DE1` and `DE2`. You model data element access as follows:

- For `Require` ports, use Simulink inports. For example, `RPort1_DE1` and `RPort1_DE2`.
- For `Provide` ports, use Simulink outports. For example, `PPort1_DE1` and `PPort1_DE2`.

*ErrorStatus* is a value that the AUTOSAR Runtime Environment (RTE) returns to indicate errors that the communication system detects for each data element. You can use a Simulink inport to model error status, for example, `RPort1_DE1 (ErrorStatus)`.

Use the Configure AUTOSAR Interface dialog box to specify the AUTOSAR settings for each inport and outport. The following figure shows settings for `ASWC`.



Configure AUTOSAR Interface: ASWC (atomic subs...

Description

AUTOSAR compliant specification supports single rate and multirate single-tasking models.

Press Get Default Configuration to populate the initial I/O configuration.
Any runnable, event or XML option that is left blank will be filled with the default value.

Get Default Configuration (*invokes update diagram)

Configure AUTOSAR Interface

Configure I/O | Configure Runnables | XML Options

| Simulink Port | Data Access Mode |
|---|---|
| RPort1_DE1 (Inport 1) | ImplicitReceive |
| RPort1_DE1_(ErrorStatu | ErrorStatus |
| NvM_Read (Inport 3) | BasicSoftwarePort |
| PPort1_DE1 (Outport 1) | ImplicitSend |
| NvM_Write (Outport 2) | BasicSoftwarePort |
| RPort1_DE2 (Inport 4) | ImplicitReceive |
| PPort1_DE2 (Outport 3) | ImplicitSend |

Properties - RPort1_DE1 (Inport 1)

AUTOSAR port: RPort1

Interface: interface1

Data element: DE1

Validation

Validate (*invokes update diagram)

Last validation succeeded.

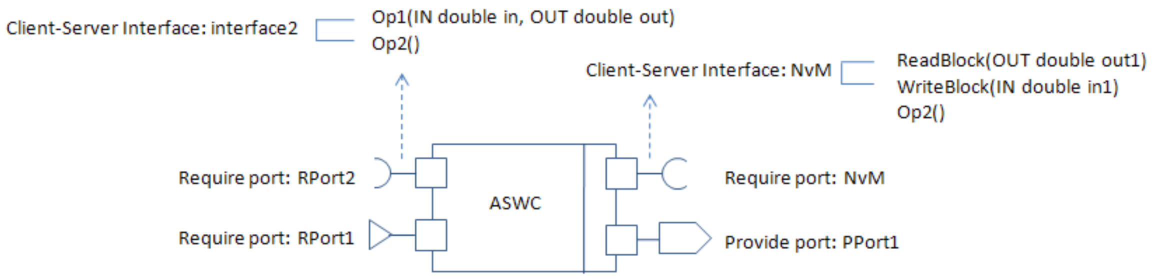
OK Cancel Help Apply

For example, the Data Access Mode for `RPort1_DE1` is set to `ImplicitReceive`. For information on how you specify settings, see “Using the Configure AUTOSAR Interface Dialog Box” on page 22-31.

## Client-Server Interface

A Client-Server Interface consists of one or more operation prototypes. An operation prototype contains one or more arguments of specific data types. A Client-Server Interface can be referenced by either a `Require` or `Provide` port.

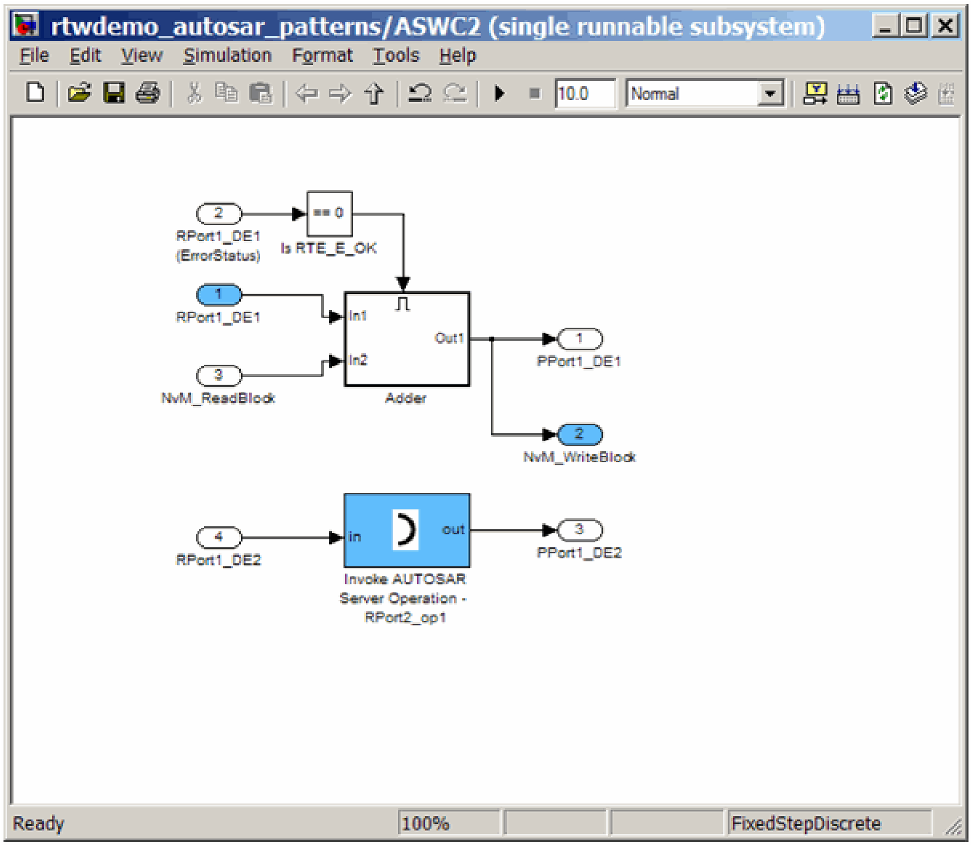
The following figure shows an AUTOSAR Software Component with `Require` ports (`RPort2` and `NvM` ) that reference Client-Server Interfaces (`Interface2` and `NvM`).


Client-Server Interface: interface2
Op1(IN double in, OUT double out)
Op2()
Client-Server Interface: NvM
ReadBlock(OUT double out1)
WriteBlock(IN double in1)
Op2()
Require port: RPort2
ASWC
Require port: NvM
Require port: RPort1
Provide port: PPort1

Simulink provides the following modeling patterns for Client-Server Interfaces:

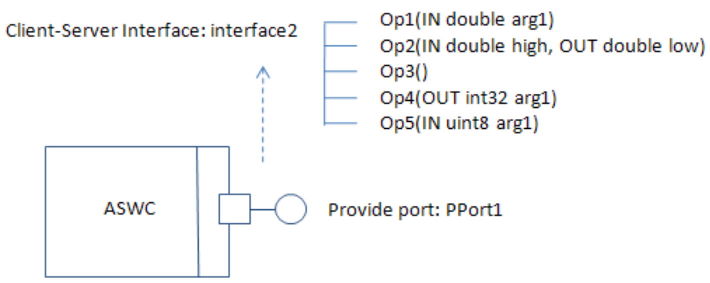
- If you want to invoke a Basic Software interface with operations that have only one argument, for example, `Client-Server Interface:  NvM`, use an inport or outport.
- If you want to invoke Basic Software or application software interfaces that contain operations with any number of arguments, for example, `Client-Server Interface:  Interface2`, use the Invoke AUTOSAR Server Operation block. See “Configuring the Invoke AUTOSAR Server Operation Block” on page 22-41

The following figure shows the use of the Invoke AUTOSAR Server Operation block in modeling an AUTOSAR Software Component in Simulink.

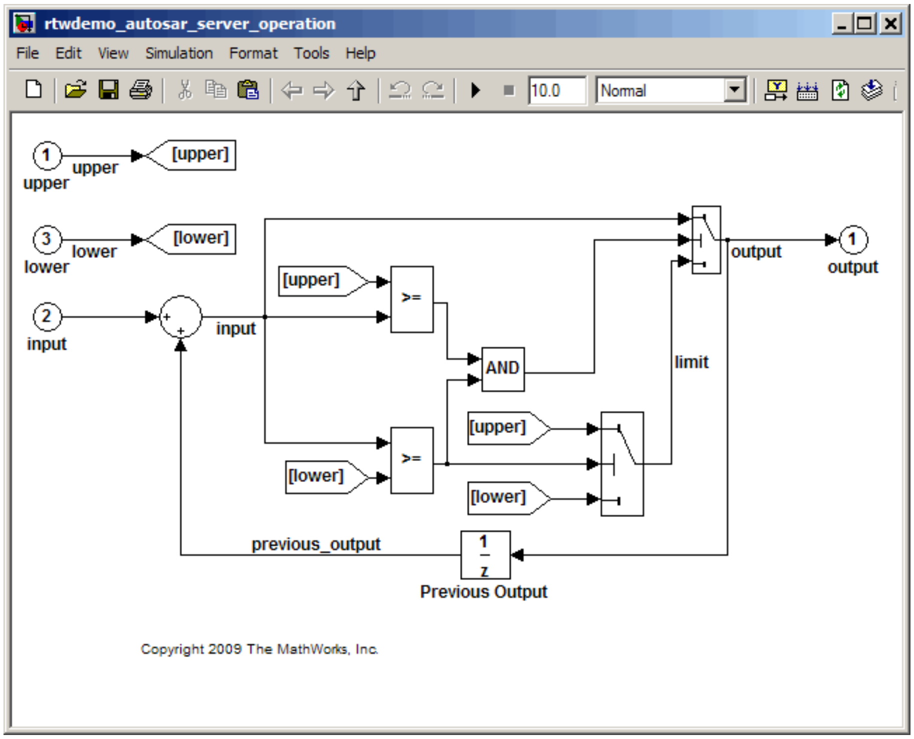


Use the Configure AUTOSAR Interface dialog box to specify the AUTOSAR settings for each inport and outport. See "Using the Configure AUTOSAR Interface Dialog Box" on page 22-31.

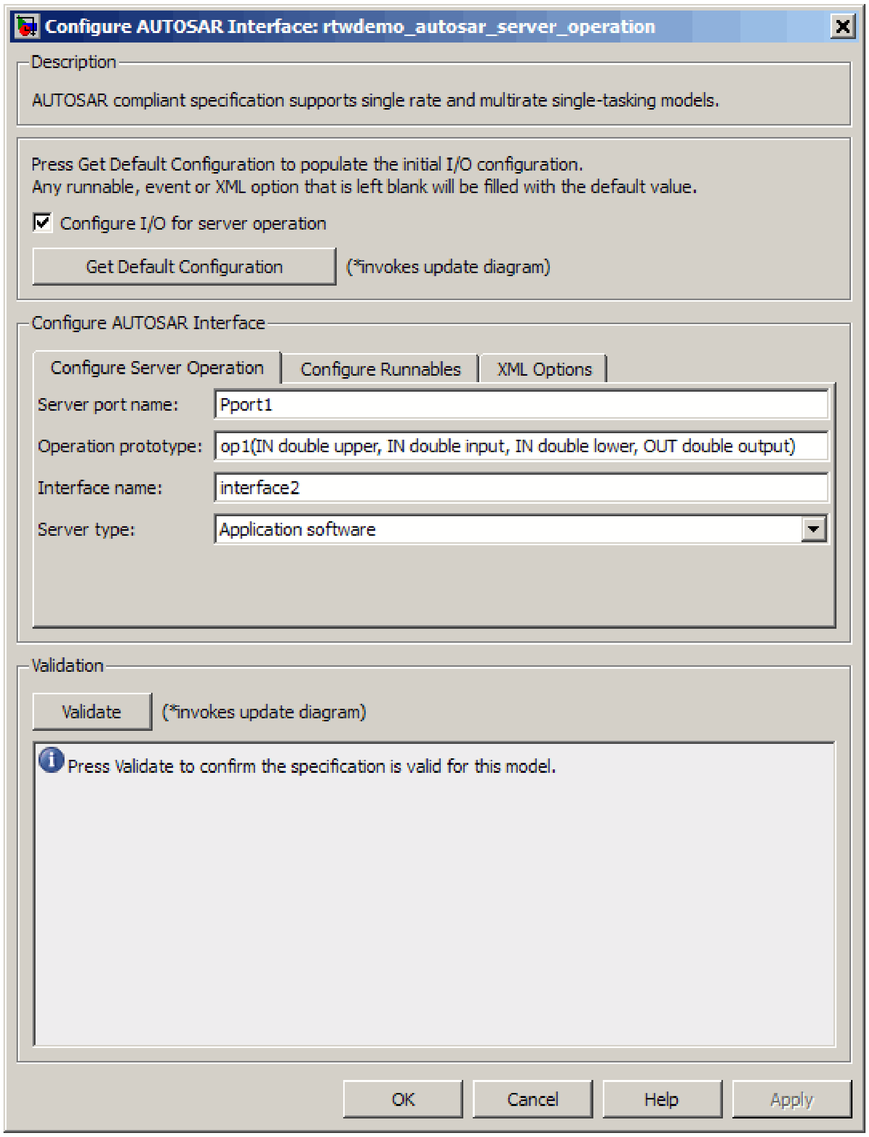
The following figure shows an AUTOSAR Software Component with a `Provide` port that references a Client-Server Interface.



In Simulink, you can model a single operation of an Atomic Software Component that is referenced by a Client-Server Interface. Consider the following model.



Use the Configure AUTOSAR Interface dialog box to map the inports and outports to the arguments of the operation prototype. For example, the inports map to arguments `upper`, `input`, and `lower`.



Configure AUTOSAR Interface: rtwdemo_autosar_server_operation

Description

AUTOSAR compliant specification supports single rate and multirate single-tasking models.

Press Get Default Configuration to populate the initial I/O configuration.
Any runnable, event or XML option that is left blank will be filled with the default value.

[✓] Configure I/O for server operation

Get Default Configuration (*invokes update diagram)

Configure AUTOSAR Interface

Configure Server Operation | Configure Runnables | XML Options

| | |
|---|---|
| Server port name: | Pport1 |
| Operation prototype: | op1(IN double upper, IN double input, IN double lower, OUT double output) |
| Interface name: | interface2 |
| Server type: | Application software |

Validation

Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

OK Cancel Help Apply

For more information, see “Configuring a Server Operation” on page 22-38 .

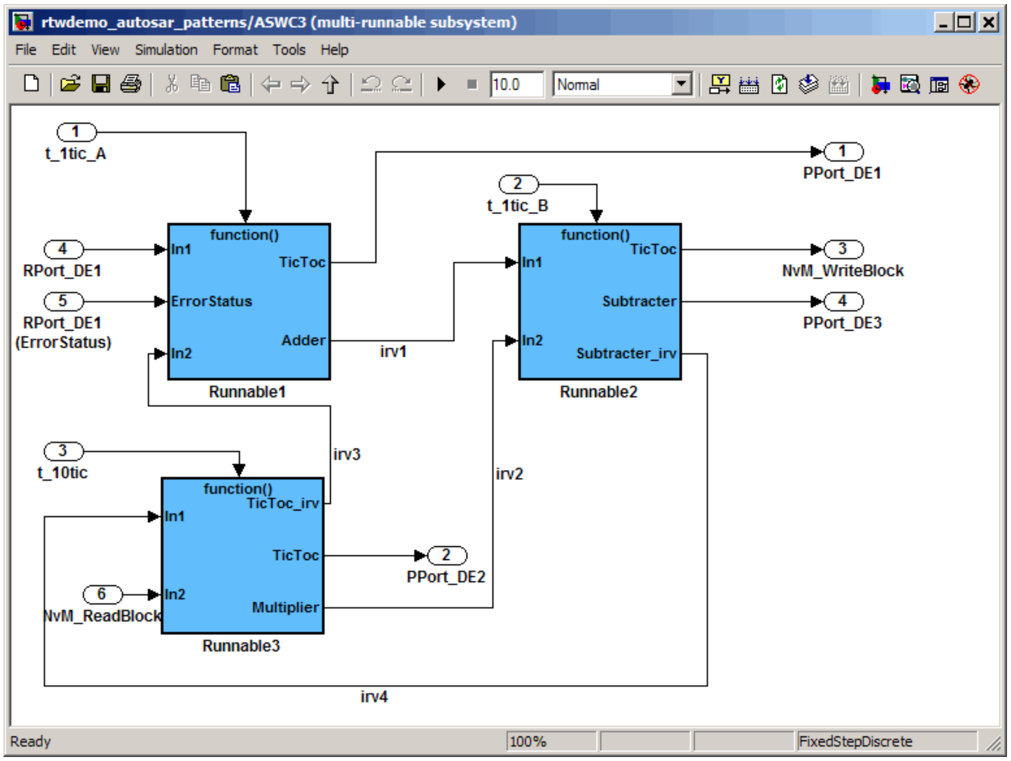
## Calibration Parameters

AUTOSAR specifies a calibration component that contains calibration parameters used by AUTOSAR Software Components. You tune the calibration parameter values using calibration tools.

You can define the calibration component using an AUTOSAR authoring tool. You then import the calibration parameters into the MATLAB base workspace. You provide your Simulink model with access to these parameters by assigning the imported parameters to block parameters in your model. See “Importing an AUTOSAR Software Component” on page 22-29 and “Configuring Calibration Parameters” on page 22-45.

## Inter-Runnable Variables

In AUTOSAR, *inter-runnable* variables are used to communicate primitive type data between runnables in the same component. You define these variables in a Simulink model by the signal lines that connect subsystems (runnables). For example, in the following figure, `irv1`, `irv2`, `irv3`, and `irv4` are inter-runnable variables.


rtwdemo_autosar_patterns/ASWC3 (multi-runnable subsystem)
File Edit View Simulation Format Tools Help
10.0
Normal
1 t_1tic_A
4 RPort_DE1
5 RPort_DE1 (ErrorStatus)
function() In1 TicToc ErrorStatus Adder In2
Runnable1
irv1
2 t_1tic_B
function() TicToc In1 Subtracter In2 Subtracter_irv
Runnable2
1 PPort_DE1
3 NvM_WriteBlock
4 PPort_DE3
irv3
irv2
3 t_10tic
function() TicToc_irv In1 TicToc In2 Multiplier
Runnable3
6 NvM_ReadBlock
2 PPort_DE2
irv4
Ready
100%
FixedStepDiscrete

See also “Configuring Multiple Runnables” on page 22-48.

## Data Types

AUTOSAR specifies data types that apply to:

- Data elements of a Sender-Receiver Interface
- Operation arguments of a Client-Server Interface
- Calibration parameters
- Inter-runnable variables

The data types fall into two categories:

- Primitive data types, which allow an efficient mapping to C.

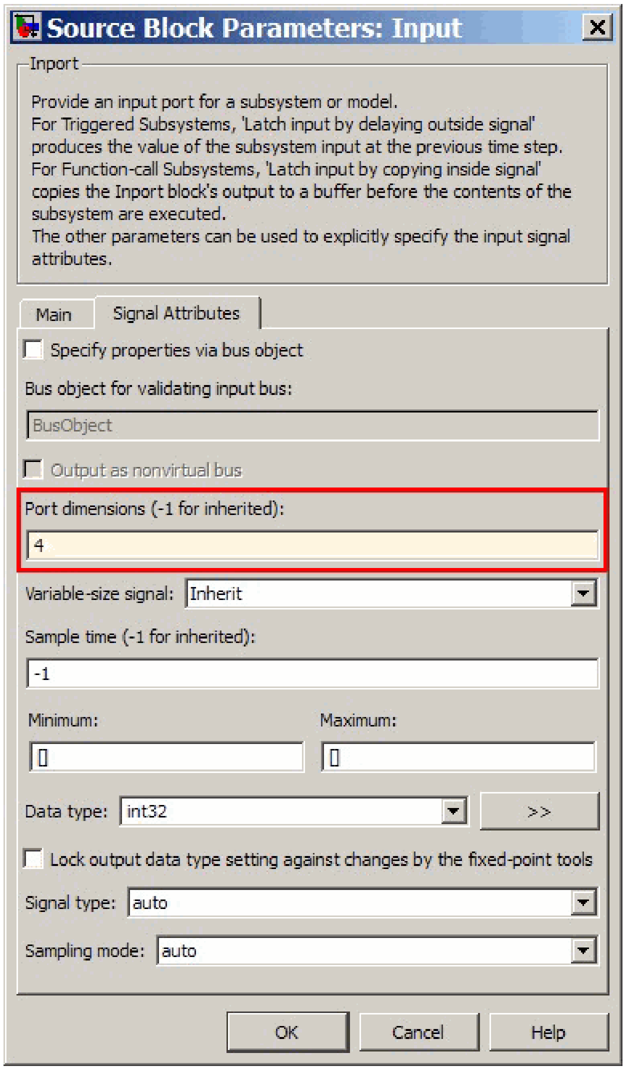
- Composite data types.

You can use Simulink data types to define AUTOSAR primitive types.

| AUTOSAR Data Type | Simulink Data Type |
|---|---|
| `UInt4` | `uint8` |
| `SInt4` | `int8` |
| `UInt8` | `uint8` |
| `SInt8` | `int8` |
| `UInt16` | `uint16` |
| `SInt16` | `int16` |
| `UInt32` | `uint32` |
| `SInt32` | `int32` |
| `Float_with_NaN` | `single` |
| `Float` | `single` |
| `Double_with_NaN` | `double` |
| `Double` | `double` |
| `Boolean` | `boolean` |
| `Char8` | `uint8` |
| `Char16` | Not supported |

AUTOSAR composite data types are arrays and records, which are represented in Simulink by wide signals and bus objects, respectively. In the Inport or Outport Block Parameters dialog box, use the **Signal Attributes** pane to configure wide signals and bus objects.

The following figure shows how to specify a wide signal, which corresponds to an AUTOSAR composite array.


Source Block Parameters: Input

Inport

Provide an input port for a subsystem or model.
For Triggered Subsystems, 'Latch input by delaying outside signal' produces the value of the subsystem input at the previous time step.
For Function-call Subsystems, 'Latch input by copying inside signal' copies the Inport block's output to a buffer before the contents of the subsystem are executed.
The other parameters can be used to explicitly specify the input signal attributes.

Main | Signal Attributes

[ ] Specify properties via bus object

Bus object for validating input bus: BusObject

[ ] Output as nonvirtual bus

Port dimensions (-1 for inherited): 4

Variable-size signal: Inherit

Sample time (-1 for inherited): -1

Minimum: []

Maximum: []

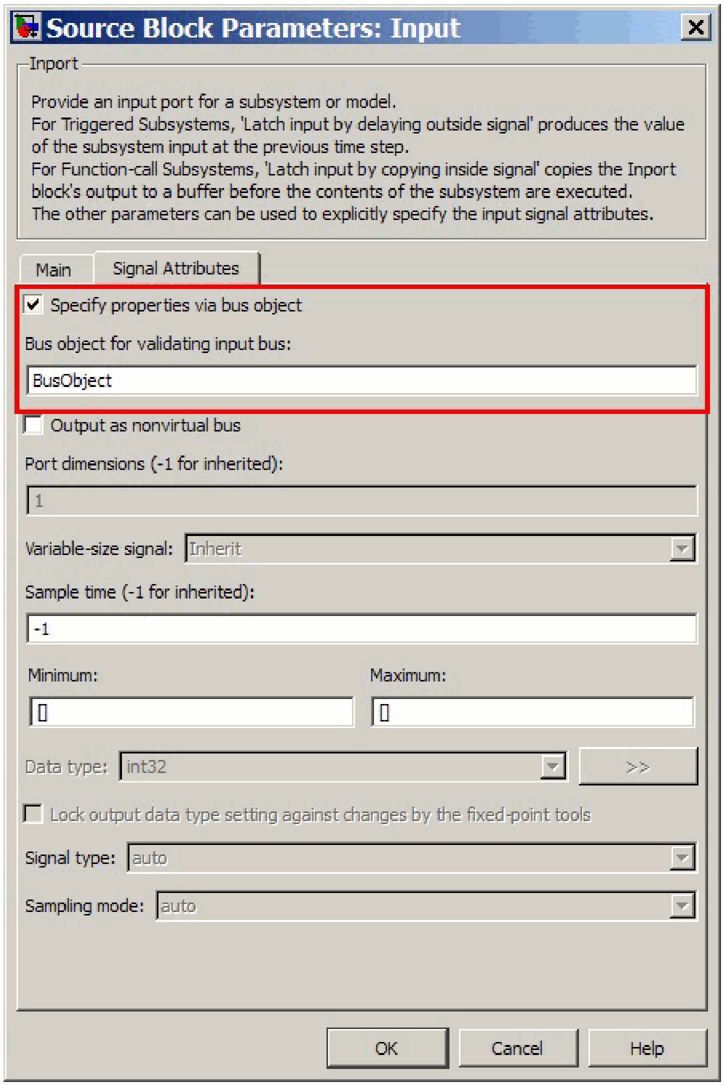
Data type: int32

[ ] Lock output data type setting against changes by the fixed-point tools

Signal type: auto

Sampling mode: auto

The following figure shows how to specify a bus object, which corresponds to an AUTOSAR composite record.


Source Block Parameters: Input

Inport

Provide an input port for a subsystem or model.
For Triggered Subsystems, 'Latch input by delaying outside signal' produces the value of the subsystem input at the previous time step.
For Function-call Subsystems, 'Latch input by copying inside signal' copies the Inport block's output to a buffer before the contents of the subsystem are executed.
The other parameters can be used to explicitly specify the input signal attributes.

Main | Signal Attributes

[✓] Specify properties via bus object

Bus object for validating input bus: BusObject

[ ] Output as nonvirtual bus

Port dimensions (-1 for inherited): 1

Variable-size signal: Inherit

Sample time (-1 for inherited): -1

Minimum: []

Maximum: []

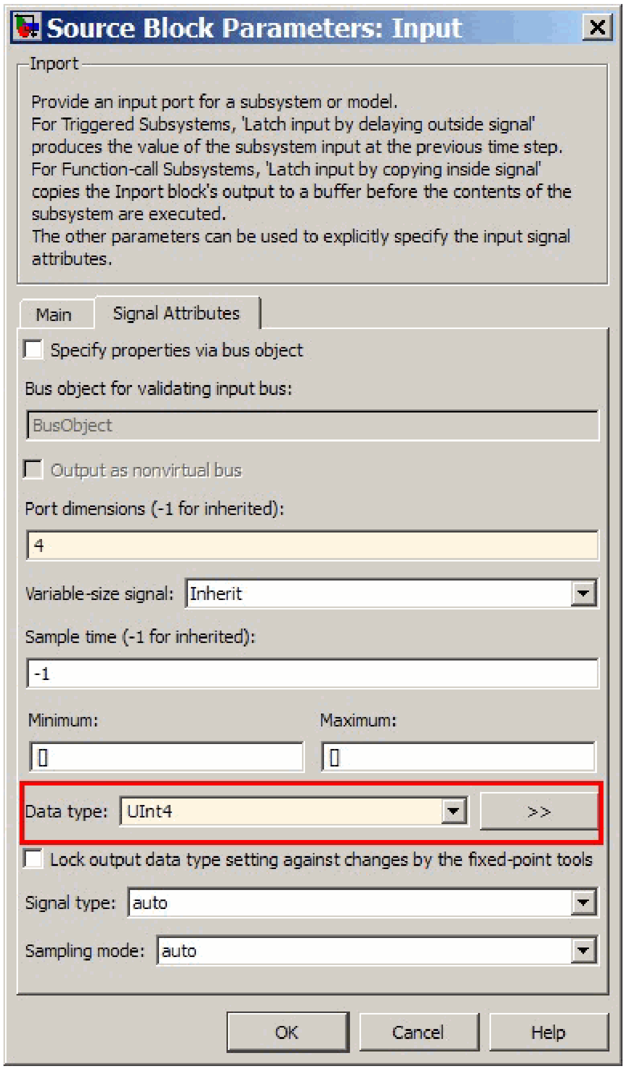
Data type: int32

[ ] Lock output data type setting against changes by the fixed-point tools

Signal type: auto

Sampling mode: auto

You can also use the **Signal Attributes** pane on the Inport or Outport Block Parameters dialog box to specify the data types of data elements and arguments of an operation prototype. If you select **Mode** to be `Built in`, then you can specify the data type to be, for example, `single` or `boolean`. Alternatively, if you select **Mode** to be `Expression`, you can specify an (alias) expression for data type. As an example, the following figure shows an alias `UInt4` in the **Data type** field.



Source Block Parameters: Input

Inport

Provide an input port for a subsystem or model.
For Triggered Subsystems, 'Latch input by delaying outside signal' produces the value of the subsystem input at the previous time step.
For Function-call Subsystems, 'Latch input by copying inside signal' copies the Inport block's output to a buffer before the contents of the subsystem are executed.
The other parameters can be used to explicitly specify the input signal attributes.

Main | Signal Attributes

[ ] Specify properties via bus object

Bus object for validating input bus: BusObject

[ ] Output as nonvirtual bus

Port dimensions (-1 for inherited): 4

Variable-size signal: Inherit

Sample time (-1 for inherited): -1

Minimum: []

Maximum: []

Data type: UInt4

[ ] Lock output data type setting against changes by the fixed-point tools

Signal type: auto

Sampling mode: auto

## AUTOSAR Terminology

| Term | Notes |
|---|---|
| AUTOSAR Runtime Environment (RTE) | • Layer between Application and Basic Software layers<br>• Realizes communication between:<br>- AUTOSAR Software Components<br>- AUTOSAR Software Components and Basic Software |
| AUTOSAR Software Component | • A software component containing one or more algorithms, which communicates with its environment through ports<br>• Connected to the AUTOSAR Runtime Environment (RTE)<br>• Relocatable |
| Characteristics | Values of characteristics can be changed on an ECU through a calibration data management tool or an offline calibration tool |
| Client-Server Interface | • PortInterface for client-server communication<br>• Defines operations provided by server and used by client |
| Composite data types | Category of data types, such as one of the following:<br>• Array — Contains more than one element of the same type, and has zero-based indexing.<br>• Record — Non-empty set of objects, where each object has a unique identifier. |
| ComSpec | Defines specific communication attributes. |
| DataElementPrototype (data element) | Data value (signal) exchanged between a sender and a receiver |

| Term | Notes |
|---|---|
| Data types | • Either primitive or composite<br>• Types data elements, arguments of operations in a Client-Server Interface, and constants |
| ErrorStatus | Indicates errors detected by communication system. Runtime Environment defines the following macros for sender-receiver communication:<br>• `RTE_E_OK: no errors`<br>• `RTE_E_INVALID: data element invalid`<br>• `RTE_E_MAX_AGE_EXCEEDED: data element outdated` |
| OperationPrototype (operation) | • Invoked by a client<br>• Provides value for each argument with direction `in` or `inout`, which must be of the correct data type.<br>• Client expects to receive a response to the invoked operation, part of which is a value (of correct data type) with direction `out` or `inout`. |
| PortInterface | • Characterizes information provided or required by a port<br>• Can be either Sender-Receiver Interface or Client-Server Interface |
| Primitive data types | Category of data types that allow an efficient mapping to programming languages such as C |
| Provide port (PPort) | Port providing data or service of a server. |
| Require port (RPort) | Port requiring data or service of a server. |

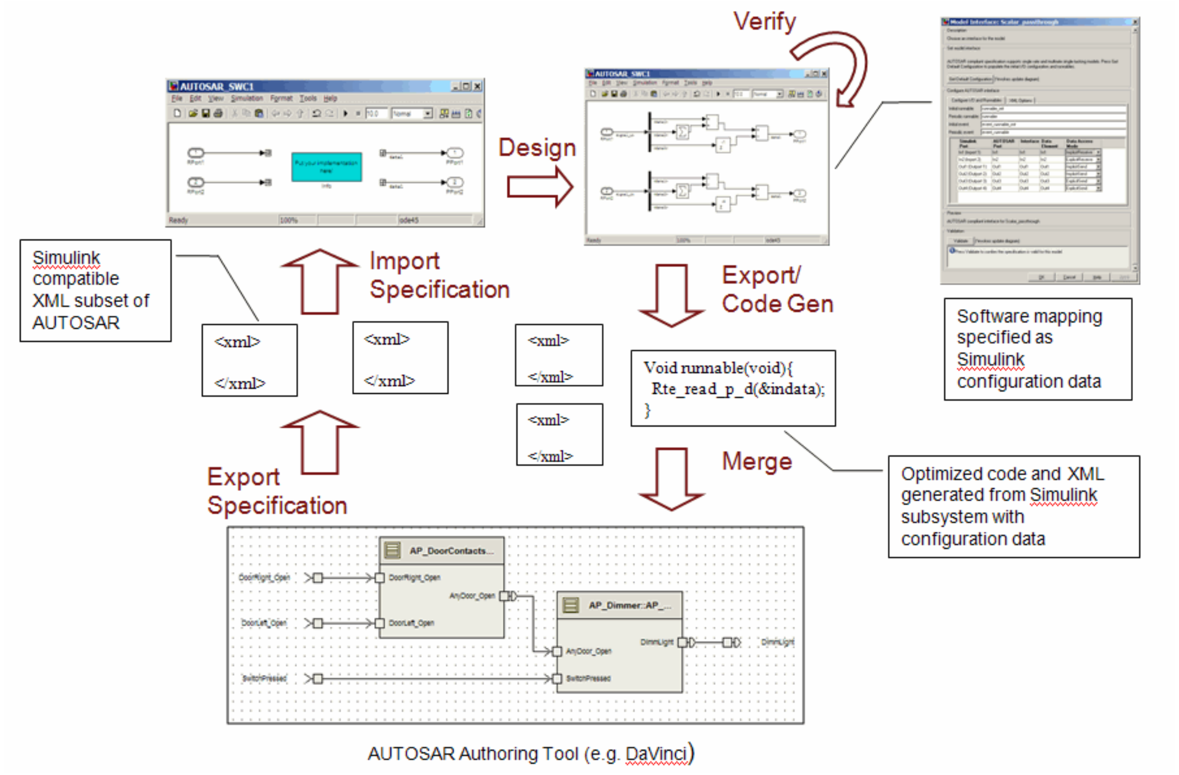
| Term | Notes |
|---|---|
| RTEEvent | Event or situation that triggers execution of a runnable by the Runtime Environment (RTE):<br>• `AsynchronousServerCallReturnsEvent`<br>• `DataSendCompletedEvent`<br>• `DataReceivedEvent`<br>• `DataReceiveErrorEvent`<br>• `OperationInvokedEvent`<br>• `TimingEvent`<br>• `ModeSwitchEvent`<br>• `ModeSwitchedAckEvent` |
| Runnable entity (runnable) | Part of AUTOSAR Software-Component that can be executed and scheduled independently of other runnable entities (runnables). |
| Sender-Receiver Interface | • PortInterface for sender-receiver communication<br>• Defines data elements sent by sending component (with `Provide` port providing Sender-Receiver Interface) or received by receiving component (with `Require` requiring Sender-Receiver Interface) |
| Sender Receiver Annotation | Annotation of data elements in a port that implements Sender-Receiver Interface. |
| Sensor Actuator Software Component | AUTOSAR Software Component dedicated to the control of a sensor or actuator. |
| Service | Logical entity of basic software that offers functionality, which is used by various AUTOSAR Software Components. |

## Workflow for AUTOSAR

**In this section...**

This section describes how you use Real-Time Workshop Embedded Coder software to generate AUTOSAR-compliant code.

The following diagram shows a workflow that you can follow.


Verify
Design
Import Specification
Export/ Code Gen
Simulink compatible XML subset of AUTOSAR
Software mapping specified as Simulink configuration data
<xml> </xml>
Void runnable(void){ Rte_read_p_d(&indata); }
Merge
Optimized code and XML generated from Simulink subsystem with configuration data
Export Specification
AP_DoorContacts...
AP_Dimmer::AP_...
AUTOSAR Authoring Tool (e.g. DaVinci)

With this workflow, you perform the following tasks:

1. Import previously specified AUTOSAR Software Components, including definitions of calibration parameters, into Simulink. See "Importing an AUTOSAR Software Component" on page 22-29 and "Configuring Calibration Parameters" on page 22-45.

2. Incorporate your Simulink design into the skeleton model or subsystem created by the import process.

3. Export, generating code and description files. This process involves configuring the AUTOSAR interface, validating this interface, and then building your Simulink models. See:

   - "Using the Configure AUTOSAR Interface Dialog Box" on page 22-31

- "Configuring Ports for Basic Software and Error Status Receivers" on page 22-35
- "Configuring Client-Server Communication" on page 22-36
- "Configuring AUTOSAR Options Programmatically" on page 22-50
- "Modifying and Validating an Existing AUTOSAR Interface" on page 22-46
- "Exporting a Single Runnable AUTOSAR Software Component" on page 22-47
- "Configuring Multiple Runnables" on page 22-48

You can also verify your generated code in a simulation. See "Verifying the AUTOSAR Code Using Software-in-the-Loop Testing" on page 22-50.

4. Merge generated code and description files with other systems using an AUTOSAR authoring tool, for example, the DaVinci tool suite from Vector Informatik GmbH. See demo rtwdemo_autosar_roundtrip_script.

   You can use the authoring tool to export specifications, which can be imported back into Simulink.

## Importing an AUTOSAR Software Component

Use the `arxml.importer` class to parse an AUTOSAR Software Component description file (for example, exported from the DaVinci tool suite from Vector Informatik GmbH) and import into a Simulink model for configuration, code generation, and export to XML. For a complete list of methods, see "AUTOSAR" in the Real-Time Workshop Embedded Coder Function Reference documentation. You use functions in the following order:

1. Call `arxml.importer('mySoftwareComponentFile.arxml')` to create an importer object that looks for atomic software components in the specified "main" XML file. You can see reports at the command line describing identified atomic software components. You can have multiple components.

   For example:

   ```
   The file "mySoftwareComponentFile.arxml" contains:
     1 Atomic-Software-Component-Type:
       '/ComponentType/complex_type_component'
   ```

```
3 CalPrm-Component-Type:
  '/ComponentType/MyCalibComp1'
  '/ComponentType/MyCalibComp2'
  '/ComponentType/MyCalibComp3'
```

Use `SetFile` to change the main file and update the list of components.

Each software component requires an `arxml.importer` object. For each `arxml.importer` object, specify the file that contains the software component that you want.

**2** Use the `setDependencies` method if you need to specify additional dependent XML files containing the information that completes the software component description (for example, data types, interfaces). You can specify a cell array of files or a single file.

Complete specifying dependencies only for components that you intend to import into Simulink.

**3** To import a parsed atomic software component into a Simulink model, call one of the following methods. If you have not specified all dependencies for the components, you will see errors.

- `arxml.importer.createComponentAsSubsystem` — Creates and configures a Simulink subsystem skeleton corresponding to the specified atomic software component description.
- `arxml.importer.createComponentAsModel` — Creates and configures a Simulink model skeleton corresponding to the specified atomic software component description.

  For example:

  ```
  importer_obj.createComponentAsModel('/ComponentType/complex_type_component')
  ```

- `arxml.importer.createCalibrationComponentObjects` — Creates Simulink calibration objects corresponding to the specified AUTOSAR calibration component description.

  For example:

  ```
  [success] = createCalibrationComponentObjects(importerObj,
  CreateSimulinkObject, 'true')
  ```

See also the limitation, "Cannot Import Internal Behavior" on page 22-52.

After you import your software component into Simulink, you can modify the skeleton model or subsystem. To configure AUTOSAR code generation options and XML export options, see "Using the Configure AUTOSAR Interface Dialog Box" on page 22-31 or "Configuring AUTOSAR Options Programmatically" on page 22-50.

To see how to import, modify, and export AUTOSAR Software Components, see the Import and Export an AUTOSAR Software Component demo.

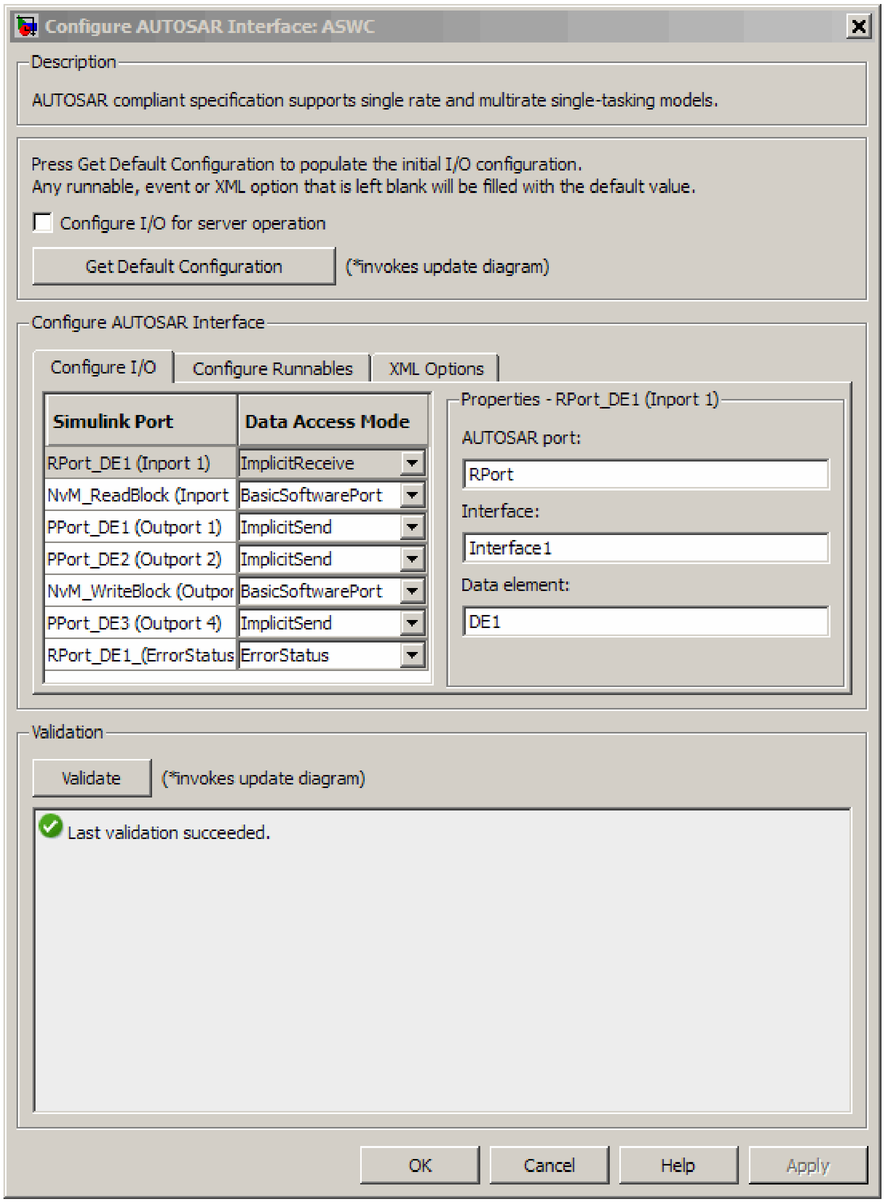
## Using the Configure AUTOSAR Interface Dialog Box

Use the Configure AUTOSAR Interface dialog box to configure your AUTOSAR code generation and XML import and export options. Alternatively, you can use functions to control all AUTOSAR options programmatically.

In any model using the `autosar.tlc` system target file, you can open the Configure AUTOSAR Interface dialog box by right-clicking a subsystem and selecting **Real-Time Workshop > AUTOSAR *`Single or Multi`*-Runnable Component > Configure**.

**Single-Runnable** menu options are enabled only for atomic or function-call subsystems.

**Multi-Runnable** menu options are enabled only for virtual subsystems.



Description

AUTOSAR compliant specification supports single rate and multirate single-tasking models.

Press Get Default Configuration to populate the initial I/O configuration.
Any runnable, event or XML option that is left blank will be filled with the default value.

☐ Configure I/O for server operation

(*invokes update diagram)

Configure AUTOSAR Interface

| Simulink Port | Data Access Mode |
|---|---|
| RPort_DE1 (Inport 1) | ImplicitReceive |
| NvM_ReadBlock (Inport | BasicSoftwarePort |
| PPort_DE1 (Outport 1) | ImplicitSend |
| PPort_DE2 (Outport 2) | ImplicitSend |
| NvM_WriteBlock (Outpor | BasicSoftwarePort |
| PPort_DE3 (Outport 4) | ImplicitSend |
| RPort_DE1_(ErrorStatus | ErrorStatus |

Properties - RPort_DE1 (Inport 1)

AUTOSAR port: RPort

Interface: Interface1

Data element: DE1

Validation

(*invokes update diagram)

✓ Last validation succeeded.

To configure your AUTOSAR options:

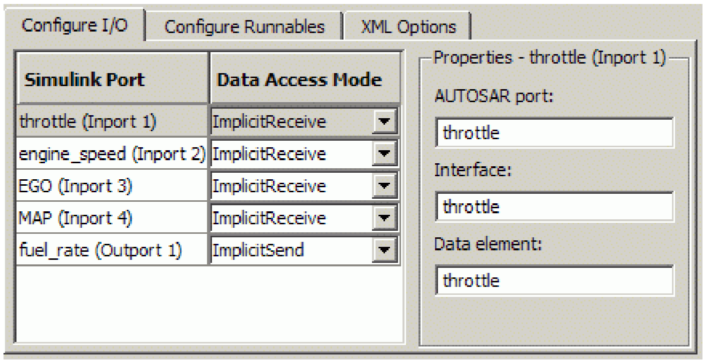
1 Clear the **Configure I/O for server operation** check box if it is selected. You select this check box only when you want to configure your Simulink model as a server operation (see "Configuring a Server Operation" on page 22-38).

2 Click **Get Default Configuration** to populate the controls for your model.

   The runnable names, XML properties, and I/O configuration are initialized. If you click **Get Default Configuration** again later, only the I/O configurations are reset to default values.

3 In the **Configure AUTOSAR Interface** pane, use the controls to change your AUTOSAR code generation options and XML export options, for example, send and receive communication options such as port and interface names, data access modes, runnable, initialization, and periodic function names.

   - On the **Configure I/O** tab, designate inports and outports as data sender/receiver ports, error status receivers, or as access points to basic software.



| Simulink Port | Data Access Mode |
|---|---|
| throttle (Inport 1) | ImplicitReceive |
| engine_speed (Inport 2) | ImplicitReceive |
| EGO (Inport 3) | ImplicitReceive |
| MAP (Inport 4) | ImplicitReceive |
| fuel_rate (Outport 1) | ImplicitSend |

Properties - throttle (Inport 1)
AUTOSAR port: throttle
Interface: throttle
Data element: throttle

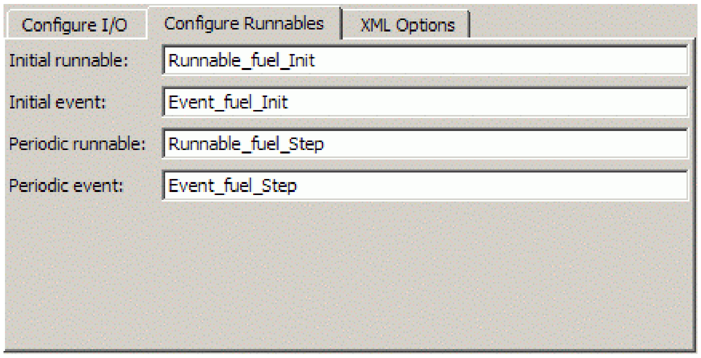
   To designate inports and outports as sender or receiver ports, set each port's **Data Access Mode** to either `Implicit`, where data is buffered by the run-time environment (RTE), or `Explicit` where data is not buffered and therefore not deterministic.

   Use the port interface settings to reflect your AUTOSAR port best practices. For example, some AUTOSAR users like to group related data into the same AUTOSAR port. You can achieve this arrangement in the GUI by duplicating AUTOSAR port names. Alternatively, you can use the AUTOSAR port to group information individually; in this case, a common approach is to set all of the data element settings to something neutral, for example, `'data'`, and leave the AUTOSAR port names as they are. You can also use the AUTOSAR interface name for any best practices that you might have. For example, you can set up interfaces for individual AUTOSAR ports by ensuring that the interface names change when the AUTOSAR port name changes, for example, by prefixing the AUTOSAR interface of the corresponding AUTOSAR port name with an `'if_'`.

For more information on all these options, see "AUTOSAR" in the Real-Time Workshop Embedded Coder Function Reference documentation.

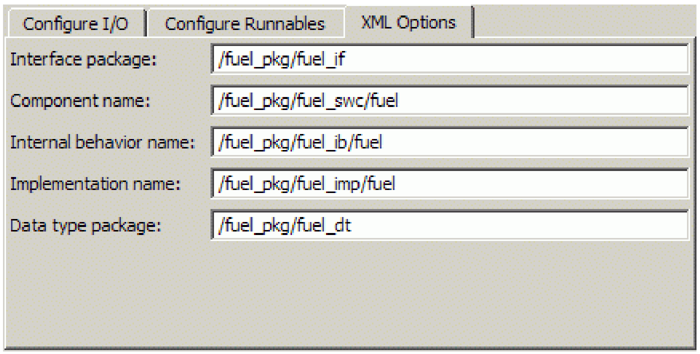
You also use **Data Access Mode** to designate ports to access basic software or error status. See "Configuring Ports for Basic Software and Error Status Receivers" on page 22-35.

- On the **Configure Runnables** tab, specify the names of your runnable, initialization, and periodic functions.



Initial runnable: Runnable_fuel_Init
Initial event: Event_fuel_Init
Periodic runnable: Runnable_fuel_Step
Periodic event: Event_fuel_Step

- On the **XML Options** tab, specify the names and package paths of the XML files that you publish when you generate code. For more details about these files, see "Exporting a Single Runnable AUTOSAR Software Component" on page 22-47.



|  |  |
|---|---|
| Interface package: | /fuel_pkg/fuel_if |
| Component name: | /fuel_pkg/fuel_swc/fuel |
| Internal behavior name: | /fuel_pkg/fuel_ib/fuel |
| Implementation name: | /fuel_pkg/fuel_imp/fuel |
| Data type package: | /fuel_pkg/fuel_dt |

**4** After you configure your options, click **Validate**, which calls `runValidation`. If there are problems, you see messages describing why the configuration is invalid.

---

**Note** For information on all validation checks, see `RTW.AutosarInterface.runValidation` in the Real-Time Workshop Embedded Coder Function Reference documentation.

---

**5** If validation succeeds, click **OK** to return to the Configuration Parameters dialog box.

**6** Save your model and then generate code to export your AUTOSAR component.

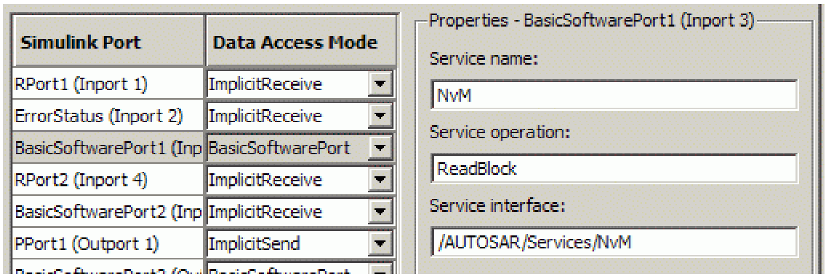
## Configuring Ports for Basic Software and Error Status Receivers

You can configure ports to access AUTOSAR services and device drivers (AUTOSAR basic software), and to access communication error status in your model. You can configure ports programmatically or by using the AUTOSAR Model Interface dialog box. To open the dialog box, right-click a subsystem and select **Real-Time Workshop > AUTOSAR *`Single or Multi`*runnable Component > Configure**.

In the dialog box, you can specify the **Data Access Mode** of every port.

- Designate inports and outports as access points to basic software.

  If you select **Basic Software**, specify the service name, operation, and interface. The service name and operation must be valid AUTOSAR identifiers, and the service interface must be a valid path of the form `AUTOSAR/Service/`*`servicename`*.



| Simulink Port | Data Access Mode |
|---|---|
| RPort1 (Inport 1) | ImplicitReceive |
| ErrorStatus (Inport 2) | ImplicitReceive |
| BasicSoftwarePort1 (Inp | BasicSoftwarePort |
| RPort2 (Inport 4) | ImplicitReceive |
| BasicSoftwarePort2 (Inp | ImplicitReceive |
| PPort1 (Outport 1) | ImplicitSend |

Properties - BasicSoftwarePort1 (Inport 3)

Service name: NvM

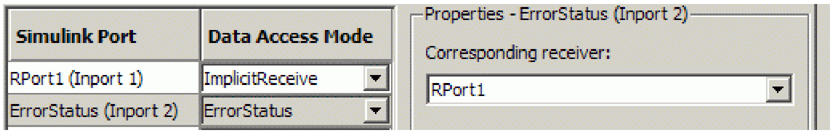
Service operation: ReadBlock

Service interface: /AUTOSAR/Services/NvM

  After you export your AUTOSAR components, you must include your service interface definition XML file to import correctly into an authoring tool.

- Designate inports to receive error status.

  If you select **Error Status** for an inport, you must select the other port (of mode Implicit or Explicit Receive) to listen to, for error status. Error status ports must use `uint8` data type (or an alias).



| Simulink Port | Data Access Mode |
|---|---|
| RPort1 (Inport 1) | ImplicitReceive |
| ErrorStatus (Inport 2) | ErrorStatus |

Properties - ErrorStatus (Inport 2)

Corresponding receiver: RPort1

## Configuring Client-Server Communication

- "Configuring a Server Operation" on page 22-38
- "Configuring the Invoke AUTOSAR Server Operation Block" on page 22-41
- "Creating Configurable Subsystems from a Client-Server Interface" on page 22-43
- "Simulating and Generating Code for Client-Server Communication" on page 22-44

AUTOSAR allows client-server communication between:

- Application software components
- An application software component and Basic Software

An AUTOSAR Client-Server Interface defines the interaction between a software component that *provides* the interface and a software component that *requires* the interface. The component that provides the interface is the server. The component that requires the interface is the client.

In Simulink, you can:

- Configure your model to implement a server operation. You generate AUTOSAR-compliant code and XML description files, including a client-server interface, when you build your model. See "Configuring a Server Operation" on page 22-38.
- Configure a client port for your model using an Invoke AUTOSAR Server Operation block that references a client-server interface. You generate AUTOSAR-compliant code and XML description files for your client port when you build your model. See "Configuring the Invoke AUTOSAR Server Operation Block" on page 22-41.

In addition, if you have a previously created client-server interface, you can generate a Simulink library of configurable, client-server subsystems that reference the:

- Invoke AUTOSAR Server Operation block for code generation
- Server operation model block for simulation

For information on how to generate this library, see "Creating Configurable Subsystems from a Client-Server Interface" on page 22-43

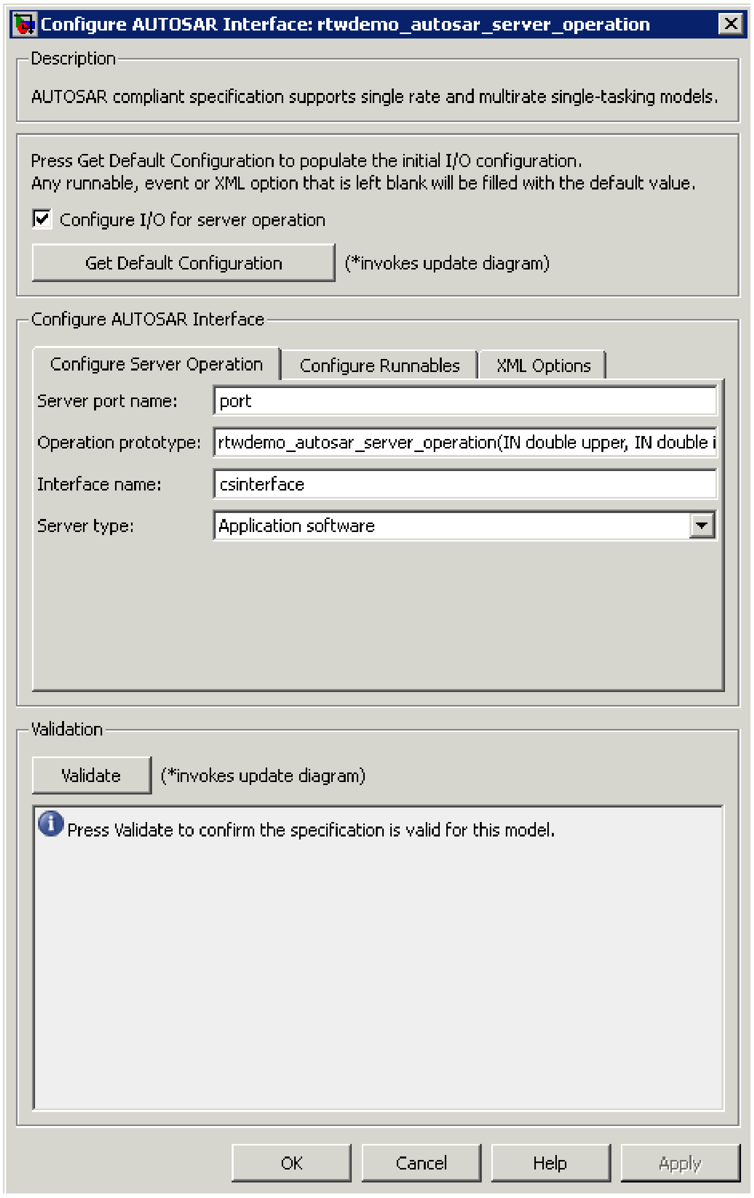
You can deploy the client-server subsystem in a Simulink model and, using the Mode Switch for Invoke AUTOSAR Server Operation, run the model in either a simulation or code-generation mode. See "Simulating and Generating Code for Client-Server Communication" on page 22-44.

For a demo on generating and using an AUTOSAR Client-Server Interface, see rtwdemo_autosar_clientserver_script.

## Configuring a Server Operation

In the Configure AUTOSAR Interface dialog box, you can configure your Simulink model as a server operation and then generate AUTOSAR-compliant code and XML files, including the client-server interface.

1. Select the **Configure I/O for server operation** check box. The **Configure I/O** tab becomes the **Configure I/O for server operation** tab.


Configure AUTOSAR Interface: rtwdemo_autosar_server_operation

Description

AUTOSAR compliant specification supports single rate and multirate single-tasking models.

Press Get Default Configuration to populate the initial I/O configuration.
Any runnable, event or XML option that is left blank will be filled with the default value.

☑ Configure I/O for server operation

(*invokes update diagram)

Configure AUTOSAR Interface

| | |
|---|---|
| Server port name: | port |
| Operation prototype: | rtwdemo_autosar_server_operation(IN double upper, IN double i |
| Interface name: | csinterface |
| Server type: | Application software |

Validation

(*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

**2** Click **Get Default Configuration** to populate the controls for your model.

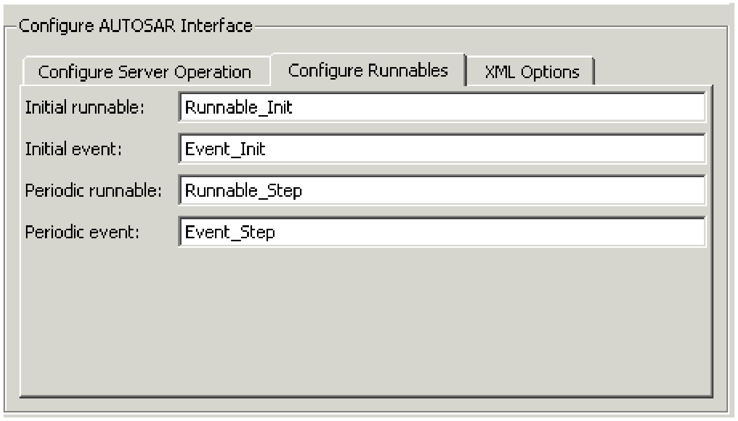
The runnable names, XML properties, and I/O configuration are initialized. If you click **Get Default Configuration** again later, only the I/O configurations are reset to default values.

Use the controls in the **Configure AUTOSAR Interface** pane to change your AUTOSAR code generation options and XML export options.

3 On the **Configure Server Operation** tab, specify the following:

- **Server port name**. Use a valid AUTOSAR short-name identifier.
- **Operation prototype** . The names of the prototype and its arguments must be valid AUTOSAR short-name identifiers, for example `rtwdemo_autosar_server_operation(IN double upper, IN double input, IN double lower, OUT double output)`.
- **Interface name**. The path reference of the client-server interface. Use a valid AUTOSAR short-name path, for example, `csinterface`
- **Server type**. From the drop-down list, select either `Application software` or `Basic software`.

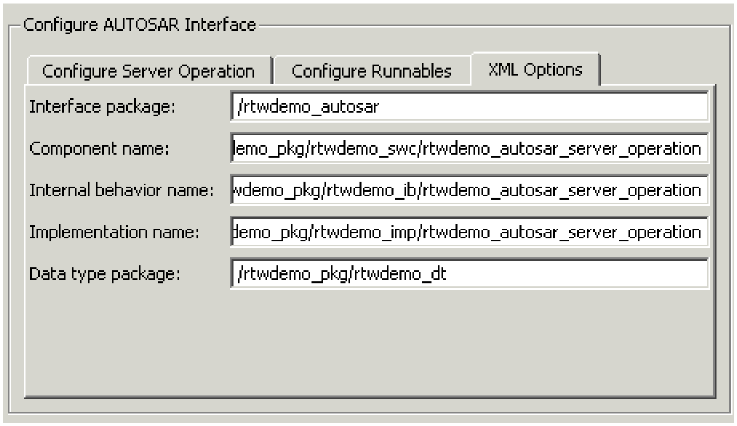
4 On the **Configure Runnables** tab, specify the names of your runnable, initialization, and periodic functions.



| | |
|---|---|
| Initial runnable: | Runnable_Init |
| Initial event: | Event_Init |
| Periodic runnable: | Runnable_Step |
| Periodic event: | Event_Step |

5 On the **XML Options** tab, specify the names and package paths of the XML files that you publish when you generate code. For more details

about these files, see "Exporting a Single Runnable AUTOSAR Software Component" on page 22-47.


Configure AUTOSAR Interface

Interface package: /rtwdemo_autosar

Component name: lemo_pkg/rtwdemo_swc/rtwdemo_autosar_server_operation

Internal behavior name: wdemo_pkg/rtwdemo_ib/rtwdemo_autosar_server_operation

Implementation name: demo_pkg/rtwdemo_imp/rtwdemo_autosar_server_operation

Data type package: /rtwdemo_pkg/rtwdemo_dt

**6** After you configure your options, click **Validate**, which calls `runValidation`. If there are problems, you see messages describing why the configuration is invalid.

---

**Note** For information on all validation checks, see `RTW.AutosarInterface.runValidation` in the Real-Time Workshop Embedded Coder Function Reference documentation.

---

**7** If validation succeeds, click **OK** to return to the Configuration Parameters dialog box.

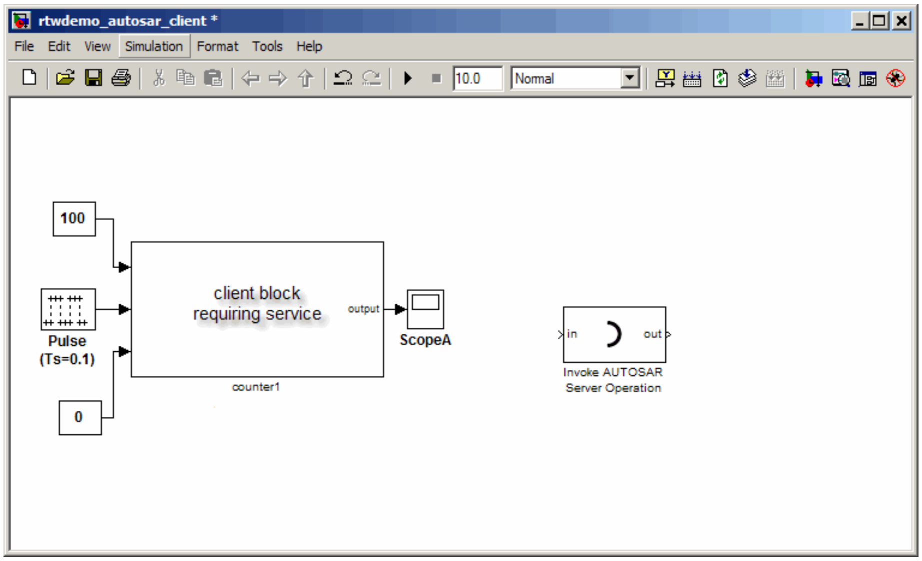
**8** Save your model.

**9** To generate AUTOSAR-compliant code and XML files, select **Tools > Real-Time Workshop > Build Model**.

## Configuring the Invoke AUTOSAR Server Operation Block

You can use the Invoke AUTOSAR Server Operation block in your Simulink model to configure a client port (that accesses either application software or AUTOSAR Basic Software). You can then build the model to generate AUTOSAR-compliant code and XML files.

1 Drag an Invoke AUTOSAR Server Operation block into your model.



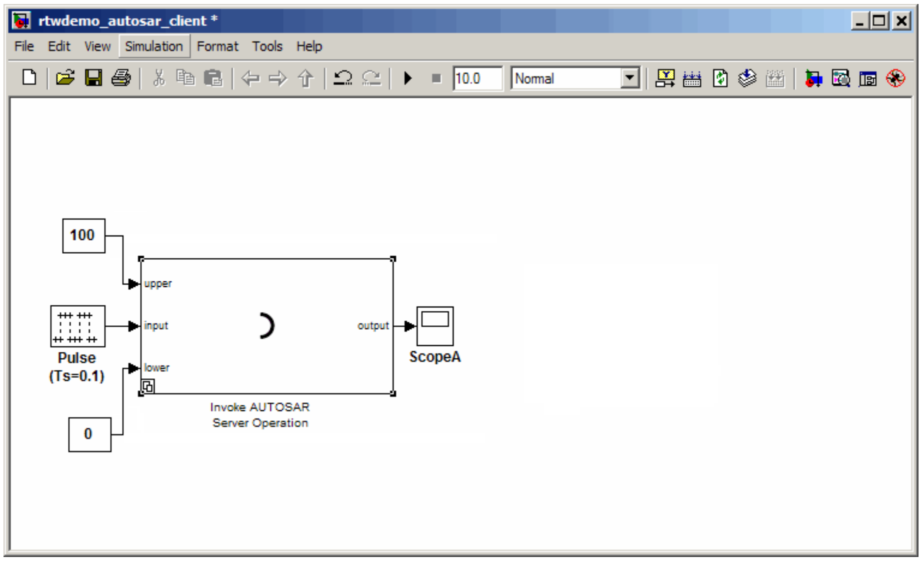
2 Double-click the block to open the Invoke AUTOSAR Server Operation dialog box. Specify the following:

- **Client port name**. A valid AUTOSAR short-name identifier
- **Operation prototype**. The names of the prototype and its arguments must be valid AUTOSAR short-name identifiers, for example, `rtwdemo_autosar_server_operation(IN double upper, IN double input, IN double lower, OUT double output)`
- **Interface path**. The path reference of the client-server interface. You must use a valid AUTOSAR short-name path, for example, `/AUTOSAR/Interface`.
- **Server type**. From the drop-down list, select either `Application software` or `Basic software`.
- **Show error status**. Select this check box if you want the client port to receive the error status of client-server communication.

- **Sample time**. Set this parameter to -1 to inherit the sample time.

3 Click **OK**. Your Invoke AUTOSAR Server Operation block is updated.

4 Replace your client block with the updated Invoke AUTOSAR Server Operation block.



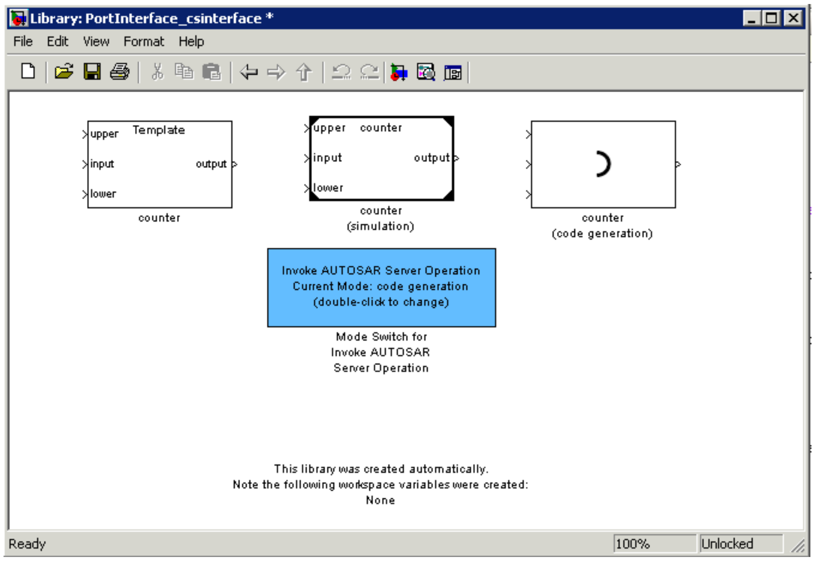
5 Select **Tools > Real-Time Workshop > Build Model**. AUTOSAR-compliant code and XML files for the client port are generated.

## Creating Configurable Subsystems from a Client-Server Interface

You can generate a Simulink library of configurable subsystems by applying the `createOperationAsConfigurableSubsystems` method to the `arxml.importer` object with the client-server interface. For example:

```
% Create an AUTOSAR importer object
obj = arxml.importer('rtwdemo_autosar_csinterface.arxml');

% Create the client-server operation configurable subsystem library
obj.createOperationAsConfigurableSubsystems('/PortInterface/csinterface', ...
                                   'CreateSimulinkObject', false);
```

yield the following `PortInterface_csinterface` library.



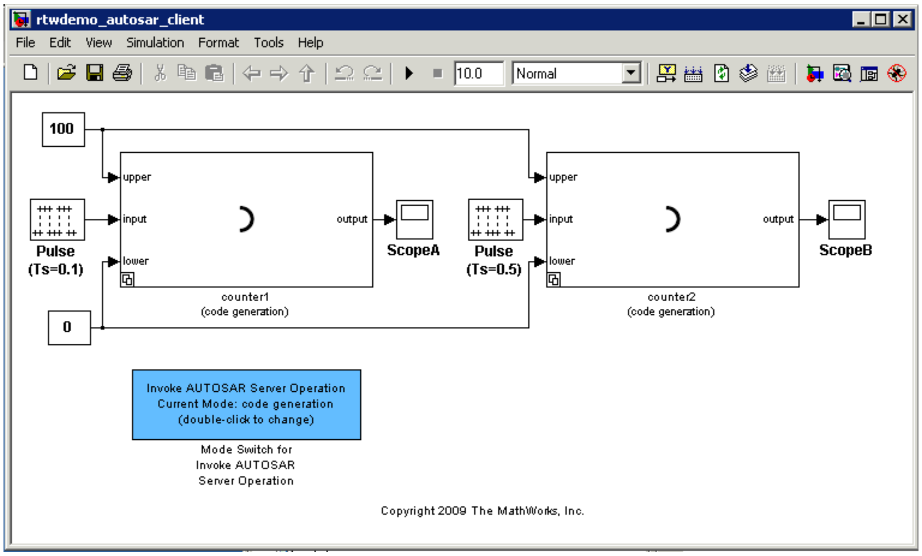
This library was created automatically.
Note the following workspace variables were created:
None

## Simulating and Generating Code for Client-Server Communication

Use the Template block from the client-server subsystem library to construct a model that can be run in either code-generation or simulation mode.

1 Drag the Template block from the subsystem library into your model window and connect it to other blocks.

2 Place the Mode Switch for Invoke AUTOSAR Server Operation in your model window.


rtwdemo_autosar_client
File Edit View Simulation Format Tools Help
10.0
Normal
100
upper
input
lower
output
Pulse (Ts=0.1)
ScopeA
counter1 (code generation)
0
Pulse (Ts=0.5)
counter2 (code generation)
ScopeB
Invoke AUTOSAR Server Operation Current Mode: code generation (double-click to change)
Mode Switch for Invoke AUTOSAR Server Operation
Copyright 2009 The MathWorks, Inc.

To simulate the model:

1 Double-click the Mode Switch for AUTOSAR Server Operation to change the current mode from `code generation` to `simulation`.

2 Select **Simulation > Start**.

To generate code for the model:

1 Double-click the Mode Switch for AUTOSAR Server Operation to change the current mode from `simulation` to `code generation`.

2 Select **Tools > Real-Time Workshop > Build Model**.

## Configuring Calibration Parameters

To import calibration parameters, use the importer method `arxml.importer.createCalibrationComponentObjects`. This method imports all of your parameters into the MATLAB workspace, and you can then assign them to block parameters in your model.

So that the calibration parameters export correctly when you generate code, check the following configuration parameter settings:

- **Inline parameters** must be selected
- **Custom Storage Class not ignored** must not be selected

After you export your AUTOSAR components, you must include your calibration interface definition XML file to import correctly into an authoring tool.

## Modifying and Validating an Existing AUTOSAR Interface

To validate your AUTOSAR interface:

1. Get the handle to an existing model-specific `RTW.AutosarInterface` object that is attached to your loaded Simulink model. Enter:

   ```
   obj = RTW.getFunctionSpecification(modelName)
   ```

   *`modelName`* is a string specifying the name of a loaded Simulink model, and *`obj`* returns a handle to an `RTW.AutosarInterface` object attached to the specified model.

   Test the AUTOSAR interface object. Enter:

   ```
   isa(obj,'RTW.AutosarInterface')
   ```

   This test must return 1. If the model does not have an AUTOSAR interface object, the function returns `[]`.

2. To view and change items, use the AUTOSAR `get` and `set` functions listed in "AUTOSAR" in the Real-Time Workshop Embedded Coder Function Reference documentation.

3. Validate the function prototype using `RTW.AutosarInterface.runValidation`.

**Note** For information on all validation checks, see `RTW.AutosarInterface.runValidation` in the Real-Time Workshop Embedded Coder Function Reference documentation.

4 If validation succeeds, save your model and then generate code.

## Exporting a Single Runnable AUTOSAR Software Component

After configuring your AUTOSAR export options, generate code to export your AUTOSAR Software Component.

Building the subsystem or model generates the code and XML files according to your customizations.

The software component C code and the following XML files are exported to the build directory.

| File Name | Description |
|---|---|
| *modelname*_behavior.arxml | Specifies the software component internal behavior. |
| *modelname*_implementation.arxml | Specifies the software component implementation. |
| *modelname*_interface.arxml | Specifies the software component interfaces, including extra interfaces. |
| *modelname*_component.arxml | Specifies the software component type, including additional ports added to the Simulink model. |
| *modelname*_datatype.arxml | Specifies the software component data types, including any modified or additional data types. |

You can then merge the software component information back into an AUTOSAR authoring tool.

This software component information is partitioned into separate files to facilitate merging. The partitioning attempts to minimize the number of merges you need to do. In general, you do not need to merge the data type file into the authoring tool because data types are usually defined early in the design process. You must, however, merge the internal behavior file because this information is part of the model implementation.

For an example of how to generate AUTOSAR-compliant code and export AUTOSAR Software Component description XML files from a Simulink model, see the AUTOSAR Code Generation demo.

### Selecting an AUTOSAR Schema

The default AUTOSAR schema version is 3.0. If you need to change the schema version, you must do so before exporting.

To select a schema version, open the Configuration Parameters dialog box:

1. In any model using the `autosar.tlc` system target file, the **AUTOSAR Code Generation Options** component appears in the tree.

   Click **AUTOSAR Code Generation Options** to open the **AUTOSAR Code Generation Options** pane.

2. Select a schema version (3.0, 2.1 or 2.0) for generating XML files.

---

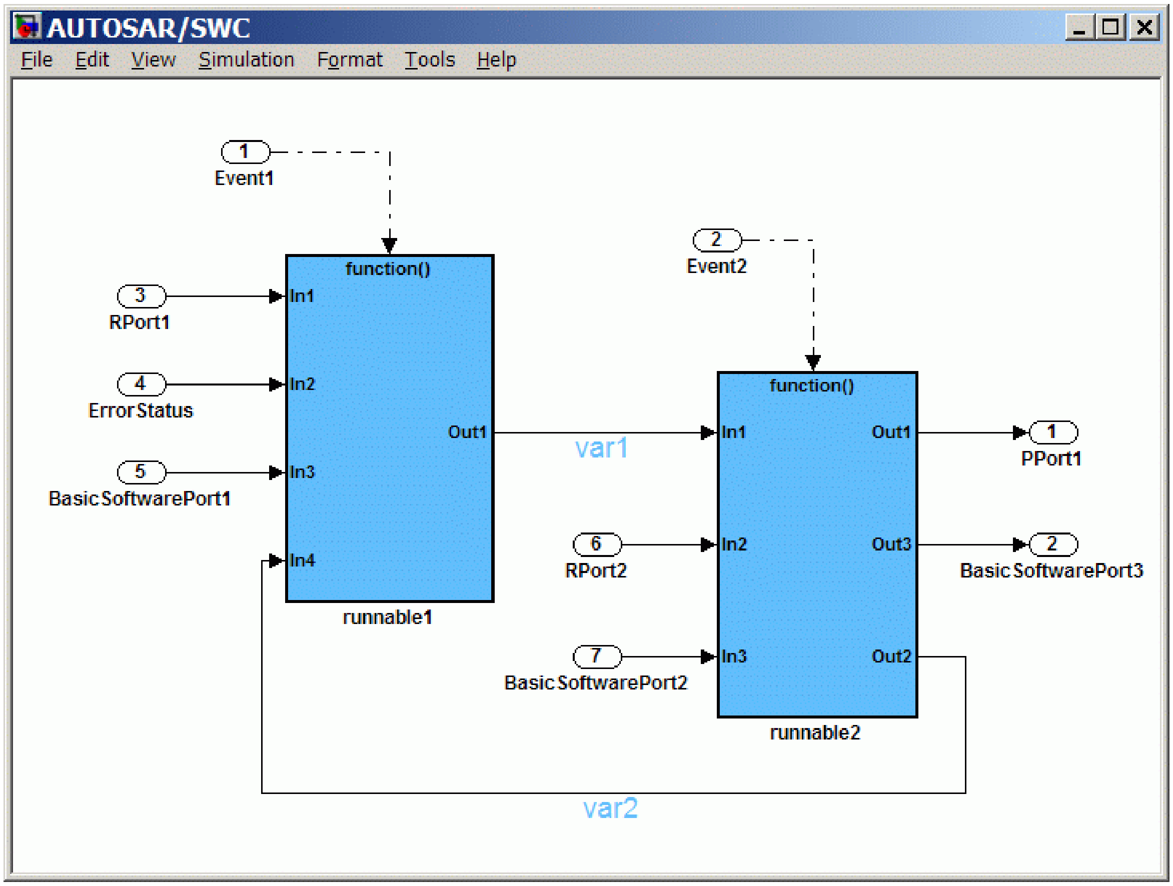
**Tip** While you are working in this view, you can also click the **Configure AUTOSAR Interface** button to open the Configure AUTOSAR Interface dialog box.

---

## Configuring Multiple Runnables

You can use subsystems to model multiple runnables explicitly in a single AUTOSAR Software Component. You can map AUTOSAR runnables to function-call subsystems by using the Export Functions feature. If your model contains function-call subsystems, as in the following example, you can use the Export Functions command to specify that you want each subsystem to represent an AUTOSAR runnable.

Specify an AUTOSAR interface for each function call subsystem being exported as a runnable. Configure the AUTOSAR interfaces for your subsystems by right-clicking the top-level wrapper subsystem and selecting **Real-Time Workshop > AUTOSAR Multi-Runnable Component > Configure**.



To specify that you want multiple runnables generated from your subsystems, right-click the top-level subsystem and select **Real-Time Workshop > AUTOSAR Multi-Runnable Component > Export Functions**.

This command builds code for an AUTOSAR runnable for each subsystem. In the example shown, `runnable1` and `runnable2` are both runnables. The build also creates an additional runnable at code generation time to aggregate the initialization functions for each of the function-call subsystems.

Inter-runnable variables communicate data between runnables to ensure data integrity. Define these inter-runnable variables by the signal lines connecting subsystems (`var1` and `var2` in the example). Double-click to edit these signal names before generating code.

In a multi-runnable software component, you may need to use blocks that depend on time, such as the Discrete-Time Integrator block. You can use a timer for each AUTOSAR runnable if a block uses time. The timer increments at each execution of the runnable. You specify the timer resolution in the AUTOSAR Model Interface dialog box, in the **Execution period** field. In the Configuration Parameters dialog box, under Optimization, specify the **Application life span (days)** . The timer data type is based on your specified application life span and execution period.

To see how to configure and generate AUTOSAR-compliant code and export AUTOSAR Software Component description XML files for a Simulink model with multiple runnables, see the AUTOSAR Code Generation for Multiple Runnable Entities demo.

## Configuring AUTOSAR Options Programmatically

To control AUTOSAR options programmatically, use the AUTOSAR functions listed in the following tables in the Real-Time Workshop Embedded Coder Function Reference documentation.

- “AUTOSAR Component Import”
- “AUTOSAR Configuration”

## Verifying the AUTOSAR Code Using Software-in-the-Loop Testing

A common technique to verify the generated code is to wrap the generated code in an S-function. This technique allows you to verify the generated code in simulation. The AUTOSAR target automatically configures the generated

S-function to route simulation data using AUTOSAR run-time environment (RTE) API calls.

1. Configure your model for software-in-the-loop (SIL) testing by setting these configuration parameters:

   ```
   set_param( modelName, 'GenerateErtSFunction', 'on' );
   set_param( modelName, 'GenCodeOnly', 'off' )
   ```

2. Generate code to build the SIL block.

3. Once the SIL block has been built, replace the existing component in your model with the new block.

4. Simulate the model and check the output to verify that the code produces the same data as the original subsystem.

## Limitations and Tips

**In this section...**

### Cannot Import Internal Behavior

Internal behavior is not parsed. This means any I/O information stored at the runnable level (for example, implicit or explicit) is not imported, and all internal I/O settings default to implicit. You can subsequently configure these I/O ports with the `setIODataAccessMode` method or in the Configure AUTOSAR Interface dialog box.

### Cannot Copy Subsystem Blocks Without Losing Interface Information

If you copy and paste a subsystem block to create a new block in either a new model or the same model, the AUTOSAR interface information stored with the original subsystem block does not copy to the new subsystem block.

### Error If No Default Configuration

To avoid build errors, do not clear the **Generate code only** check box. Configure your model using the **Get Default Configuration** button or the `RTW.AutosarInterface.getDefaultConf` method. If you try to build an executable with the AUTOSAR target without supplying your own system target file or generating a software-in-the-loop (SIL) S-function, you see an error.

## Server Operation Model with Reusable Function Subsystems

The software does not provide AUTOSAR support for a model that is configured as a server operation and contains subsystems that have the reusable function code generation option selected (see "Reusable Function Option" and "Generating Reusable Code for Subsystems Containing S-Function Blocks").

## Cannot Save Importer Objects in MAT-Files

If you try to save an `arxml.importer` object in a MAT-file, you lose all the information. If you reload the MAT-file, then the object is null (handle = –1), because of the Java™ objects that compose the `arxml.importer` object.

## Using the Merge Block for Inter-Runnable Variables

You can use the Merge block to merge inter-runnable variables. However, you must do the following:

- Ensure that the output signal of the Merge block is connected to either one root outport or one or more subsystems.
- If the output signal of the Merge block is connected to the inputs of one or more subsystems, assign the same signal name to the Merge block's output and inputs.

## Migrating AUTOSAR Development Kit Models

Use the `autosar_adk_migrate` function to migrate an AUTOSAR Development Kit (ADK) model (from releases before R2008a) to the AUTOSAR interface.

Enter:

```
autosar_adk_migrate(PATHNAME)
```

to migrate the ADK model/system specified by the full path name `PATHNAME` from the ADK settings to the new AUTOSAR interface. The model must be open before you invoke this function. The MathWorks recommends that you save the migrated model to a different file name.

## Demos and Further Reading

### AUTOSAR Demos

For detailed explanations of AUTOSAR workflows with Real-Time Workshop Embedded Coder software, see the demos in the following table.

| Demo | Description |
|---|---|
| AUTOSAR Code Generation: rtwdemo_autosar_legacy_script | How to generate AUTOSAR-compliant code and export AUTOSAR Software Component description XML files from a Simulink model |
| Using an AUTOSAR Client-Server Interface rtwdemo_autosar_clientserver_script | How to configure and generate AUTOSAR-compliant code and export AUTOSAR-compliant XML files for a Simulink model with an AUTOSAR client-server interface |
| AUTOSAR Code Generation for Multiple Runnable Entities: rtwdemo_autosar_multirunnables_script | How to configure and generate AUTOSAR-compliant code and export AUTOSAR Software Component description XML files for a Simulink model with multiple runnables. |
| Import and Export an AUTOSAR Software Component: rtwdemo_autosar_roundtrip_script | How to use an AUTOSAR authoring tool with Simulink to develop AUTOSAR Software Components. Learn how to import software component interfaces into Simulink, modify and export them, and merge the completed software component back into an AUTOSAR authoring tool. |

## Further Reading

For more information, see the AUTOSAR Web site: `http://www.autosar.org/`

# Customizing the Build Process

## Customizing the Target Build Process with the STF_make_rtw Hook File

**In this section...**

### Overview

The build process lets you supply optional hook files that are executed at specified points in the code-generation and make process. You can use hook files to add target-specific actions to the build process.

This section describes an important M-file hook, generically referred to as `STF_make_rtw_hook.m`, where `STF` is the name of a system target file, such as `ert` or `mytarget`. This hook file implements a function, `STF_make_rtw_hook`, that dispatches to a specific action, depending on the `hookMethod` argument passed in.

The build process automatically calls `STF_make_rtw_hook`, passing in the correct `hookMethod` argument (as well as other arguments described below). You need to implement only those hook methods that your build process requires.

### File and Function Naming Conventions

To ensure that `STF_make_rtw_hook` is called correctly by the build process, you must ensure that the following conditions are met:

- The `STF_make_rtw_hook.m` file is on the MATLAB path.
- The filename is the name of your system target file (`STF`), appended to the string `_make_rtw_hook.m`. For example, if you were generating code with a custom system target file `mytarget.tlc`, you would name your

*STF*_make_rtw_hook.m file to mytarget_make_rtw_hook.m. Likewise, the hook function implemented within the file should follow the same naming convention.

- The hook function implemented in the file follows the function prototype described in the next section.

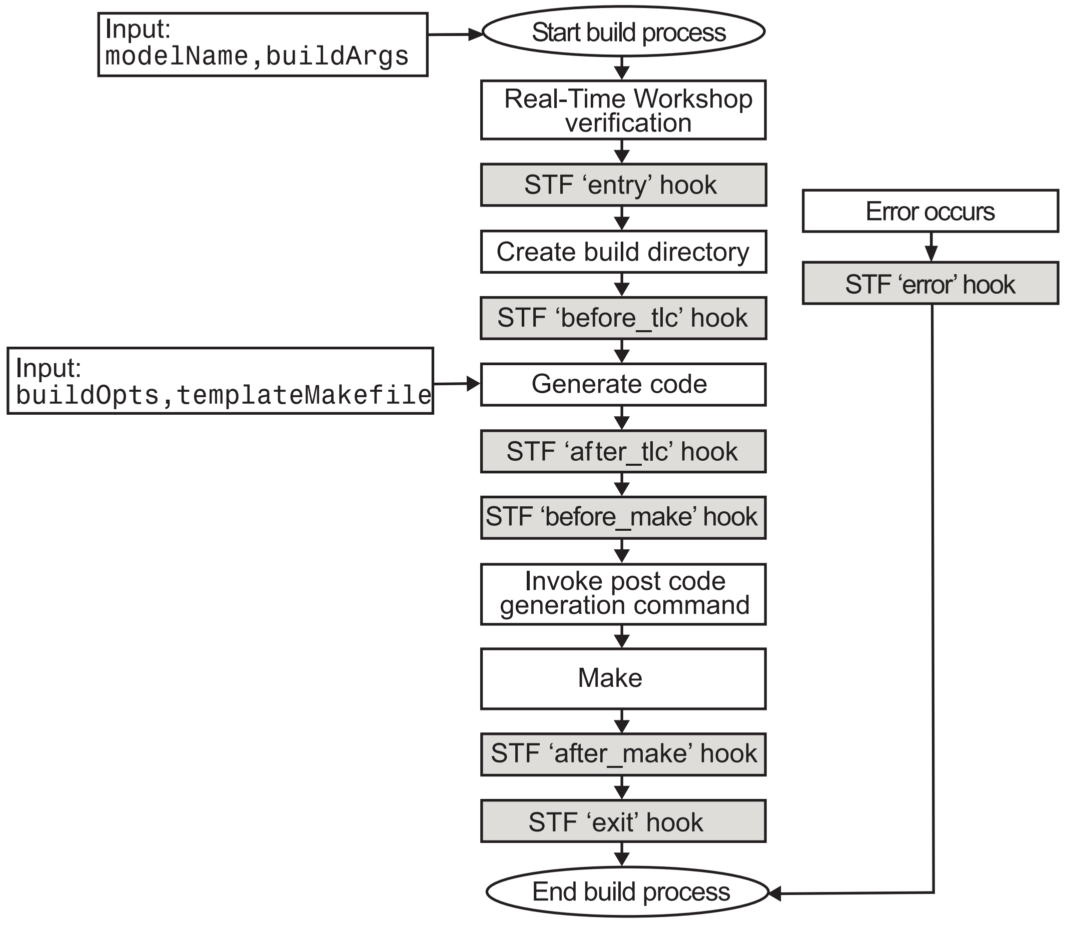
## STF_make_rtw_hook.m Function Prototype and Arguments

The function prototype for *STF*_make_rtw_hook is

```
function STF_make_rtw_hook(hookMethod, modelName, rtwRoot, templateMakefile,
buildOpts, buildArgs)
```

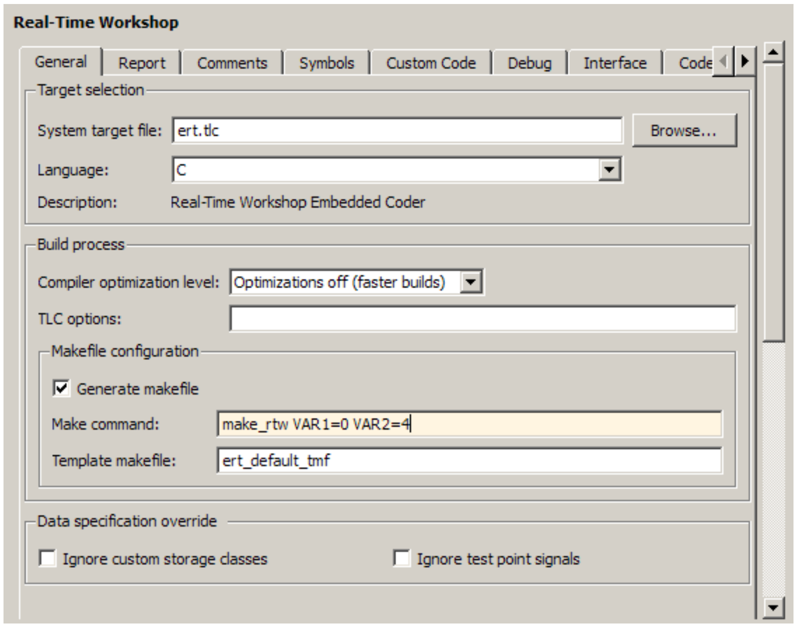
The arguments are defined as:

- hookMethod: String specifying the stage of build process from which the *STF*_make_rtw_hook function is called. The flowchart below summarizes the build process, highlighting the hook points. Valid values for hookMethod are 'entry', 'before_tlc', 'after_tlc', 'before_make', 'after_make', 'exit', and 'error'. The *STF*_make_rtw_hook function dispatches to the relevant code with a switch statement.



- `modelName`: String specifying the name of the model. Valid at all stages of the build process.
- `rtwRoot`: Reserved.
- `templateMakefile`: Name of template makefile.

- `buildOpts`: A MATLAB structure containing the fields described in the list below. Valid for the `'before_make'`, `'after_make'`, and `'exit'` stages only. The `buildOpts` fields are
  - `modules`: Character array specifying a list of additional files that need to be compiled.
  - `codeFormat`: Character array containing code format specified for the target. (ERT-based targets must use the `'Embedded-C'` code format.)
  - `noninlinedSFcns`: Cell array specifying list of noninlined S-functions in the model.
  - `compilerEnvVal`: String specifying compiler environment variable value (for example, `C:\Applications\Microsoft Visual`).
- `buildArgs`: Character array containing the argument to `make_rtw`. When you invoke the build process, `buildArgs` is copied from the argument string (if any) following `"make_rtw"` in the **Make command** field of the **Real-Time Workshop** pane of the Configuration Parameters dialog box.



Real-Time Workshop

Target selection

System target file: ert.tlc

Language: C

Description: Real-Time Workshop Embedded Coder

Build process

Compiler optimization level: Optimizations off (faster builds)

TLC options:

Makefile configuration

☑ Generate makefile

Make command: make_rtw VAR1=0 VAR2=4

Template makefile: ert_default_tmf

Data specification override

☐ Ignore custom storage classes ☐ Ignore test point signals

The make arguments from the **Make command** field in the figure above, for example, generate the following:

```
% make -f untitled.mk VAR1=0 VAR2=4
```

## Applications for STF_make_rtw_hook.m

An enumeration of all possible uses for *STF*_make_rtw_hook.m is beyond the scope of this document. However, this section provides some suggestions of how you might apply the available hooks.

In general, you can use the 'entry' hook to initialize the build process before any code is generated, for example to change or validate settings. One application for the 'entry' hook is to rerun the auto-configuration script that initially ran at target selection time to compare model parameters before and after the script executes for validation purposes.

The other hook points, 'before_tlc', 'after_tlc', 'before_make', 'after_make', 'exit', and 'error' are useful for interfacing with external tool chains, source control tools, and other environment tools.

For example, you could use the *STF*_make_rtw_hook.m file at any stage after 'entry' to obtain the path to the build directory. At the 'exit' stage, you could then locate generated code files within the build directory and check them into your version control system. You might use 'error' to clean up static or global data used by the hook function when an error occurs during code generation or the build process.

Note that the build process temporarily changes the MATLAB working directory to the build directory for stages 'before_make', 'after_make', 'exit', and 'error'. Your *STF*_make_rtw_hook.m file should not make incorrect assumptions about the location of the build directory. You can obtain the path to the build directory anytime after the 'entry' stage. In the following code example, the build directory path is returned as a string to the variable buildDirPath.

```
makertwObj = get_param(gcs, 'MakeRTWSettingsObject');
buildDirPath = getfield(makertwObj, 'BuildDirectory');
```

## Using STF_make_rtw_hook.m for Your Build Procedure

To create a custom *`STF`*`_make_rtw_hook` hook file for your build procedure, copy and edit the example `ert_make_rtw_hook.m` file (located in the *`matlabroot`*`/toolbox/rtw/targets/ecoder` directory) as follows:

1. Copy `ert_make_rtw_hook.m` to a directory in the MATLAB path, and rename it in accordance with the naming conventions described in "File and Function Naming Conventions" on page 23-2. For example, to use it with the GRT target `grt.tlc`, rename it to `grt_make_rtw_hook.m`.

2. Rename the `ert_make_rtw_hook` function within the file to match the filename.

3. Implement the hooks that you require by adding code to the appropriate case statements within the `switch hookMethod` statement.

# Customizing the Target Build Process with sl_customization.m

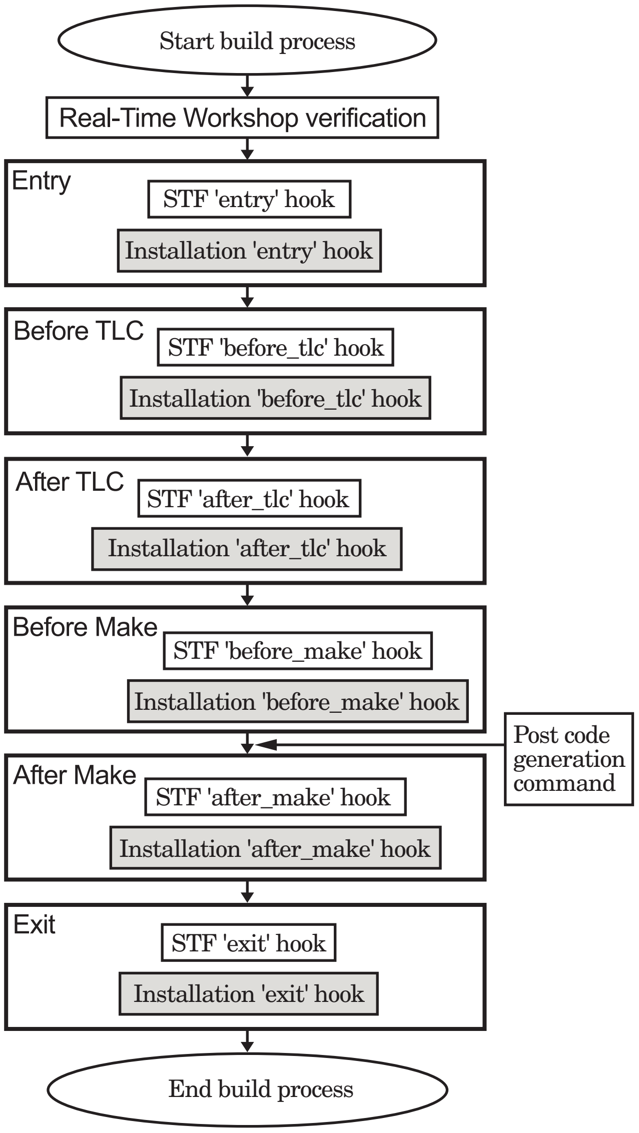
**In this section...**

## Overview

The Simulink customization file `sl_customization.m` is a mechanism that allows you to use M-code to perform customizations of the standard Simulink user interface. The Simulink software reads the `sl_customization.m` file, if present on the MATLAB path, when it starts and the customizations specified in the file are applied to the Simulink session. For more information on the `sl_customization.m` customization file, see "Customizing the Simulink User Interface" in the Simulink documentation.

The `sl_customization.m` file can be used to register installation-specific hook functions to be invoked during the Real-Time Workshop build process. The hook functions that you register through `sl_customization.m` complement System Target File (STF) hooks (described in "Customizing the Target Build Process with the STF_make_rtw Hook File" on page 23-2) and post-code generation commands (described in "Customizing Post Code Generation Build Processing" in the Real-Time Workshop documentation).

The following figure shows the relationship between installation-level hooks and the other available mechanisms for customizing the build process.


Start build process
Real-Time Workshop verification
Entry
STF 'entry' hook
Installation 'entry' hook
Before TLC
STF 'before_tlc' hook
Installation 'before_tlc' hook
After TLC
STF 'after_tlc' hook
Installation 'after_tlc' hook
Before Make
STF 'before_make' hook
Installation 'before_make' hook
Post code generation command
After Make
STF 'after_make' hook
Installation 'after_make' hook
Exit
STF 'exit' hook
Installation 'exit' hook
End build process

## Registering Build Process Hook Functions Using sl_customization.m

To register installation-level hook functions that will be invoked during the Real-Time Workshop build process, you create an M-file function called `sl_customization.m` and include it on the MATLAB path of the Simulink installation that you want to customize. The `sl_customization` function accepts one argument: a handle to a customization manager object. For example,

```
function sl_customization(cm)
```

As a starting point for your customizations, the `sl_customization` function must first get the default (factory) customizations, using the following assignment statement:

```
hObj = cm.RTWBuildCustomizer;
```

You then invoke methods to register your customizations. The customization manager object includes the following method for registering Real-Time Workshop build process hook customizations:

- `addUserHook(hObj, hookType, hook)`

  Registers the hook function M-script or M-function specified by `hook` for the build process stage represented by `hookType`. The valid values for `hookType` are `'entry'`, `'before_tlc'`, `'after_tlc'`, `'before_make'`, `'after_make'`, and `'exit'`.

Your instance of the `sl_customization` function should use this method to register installation-specific hook functions.

The Simulink software reads the `sl_customization.m` file when it starts. If you subsequently change the file, you must restart the Simulink session or enter the following command at the MATLAB command line to effect the changes:

```
sl_refresh_customizations
```

## Variables Available for sl_customization.m Hook Functions

The following variables are available for `sl_customization.m` hook functions to use:

- `modelName` — The name of the Simulink model (valid for all stages)
- `dependencyObject` — An object containing the dependencies of the generated code (valid only for the `'after_make'` stage)

If a hook is an M-script, it can directly access the valid variables. If a hook is an M-function, it can pass the valid variables as arguments to the function. For example:

```
hObj.addUserHook('after_make', 'afterMakeFunction(modelName,dependencyObject);');
```

## Example Build Process Customization Using sl_customization.m

The `sl_customization.m` file shown in Example 1: sl_customization.m for Real-Time Workshop® Build Process Customizations on page 23-12 uses the `addUserHook` method to specify installation-specific build process hooks to be invoked at the `'entry'` and `'after_tlc'` stages of the Real-Time Workshop build. For the hook function source code, see Example 2: CustomRTWEntryHook.m on page 23-13 and Example 3: CustomRTWPostProcessHook.m on page 23-13.

### Example 1: sl_customization.m for Real-Time Workshop Build Process Customizations

```
function sl_customization(cm)
% Register user customizations

% Get default (factory) customizations
hObj = cm.RTWBuildCustomizer;

% Register Real-Time Workshop build process hooks
hObj.addUserHook('entry', 'CustomRTWEntryHook(modelName);');
hObj.addUserHook('after_tlc', 'CustomRTWPostProcessHook(modelName);');

end
```

### Example 2: CustomRTWEntryHook.m

```
function [str, status] = CustomRTWEntryHook(modelName)
str =sprintf('Custom entry hook for model ''%s.''',modelName);
disp(str)
status =1;
```

### Example 3: CustomRTWPostProcessHook.m

```
function [str, status] = CustomRTWPostProcessHook(modelName)
str =sprintf('Custom post process hook for model ''%s.''',modelName);
disp(str)
status =1;
```

If you include the above three files on the MATLAB path of the Simulink installation that you want to customize, the coded hook function messages will appear in the displayed output for Real-Time Workshop builds. For example, if you open the ERT-based model `rtwdemo_udt`, open the **Real-Time Workshop** pane of the Configuration Parameters dialog box, and click the **Build** button to initiate a Real-Time Workshop build, the following messages are displayed:

```
>> rtwdemo_udt

### Starting Real-Time Workshop build procedure for model: rtwdemo_udt
Custom entry hook for model 'rtwdemo_udt.'
Custom post process hook for model 'rtwdemo_udt.'
### Successful completion of Real-Time Workshop build procedure for model: rtwdemo_udt
>>
```

## Replacing the STF_rtw_info_hook Mechanism

Prior to MATLAB Release 14, custom targets supplied target-specific information with a hook file (referred to as *STF*_rtw_info_hook.m). The *STF*_rtw_info_hook specified properties such as word sizes for integer data types (for example, char, short, int, and long), and C implementation-specific properties of the custom target.

The *STF*_rtw_info_hook mechanism has been replaced by the **Hardware Implementation** pane of the Configuration Parameters dialog box. Using this dialog box, you can specify all properties that were formerly specified in your *STF*_rtw_info_hook file.

For backward compatibility, existing *STF*_rtw_info_hook files continue to operate correctly. However, you should convert your target and models to use of the **Hardware Implementation** pane. See the "Configuring the Hardware Implementation" section of the Real-Time Workshop documentation.

# Integrating External Code and Generated C and C++ Code

# About External Code Integration Extensions

The Real-Time Workshop documentation introduces capabilities for integrating external code with generated C and C++ code. Topics include

- “About External Code Integration”
- “Integrating External Code Using Model Configuration Parameters”
- “Integrating External Code Using Custom Code Blocks”
- “Integrating External Code Using S-Functions”

The Real-Time Workshop Embedded Coder product extends the preceding capabilities to support

- Chapter 25, “Generating S-Function Wrappers”
- Chapter 26, “Exporting Function-Call Subsystems”
- Chapter 27, “Nonvirtual Subsystem Modular Function Code Generation”
- Chapter 28, “Controlling Generation of Function Prototypes”
- Chapter 29, “Controlling Generation of Encapsulated C++ Model Interfaces”
- Chapter 30, “Replacing Math Functions and Operators Using Target Function Libraries”

# Generating S-Function Wrappers

## About S-Function Wrapper Generation

An S-function wrapper is an S-function that calls your C or C++ code from within Simulink. S-function wrappers provide a standard interface between Simulink and externally written code, allowing you to integrate your code into a model with minimal modification. This is useful for software-in-the-loop (SIL) code verification (validating your generated code in Simulink), as well as for simulation acceleration purposes (see “Generating an S-Function Wrapper for SIL Testing” on page 37-6). For a complete description of wrapper S-functions, see the Simulink Writing S-Functions document.

Using the Real-Time Workshop Embedded Coder **Create Simulink (S-Function) block** option, you can build, in one automated step:

- A noninlined C or C++ MEX S-function wrapper that calls Real-Time Workshop Embedded Coder generated code
- A model containing the generated S-function block, ready for use with other blocks or models

When the **Create Simulink (S-Function) block** option is on, the Real-Time Workshop build process generates an additional source code file, `*model*_sf.c` or `.cpp`, in the build directory. This module contains the S-function that calls the Real-Time Workshop Embedded Coder code that you deploy. You can use this S-function within Simulink.

The build process then compiles and links `*model*_sf.c` or `.cpp` with `*model*.c` or `.cpp` and the other Real-Time Workshop Embedded Coder generated code modules, building a MEX-file. The MEX-file is named `*model*_sf.*mexext*`. (`*mexext*` is the file extension for MEX-files on your platform, as given by the MATLAB `mexext` command.) The MEX-file is stored in your working directory. Finally, the Real-Time Workshop build process creates and opens an untitled model containing the generated S-Function block.

---

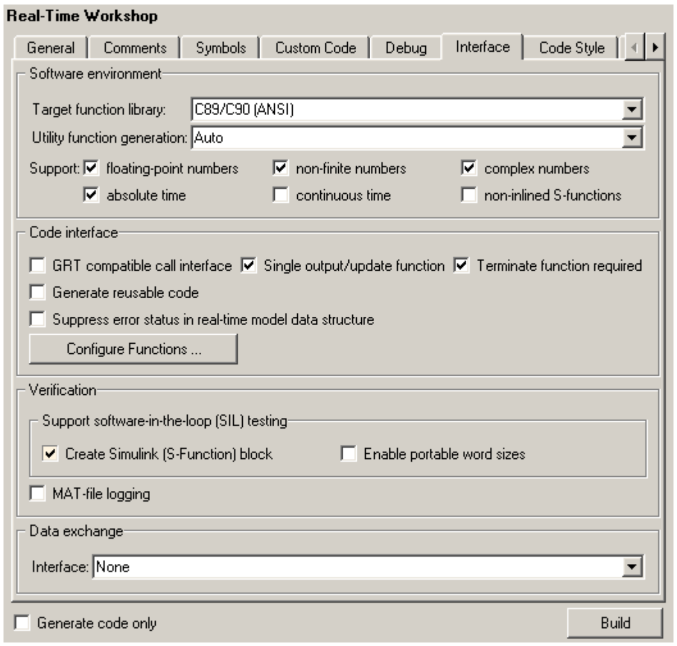
**Note** To generate a wrapper S-function for a subsystem, you can use a right-click subsystem build. Right-click the subsystem block in your model, select **Real-Time Workshop > Generate S-Function**, and in the Generate S-Function dialog box, select **Use Embedded Coder** and click **Build**.

---

## Generating an ERT S-Function Wrapper

To generate an S-function wrapper for your Real-Time Workshop Embedded Coder code, open your ERT-based Simulink model and do the following:

1. Open the Configuration Parameters dialog box.
2. Select the **Interface** pane.
3. Select the **Create Simulink (S-Function) block** option, as shown in this figure.



Real-Time Workshop

General | Comments | Symbols | Custom Code | Debug | Interface | Code Style

Software environment

Target function library: C89/C90 (ANSI)

Utility function generation: Auto

Support: [✓] floating-point numbers [✓] non-finite numbers [✓] complex numbers [✓] absolute time [ ] continuous time [ ] non-inlined S-functions

Code interface

[ ] GRT compatible call interface [✓] Single output/update function [✓] Terminate function required

[ ] Generate reusable code

[ ] Suppress error status in real-time model data structure

Configure Functions ...

Verification

Support software-in-the-loop (SIL) testing

[✓] Create Simulink (S-Function) block [ ] Enable portable word sizes

[ ] MAT-file logging

Data exchange

Interface: None

[ ] Generate code only

Build

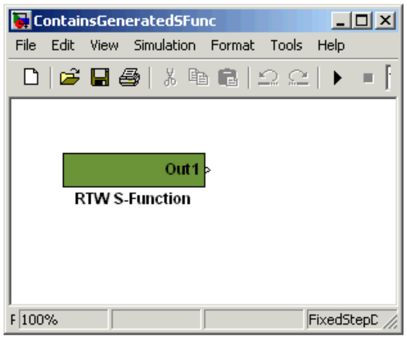
4. Configure the other code generation options as required.
5. To ensure that memory for the S-Function is initialized to zero, you should deselect the following options in the **Optimization > Data Initialization** pane:

   - **"Remove root level I/O zero initialization"**

- **“Remove internal data zero initialization”**
- **“Use memset to initialize floats and doubles to 0.0”**

6 Select the **Real-Time Workshop** pane and click the **Build** button.

7 When the build process completes, an untitled model window opens. This model contains the generated S-Function block.



8 Save the new model.

9 The generated S-Function block is now ready to use with other blocks or models in Simulink.

## S-Function Wrapper Generation Limitations

The following limitations apply to Real-Time Workshop Embedded Coder S-function wrapper generation:

- Continuous sample time is not supported. The **Support continuous time** option should not be selected when generating a Real-Time Workshop Embedded Coder S-function wrapper.
- Models that contain S-function blocks for which the S-function is not inlined with a TLC file are not supported when generating a Real-Time Workshop Embedded Coder S-function wrapper.
- You cannot use multiple instances of a Real-Time Workshop Embedded Coder generated S-function block within a model, because the code uses static memory allocation. Each instance potentially can overwrite global data values of the others.
- Real-Time Workshop Embedded Coder S-function wrappers can be used with other blocks and models for such purposes as SIL code verification and simulation acceleration, but cannot be used for code generation.
- A MEX S-function wrapper must only be used in the version of MATLAB in which the wrapper is created.

# Exporting Function-Call Subsystems

## Overview

Real-Time Workshop Embedded Coder software provides code export capabilities that you can use to

- Automatically generate code for
  - A function-call subsystem that contains only blocks that support code generation
  - A virtual subsystem that contains only such subsystems and a few other types of blocks
- Optionally generate an ERT S-function wrapper for the generated code

You can use these capabilities only if the subsystem and its interface to the Simulink model conform to certain requirements and constraints, as described in "Requirements for Exporting Function-Call Subsystems" on page 26-4. For limitations that apply, see "Function-Call Subsystems Export Limitations" on page 26-14.

---

**Note** For models designed in earlier releases, Real-Time Workshop Embedded Coder software also supports the ability to export functions from triggered subsystems. In general, the requirements and limitations stated for exporting functions from function-call subsystems also apply to exporting functions from triggered subsystems, with the following exceptions:

- Triggered subsystems from which you intend to export functions must be encapsulated in a single top-level virtual subsystem.
- Triggered subsystems do not have to meet the requirements in "Trigger Signals Require a Common Source" on page 26-5 and "Requirements for Exported Virtual Subsystems" on page 26-5.
- The section "Exporting Function-Call Subsystems That Depend on Elapsed Time" on page 26-9 is not applicable to exporting functions from triggered subsystems.

---

## Exported Subsystems Demo

To see a demo of exported function-call subsystems, type `rtwdemo_export_functions` in the MATLAB Command Window.

## Additional Information

See the following in the Simulink documentation for additional information relating to exporting function-call subsystems:

- "Systems and Subsystems"
- "Signals"
- "Triggered Subsystems"
- "Function-Call Subsystems"
- *Writing S-Functions*

If you want to use Stateflow blocks to trigger exportable function-call subsystems, you may also need information from the *Stateflow and Stateflow® Coder™ User's Guide*.

## Requirements for Exporting Function-Call Subsystems

To be exportable as code, a function-call subsystem, or a virtual subsystem that contains such subsystems, must meet certain requirements. Most requirements are similar for either type of export, but some apply only to virtual subsystems. The requirements that affect all Simulink code generation also apply.

For brevity, *exported subsystem* in this section means only an exported function-call subsystem or an exported virtual subsystem that contains such subsystems. The requirements listed do not necessarily apply to other types of exported subsystems.

### Requirements for All Exported Subsystems

These requirements apply to both exported function-call subsystems and exported virtual subsystems that contain such subsystems.

#### Blocks Must Support Code Generation

All blocks within an exported subsystem must support code generation. However, blocks outside the subsystem need not support code generation unless they will be converted to code in some other context.

#### Blocks Must Not Use Absolute Time

Certain blocks use absolute time. Blocks that use absolute time are not supported in exported function-call subsystems. For a complete list of such blocks, see “Limitations on the Use of Absolute Time” in the Real-Time Workshop documentation.

#### Blocks Must Not Depend on Elapsed Time

Certain blocks, like the Sine Wave block and Discrete Integrator block, depend on elapsed time. If an exported function-call subsystem contains any blocks that depend on elapsed time, the subsystem must specify periodic execution. See “Exporting Function-Call Subsystems That Depend on Elapsed Time” on page 26-9 in the Real-Time Workshop documentation.

### Trigger Signals Require a Common Source

If more than one trigger signal crosses the boundary of an exported system, all of the trigger signals must be periodic and originate from the same function-call initiator.

### Trigger Signals Must Be Scalar

A trigger signal that crosses the boundary of an exported subsystem must be scalar. Input and output data signals that do not act as triggers need not be scalar.

### Data Signals Must Be Nonvirtual

A data signal that crosses the boundary of an exported system cannot be a virtual bus, and cannot be implemented as a `Goto-From` connection. Every data signal crossing the export boundary must be scalar, muxed, or a nonvirtual bus.

## Requirements for Exported Virtual Subsystems

These requirements apply only to exported virtual subsystems that contain function-call subsystems.

### Virtual Subsystem Must Use Only Permissible Blocks

The top level of an exported virtual subsystem that contains function-call subsystem blocks can contain only the following other types of blocks:

- Input and Output blocks (ports)
- Constant blocks (including blocks that resolve to constants, such as Add)
- Merge blocks
- Virtual connection blocks (Mux, Demux, Bus Creator, Bus Selector, Signal Specification)
- Signal-viewer blocks, such as `Scope` blocks

These restrictions do *not* apply within function-call subsystems, whether or not they appear in a virtual subsystem. They apply only at the top level of an exported virtual subsystem that contains one or more function-call subsystems.

### Constant Blocks Must Be Inlined

When a constant block appears at the top level of an exported virtual subsystem, the containing model must check `Inline parameters` on the **Optimization** pane of the Configuration Parameters dialog box.

### Constant Outputs Must Specify a Storage Class

When a constant signal drives an output port of an exported virtual subsystem, the signal must specify a storage class.

## Techniques for Exporting Function-Call Subsystems

To export a function-call subsystem, or a virtual subsystem that contains function-call subsystems,

1. Ensure that the subsystem to be exported satisfies the "Requirements for Exporting Function-Call Subsystems" on page 26-4.

2. In the Configuration Parameters dialog box:

   a. On the **Real-Time Workshop** pane, specify an ERT code generation target such as `ert.tlc`.

   b. If you want an ERT S-function wrapper for the generated code, go to the **Interface** pane and select **Create Simulink (S-function) block**.

   c. Click **OK** or **Apply**.

3. Right-click the subsystem block and choose **Real-Time Workshop > Export Functions** from the context menu.

   The `Build code for subsystem:` *`Subsystem`* dialog box appears. This dialog box is not specific to exporting function-call subsystems, and generating code does not require entering information in the box.

4. Click **Build**.

   The MATLAB Command Window displays messages similar to those for any code generation sequence. Simulink generates code and places it in the working directory.

   If you checked **Create Simulink (S-function) block** in step 2b, Simulink opens a new window that contains an S-function block that represents the generated code. This block has the same size, shape, and connectors as the original subsystem.

Code generation and optional block creation are now complete. You can test and use the code and optional block as you could any generated ERT code and S-function block.

## Optimizing Exported Function-Call Subsystems

You can use Real-Time Workshop options to optimize the code generated for a function-call subsystem or virtual block that contains such subsystems. To obtain faster code,

- Specify a storage class for every input signal and output signal that crosses the boundary of the subsystem.
- For each function-call subsystem to be exported (whether directly or within a virtual subsystem):

  1. Right-click the subsystem and choose **Subsystem Parameters** from the context menu.
  2. Set the **Real-Time Workshop system code** parameter to `Auto`.
  3. Click **OK** or **Apply**.

## Exporting Function-Call Subsystems That Depend on Elapsed Time

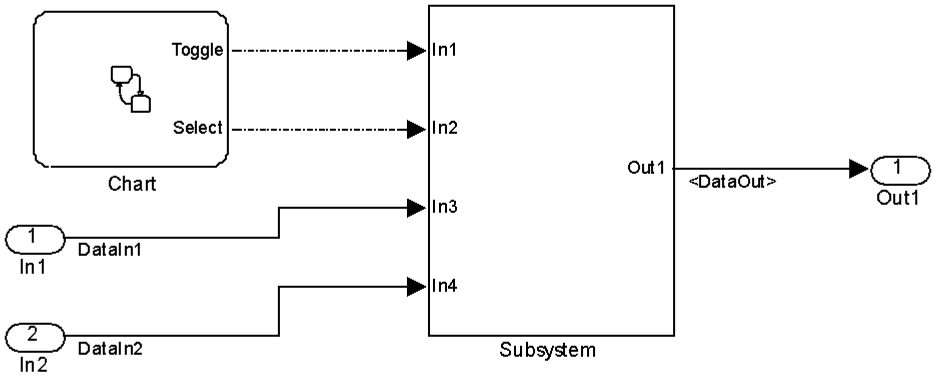
Some blocks, such as the Sine Wave block (if sample-based) and the Discrete-Time Integrator block, depend on elapsed time. See “Absolute and Elapsed Time Computation” in the Real-Time Workshop documentation for more information.

When a block that depends on elapsed time exists in a function-call subsystem, the subsystem cannot be exported unless it specifies periodic execution. To provide the necessary specification,

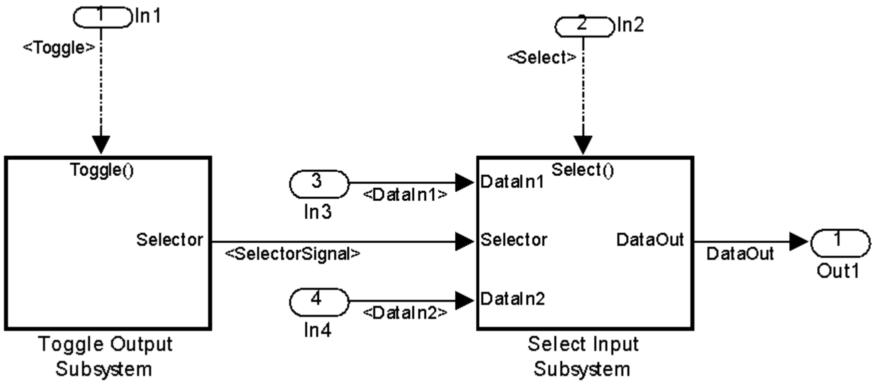
1. Right-click the trigger port block in the function-call subsystem and choose **TriggerPort Parameters** from the context menu.
2. Specify **periodic** in the **Sample time type** field.
3. Set the **Sample time** to the same granularity specified (directly or by inheritance) in the function-call initiator.
4. Click **OK** or **Apply**.

## Function-Call Subsystem Export Example

The next figure shows the top level of a model that uses a Stateflow chart named `Chart` to input two function-call trigger signals (denoted by dash-dot lines) to a virtual subsystem named `Subsystem`.



The next figure shows the contents of `Subsystem` in the previous figure. The subsystem contains two function-call subsystems, each driven by one of the signals input from the top level.



In the preceding model, the Stateflow chart can assert either of two scalar signals, `Toggle` and `Select`.

- Asserting Toggle toggles the Boolean state of the function-call subsystem Toggle Output Subsystem.
- Asserting Select causes the function-call subsystem Select Input Subsystem to assign the value of DataIn1 or DataIn2 to its output signal. The value assigned depends on the current state of Toggle Output Subsystem.

The following generated code implements the subsystem named Subsystem. The code is typical for virtual subsystems that contain function-call subsystems. It specifies an initialization function and a function for each contained subsystem, and would also include functions to enable and disable subsystems if applicable.

```
#include "Subsystem.h"
#include "Subsystem_private.h"

/* Exported block signals */
real_T DataIn1;                    /* '<Root>/In3' */
real_T DataIn2;                    /* '<Root>/In4' */
real_T DataOut;                    /* '<S4>/Switch' */
boolean_T SelectorSignal;          /* '<S5>/Logical Operator' */

/* Exported block states */
boolean_T SelectorState;           /* '<S5>/Unit Delay' */

/* Real-time model */
RT_MODEL_Subsystem Subsystem_M_;
RT_MODEL_Subsystem *Subsystem_M = &Subsystem_M_;

/* Initial conditions for exported function: Toggle */

void Toggle_Init(void)
{
  /* Initial conditions for function-call system: '<S1>/Toggle Output Subsystem' */

  /* InitializeConditions for UnitDelay: '<S5>/Unit Delay' */
  SelectorState = Subsystem_P.UnitDelay_X0;
}

/* Output and update for exported function: Toggle */
```

```
void Toggle(void)
{
  /* Output and update for function-call system: '<S1>/Toggle Output Subsystem' */

  /* Logic: '<S5>/Logical Operator' incorporates:
   *  UnitDelay: '<S5>/Unit Delay'
   */
  SelectorSignal = !SelectorState;

  /* Update for UnitDelay: '<S5>/Unit Delay' */
  SelectorState = SelectorSignal;
}

/* Output and update for exported function: Select */

void Select(void)
{
  /* Output and update for function-call system: '<S1>/Select Input Subsystem' */

  /* Switch: '<S4>/Switch' incorporates:
   *  Inport: '<Root>/In3'
   *  Inport: '<Root>/In4'
   */
  if(SelectorSignal) {
    DataOut = DataIn1;
  } else {
    DataOut = DataIn2;
  }
}

/* Model initialize function */

void Subsystem_initialize(void)
{
  /* initialize error status */
  rtmSetErrorStatus(Subsystem_M, (const char_T *)0);

  /* block I/O */
  /* exported global signals */
  DataOut = 0.0;
  SelectorSignal = FALSE;

  /* states (dwork) */

  /* exported global states */
  SelectorState = FALSE;

  /* external inputs */
  DataIn1 = 0.0;
  DataIn2 = 0.0;

  Toggle_Init();
}

/* Model terminate function */

void Subsystem_terminate(void)
{
  /* (no terminate code required) */
}
```

## Function-Call Subsystems Export Limitations

The function-call subsystem export capabilities have the following limitations:

- Real-Time Workshop options do not control the names of the files containing the generated code. All such filenames begin with the name of the exported subsystem. Each filename is suffixed as appropriate to the file.
- Real-Time Workshop options do not control the names of top-level functions in the generated code. Each function name reflects the name of the signal that triggers the function, or for an unnamed signal, the block from which the signal originates.
- This release cannot export reusable code for a function-call subsystem. Checking **Configuration Parameters > Real-Time Workshop > Interface > Generate reusable code** has no effect on the generated code for the subsystem.
- This release supports code generation for ERT generated S-function blocks if the block does not have function-call input ports, but the ERT S-function block will appear as a noninlined S-function in the generated code.
- This release supports an ERT generated S-function block in accelerator mode only if its function-call initiator is noninlined in accelerator mode. Examples of noninlined initiators include all Stateflow charts.
- The ERT S-function wrapper must be driven by a Level-2 S-function initiator block, such as a Stateflow chart or the built-in Function-call Generator block.
- An asynchronous (sample-time) function-call system can be exported, but this release does not support the ERT S-function wrapper for an asynchronous system.
- This release does not support code generation for an ERT generated S-function block if the block was generated as a wrapper for exported function calls.
- The output port of an ERT generated S-function block cannot be merged using the Merge block.
- This release does not support MAT-file logging for exported function calls. Any specification that enables MAT-file logging is ignored.

- The use of the TLC function `LibIsFirstInit` is deprecated for exported function calls.
- The `*model*_initialize` function generated in the code for an exported function-call subsystem never includes a `firstTime` argument, regardless of the value of the model configuration parameter `IncludeERTFirstTime`. Thus, you cannot call `*model*_initialize` at a time greater than start time, for example, to reset block states.

# Nonvirtual Subsystem Modular Function Code Generation

## Overview

The Real-Time Workshop Embedded Coder software provides a subsystem option, **Function with separate data**, that allows you to generate modular function code for nonvirtual subsystems, including atomic subsystems and conditionally executed subsystems.

By default, the generated code for a nonvirtual subsystem does not separate a subsystem's internal data from the data of its parent Simulink model. This can make it difficult to trace and test the code, particularly for nonreusable subsystems. Also, in large models containing nonvirtual subsystems, data structures can become large and potentially difficult to compile.

The Subsystem Parameters dialog box option **Function with separate data** allows you to generate subsystem function code in which the internal data for a nonvirtual subsystem is separated from its parent model and is owned by the subsystem. As a result, the generated code for the subsystem is easier to trace and test. The data separation also tends to reduce the size of data structures throughout the model.

---

**Note** Selecting the **Function with separate data** option for a nonvirtual subsystem has no semantic effect on the parent Simulink model.

---

To be able to use this option,

- Your Simulink model must use an ERT-based system target file (requires a Real-Time Workshop Embedded Coder license).
- Your subsystem must be configured to be atomic or conditionally executed (for more information, see "Systems and Subsystems" in the Simulink documentation).
- Your subsystem must use the `Function` setting for the **Real-Time Workshop system code** parameter.

To configure your subsystem for generating modular function code, you invoke the Subsystem Parameters dialog box and make a series of selections to display and enable the **Function with separate data** option. See "Configuring Nonvirtual Subsystems for Generating Modular Function

Code" on page 27-4 and "Examples of Modular Function Code for Nonvirtual Subsystems" on page 27-9 for details. For limitations that apply, see "Nonvirtual Subsystem Modular Function Code Limitations" on page 27-15.

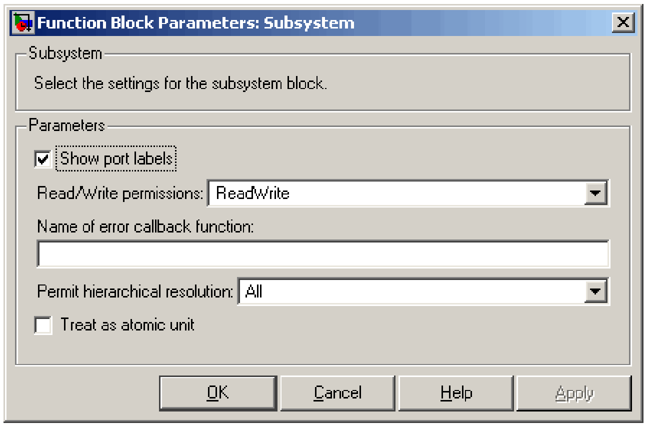
For more information about generating code for atomic subsystems, see the sections "Creating Subsystems" and "Generating Code and Executables from Subsystems" in the Real-Time Workshop documentation.

## Configuring Nonvirtual Subsystems for Generating Modular Function Code

This section summarizes the steps needed to configure a subsystem in a Simulink model for modular function code generation.

1 Verify that the Simulink model containing the subsystem uses an ERT-based system target file (see the **System target file** parameter on the **Real-Time Workshop** pane of the Configuration Parameters dialog box).

2 In your Simulink model, select the subsystem for which you want to generate modular function code and launch the Subsystem Parameters dialog box (for example, right-click the subsystem and select **Subsystem Parameters**). The dialog box for an atomic subsystem is shown below. (In the dialog box for a conditionally executed subsystem, the dialog box option **Treat as atomic unit** is greyed out, and you can skip Step 3.)


Function Block Parameters: Subsystem

Subsystem

Select the settings for the subsystem block.

Parameters

☑ Show port labels

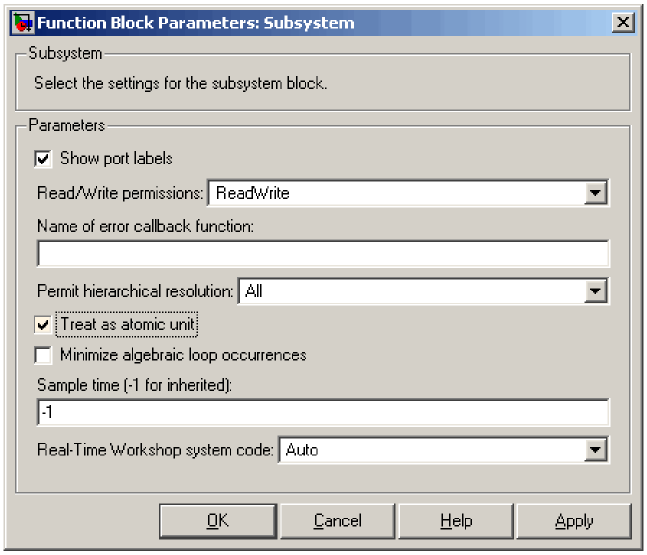
Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

☐ Treat as atomic unit

3 If the Subsystem Parameters dialog box option **Treat as atomic unit** is available for selection but not selected, the subsystem is neither atomic nor conditionally executed. Select the option **Treat as atomic unit**. After you make this selection, the **Real-Time Workshop system code** parameter is displayed.


Function Block Parameters: Subsystem

Subsystem

Select the settings for the subsystem block.

Parameters

☑ Show port labels

Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

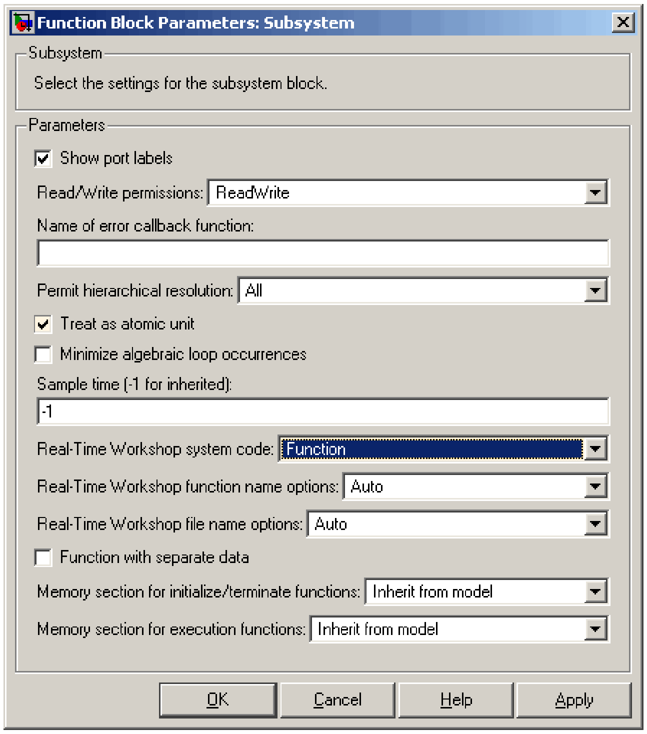
☑ Treat as atomic unit

☐ Minimize algebraic loop occurrences

Sample time (-1 for inherited): -1

Real-Time Workshop system code: Auto

**4** For the **Real-Time Workshop system code** parameter, select the value `Function`. After you make this selection, the **Function with separate data** option is displayed.



Function Block Parameters: Subsystem

Subsystem

Select the settings for the subsystem block.

Parameters

[✓] Show port labels

Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

[✓] Treat as atomic unit

[ ] Minimize algebraic loop occurrences

Sample time (-1 for inherited): -1

Real-Time Workshop system code: Function

Real-Time Workshop function name options: Auto

Real-Time Workshop file name options: Auto

[ ] Function with separate data

Memory section for initialize/terminate functions: Inherit from model

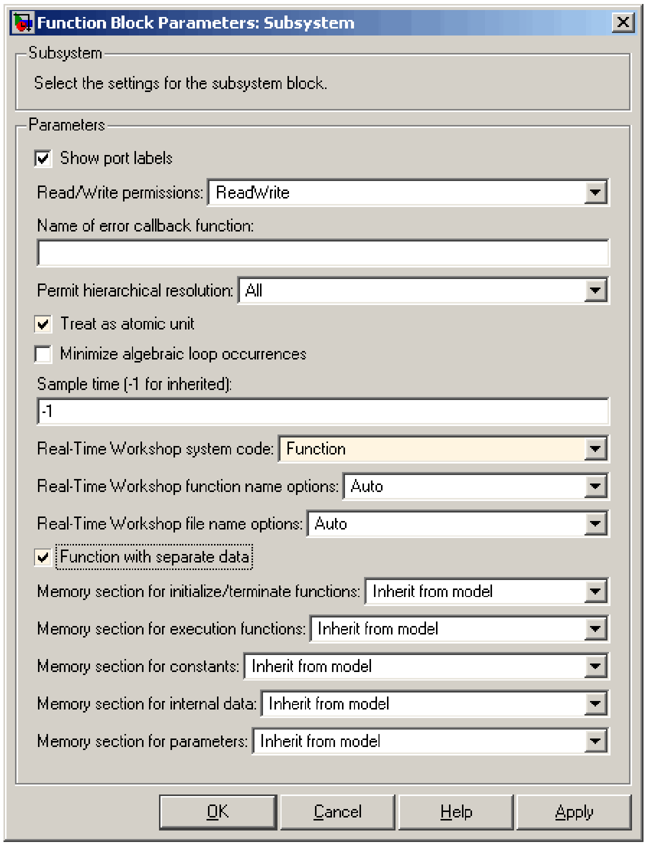
Memory section for execution functions: Inherit from model

---

**Note** Before you generate nonvirtual subsystem function code with the **Function with separate data** option selected, you might want to generate function code with the option *deselected* and save the generated function `.c` and `.h` files in a separate directory for later comparison.

---

**5** Select the **Function with separate data** option. After you make this selection, additional configuration parameters are displayed.



Function Block Parameters: Subsystem

Subsystem

Select the settings for the subsystem block.

Parameters

[✓] Show port labels

Read/Write permissions: ReadWrite

Name of error callback function:

Permit hierarchical resolution: All

[✓] Treat as atomic unit

[ ] Minimize algebraic loop occurrences

Sample time (-1 for inherited):
-1

Real-Time Workshop system code: Function

Real-Time Workshop function name options: Auto

Real-Time Workshop file name options: Auto

[✓] Function with separate data

Memory section for initialize/terminate functions: Inherit from model

Memory section for execution functions: Inherit from model

Memory section for constants: Inherit from model

Memory section for internal data: Inherit from model

Memory section for parameters: Inherit from model

---

**Note** To control the naming of the subsystem function and the subsystem files in the generated code, you can modify the subsystem parameters **Real-Time Workshop function name options** and **Real-Time Workshop file name options**.

---

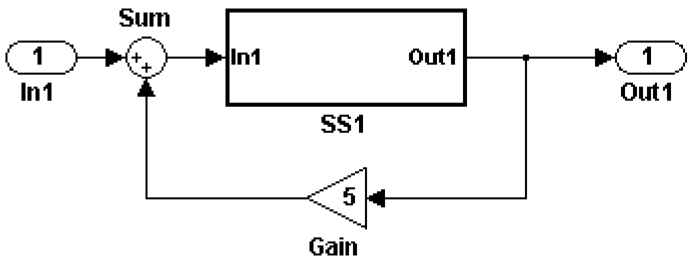
**6** To save your subsystem parameter settings and exit the dialog box, click **OK**.

This completes the subsystem configuration needed to generate modular function code. You can now generate the code for the subsystem and examine the generated files, including the function `.c` and `.h` files named according to your subsystem parameter specifications. For more information on generating code for nonvirtual subsystems, see “Creating Subsystems” in the Real-Time Workshop documentation. For examples of generated subsystem function code, see “Examples of Modular Function Code for Nonvirtual Subsystems” on page 27-9.

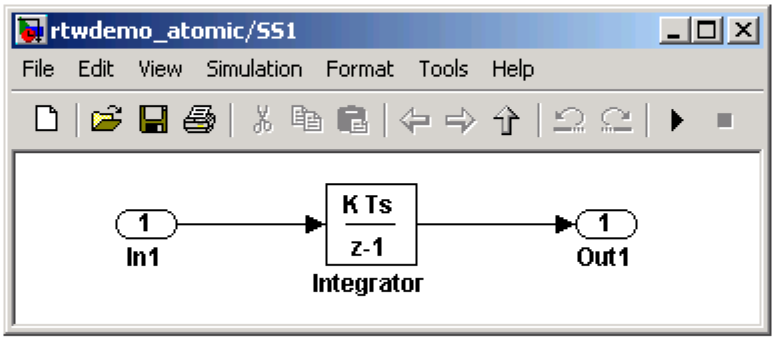
## Examples of Modular Function Code for Nonvirtual Subsystems

To illustrate the effect of selecting the **Function with separate data** option for a nonvirtual subsystem, the following procedure generates atomic subsystem function code with and without the option selected and compares the results.

1. Open MATLAB and launch `rtwdemo_atomic.mdl` using the MATLAB command `rtwdemo_atomic`. Examine the Simulink model.



2. Double-click the SS1 subsystem and examine the contents. (You can close the subsystem window when you are finished.)



3. Use the Configuration Parameters dialog box to change the model's **System target file** from GRT to ERT. For example, from the Simulink window, select **Simulation > Configuration Parameters**, select the **Real-Time**

**Workshop** pane, select **System target file** `ert.tlc`, and click **OK** twice to confirm the change.

**4** Create a variant of `rtwdemo_atomic.mdl` that illustrates function code *without* data separation.

**a** In the Simulink view of `rtwdemo_atomic.mdl`, right-click the SS1 subsystem and select **Subsystem Parameters**. In the Subsystem Parameters dialog box, verify that

- **Treat as atomic unit** is checked
- `User specified` is selected as the value for the **Real-Time Workshop function name options** parameter
- `myfun` is specified as the value for the **Real-Time Workshop function name** parameter

**b** In the Subsystem Parameters dialog box,

**i** Select the value `Function` for the **Real-Time Workshop system code** parameter. After this selection, additional parameters and options will appear.

**ii** Select the value `Use function name` for the **Real-Time Workshop file name** parameter. This selection is optional but simplifies the later task of code comparison by causing the atomic subsystem function code to be generated into the files `myfun.c` and `myfun.h`.

Do *not* select the option **Function with separate data**. Click **Apply** to apply the changes and click **OK** to exit the dialog box.

**c** Save this model variant to a personal work directory, for example, `d:/atomic/rtwdemo_atomic1.mdl`.

**5** Create a variant of `rtwdemo_atomic.mdl` that illustrates function code *with* data separation.

**a** In the Simulink view of `rtwdemo_atomic1.mdl` (or `rtwdemo_atomic.mdl` with step 3 reapplied), right-click the SS1 subsystem and select **Subsystem Parameters**. In the Subsystem Parameters dialog box, verify that

- **Treat as atomic unit** is checked

- `Function` is selected for the **Real-Time Workshop system code** parameter
- `User specified` is selected as the value for the **Real-Time Workshop function name options** parameter
- `myfun` is specified as the value for the **Real-Time Workshop function name** parameter
- `Use function name` is selected for the **Real-Time Workshop file name options** parameter

**b** In the Subsystem Parameters dialog box, select the option **Function with separate data**. Click **Apply** to apply the change and click **OK** to exit the dialog box.

**c** Save this model variant, using a different name than the first variant, to a personal work directory, for example, `d:/atomic/rtwdemo_atomic2.mdl`.

6. Generate code for each model, `d:/atomic/rtwdemo_atomic1.mdl` and `d:/atomic/rtwdemo_atomic2.mdl`.

7. In the generated code directories, compare the *`model`*`.c/.h` and `myfun.c/.h` files generated for the two models. (In this example, there are no significant differences in the generated variants of `ert_main.c`, *`model`*`_private.h`, *`model`*`_types.h`, or `rtwtypes.h`.)

## H File Differences for Nonvirtual Subsystem Function Data Separation

The differences between the H files generated for `rtwdemo_atomic1.mdl` and `rtwdemo_atomic2.mdl` help illustrate the effect of selecting the **Function with separate data** option for nonvirtual subsystems.

1. Selecting **Function with separate data** causes `typedef`s for subsystem data to be generated in the `myfun.h` file for `rtwdemo_atomic2`:

```
/* Block signals for system '<Root>/SS1' */
typedef struct {
  real_T Integrator;                   /* '<S1>/Integrator' */
} rtB_myfun;

/* Block states (auto storage) for system '<Root>/SS1' */
```

```
typedef struct {
  real_T Integrator_DSTATE;             /* '<S1>/Integrator' */
} rtDW_myfun;
```

By contrast, for `rtwdemo_atomic1`, `typedef`s for subsystem data belong to the model and appear in `rtwdemo_atomic1.h`:

```
/* Block signals (auto storage) */
typedef struct {
...
    real_T Integrator;                  /* '<S1>/Integrator' */
} BlockIO_rtwdemo_atomic1;

/* Block states (auto storage) for system '<Root>' */
typedef struct {
  real_T Integrator_DSTATE;             /* '<S1>/Integrator' */
} D_Work_rtwdemo_atomic1;
```

**2** Selecting **Function with separate data** generates the following external declarations in the `myfun.h` file for `rtwdemo_atomic2`:

```
/* Extern declarations of internal data for 'system '<Root>/SS1'' */
extern rtB_myfun rtwdemo_atomic2_myfunB;

extern rtDW_myfun rtwdemo_atomic2_myfunDW;

extern void myfun_initialize(void);
```

By contrast, the generated code for `rtwdemo_atomic1` contains model-level external declarations for the subsystem's `BlockIO` and `D_Work` data, in `rtwdemo_atomic1.h`:

```
/* Block signals (auto storage) */
extern BlockIO_rtwdemo_atomic1 rtwdemo_atomic1_B;

/* Block states (auto storage) */
extern D_Work_rtwdemo_atomic1 rtwdemo_atomic1_DWork;
```

## C File Differences for Nonvirtual Subsystem Function Data Separation

The differences between the C files generated for `rtwdemo_atomic1.mdl` and `rtwdemo_atomic2.mdl` illustrate the key effects of selecting the **Function with separate data** option for nonvirtual subsystems.

1 Selecting **Function with separate data** causes a separate subsystem initialize function, `myfun_initialize`, to be generated in the `myfun.c` file for `rtwdemo_atomic2`:

```
void myfun_initialize(void) {
  {
    ((real_T*)&rtwdemo_atomic2_myfunB.Integrator)[0] = 0.0;
  }
  rtwdemo_atomic2_myfunDW.Integrator_DSTATE = 0.0;
}
```

The subsystem initialize function in `myfun.c` is invoked by the model initialize function in `rtwdemo_atomic2.c`:

```
/* Model initialize function */

void rtwdemo_atomic2_initialize(void)
{
...

  /* Initialize subsystem data */
  myfun_initialize();
}
```

By contrast, for `rtwdemo_atomic1`, subsystem data is initialized by the model initialize function in `rtwdemo_atomic1.c`:

```
/* Model initialize function */

void rtwdemo_atomic1_initialize(void)
{
...
  /* block I/O */
  {
```

```
 ...
    ((real_T*)&rtwdemo_atomic1_B.Integrator)[0] = 0.0;
  }

  /* states (dwork) */

  rtwdemo_atomic1_DWork.Integrator_DSTATE = 0.0;
...
}
```

**2** Selecting **Function with separate data** generates the following declarations in the `myfun.c` file for `rtwdemo_atomic2`:

```
/* Declare variables for internal data of system '<Root>/SS1' */
rtB_myfun rtwdemo_atomic2_myfunB;

rtDW_myfun rtwdemo_atomic2_myfunDW;
```

By contrast, the generated code for `rtwdemo_atomic1` contains model-level declarations for the subsystem's `BlockIO` and `D_Work` data, in `rtwdemo_atomic1.c`:

```
/* Block signals (auto storage) */
BlockIO_rtwdemo_atomic1 rtwdemo_atomic1_B;

/* Block states (auto storage) */
D_Work_rtwdemo_atomic1 rtwdemo_atomic1_DWork;
```

**3** Selecting **Function with separate data** generates identifier naming that reflects the subsystem orientation of data items. Notice the references to subsystem data in subsystem functions such as `myfun` and `myfun_update` or in the model's `*model*_step` function. For example, compare this code from `myfun` for `rtwdemo_atomic2`

```
/* DiscreteIntegrator: '<S1>/Integrator' */
rtwdemo_atomic2_myfunB.Integrator = rtwdemo_atomic2_myfunDW.Integrator_DSTATE;
```

to the corresponding code from `myfun` for `rtwdemo_atomic1`.

```
/* DiscreteIntegrator: '<S1>/Integrator' */
rtwdemo_atomic1_B.Integrator = rtwdemo_atomic1_DWork.Integrator_DSTATE;
```

## Nonvirtual Subsystem Modular Function Code Limitations

The nonvirtual subsystem option **Function with separate data** has the following limitations:

- The **Function with separate data** option is available only in ERT-based Simulink models (requires a Real-Time Workshop Embedded Coder license).
- The nonvirtual subsystem to which the option is applied cannot have multiple sample times or continuous sample times; that is, the subsystem must be single-rate with a discrete sample time.
- The nonvirtual subsystem cannot contain continuous states.
- The nonvirtual subsystem cannot output function call signals.
- The nonvirtual subsystem cannot contain noninlined S-functions.
- The generated files for the nonvirtual subsystem will reference model-wide header files, such as `model.h` and `model_private.h`.
- The **Function with separate data** option is incompatible with the **GRT compatible call interface** option, located on the **Real-Time Workshop/Interface** pane of the Configuration Parameters dialog box. Selecting both will generate an error.
- The **Function with separate data** option is incompatible with the **Generate reusable code** option (**Real-Time Workshop/Interface** pane). Selecting both will generate an error.
- Although the `model_initialize` function generated for a model containing a nonvirtual subsystem that uses the **Function with separate data** option may have a `firstTime` argument, the argument is not used. Thus, you cannot call `model_initialize` at a time greater than start time, for example, to reset block states. To suppress inclusion of the `firstTime` flag in the `model_initialize` function definition, set the model configuration parameter `IncludeERTFirstTime` to `off`.

# Controlling Generation of Function Prototypes

## Overview

The Real-Time Workshop Embedded Coder software provides a **Configure Model Functions** button, located on the **Interface** pane of the Configuration Parameters dialog box, that allows you to control the model function prototypes that are generated for ERT-based Simulink models.

By default, the function prototype of an ERT-based model's generated `model_step` function resembles the following:

```
void model_step(void);
```

The function prototype of an ERT-based model's generated `model_init` function resembles the following:

```
void model_init(void);
```

(For more detailed information about the default calling interface for the `model_step` function, see the `model_step` reference page.)

The **Configure Model Functions** button on the **Interface** pane provides you flexible control over the model function prototypes that are generated for your model. Clicking **Configure Model Functions** launches a Model Interface dialog box (see "Configuring Model Function Prototypes" on page 28-4). Based on the **Function specification** value you specify for your model function (supported values include `Default model initialize and step functions` and `Model specific C prototypes`), you can preview and modify the function prototypes. Once you validate and apply your changes, you can generate code based on your function prototype modifications.

For more information about using the **Configure Model Functions** button and the Model Interface dialog box, see "Model Function Prototypes Example" on page 28-12 and the demo model `rtwdemo_fcnprotoctrl`, which is preconfigured to demonstrate function prototype control.

Alternatively, you can use function prototype control functions to programmatically control model function prototypes. For more information, see "Configuring Model Function Prototypes Programmatically" on page 28-18.

You can also control model function prototypes for nonvirtual subsystems, if you generate subsystem code using right-click build. To launch the **Model Interface for subsystem** dialog box, use the `RTW.configSubsystemBuild` function.

Right-click building the subsystem generates the step and initialization functions according to the customizations you make. For more information, see "Configuring Function Prototypes for Nonvirtual Subsystems" on page 28-9.

For limitations that apply, see "Model Function Prototype Control Limitations" on page 28-25.

## Configuring Model Function Prototypes

**In this section...**

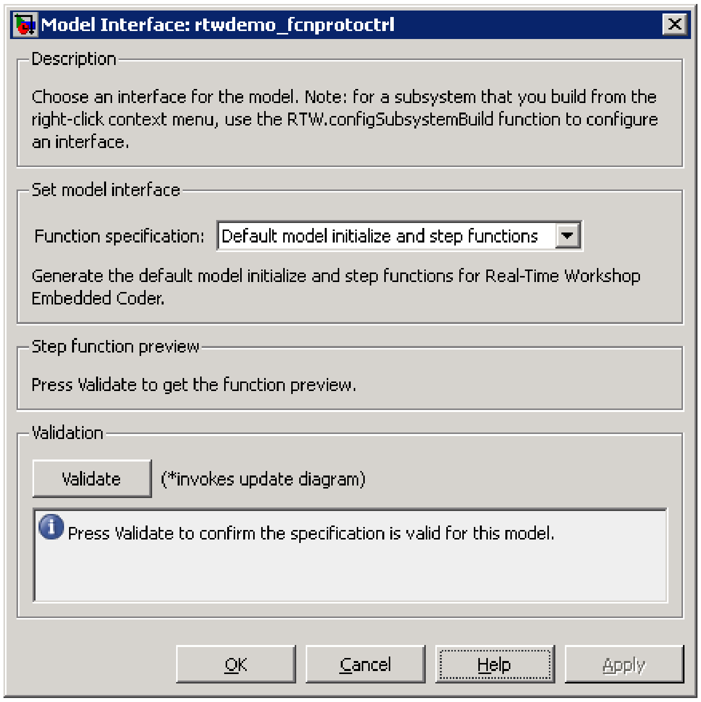
### Launching the Model Interface Dialog Boxes

Clicking the **Configure Model Functions** button on the **Interface** pane of the Configuration Parameters dialog box launches the Model Interface dialog box. This dialog box is the starting point for configuring the model function prototypes that are generated during code generation for ERT-based Simulink models. Based on the **Function specification** value you select for your model function (supported values include `Default model initialize and step functions` and `Model specific C prototypes`), you can preview and modify the function prototype. Once you validate and apply your changes, you can generate code based on your function prototype modifications.

To configure function prototypes for a right-click build of a nonvirtual subsystem, invoke the `RTW.configSubsystemBuild` function, which launches the Model Interface for subsystem dialog box. For more information, see "Configuring Function Prototypes for Nonvirtual Subsystems" on page 28-9

### Default Model Initialize and Step Functions View

The figure below shows the Model Interface dialog box in the `Default model initialize and step functions` view.


Model Interface: rtwdemo_fcnprotoctrl

Description

Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set model interface

Function specification: Default model initialize and step functions

Generate the default model initialize and step functions for Real-Time Workshop Embedded Coder.

Step function preview

Press Validate to get the function preview.

Validation

Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

The `Default model initialize and step functions` view allows you to validate and preview the predicted default model step and initialization function prototypes. To validate the default function prototype configuration against your model, click the **Validate** button. If the validation succeeds, the predicted step function prototype appears in the **Step function preview** subpane.

---

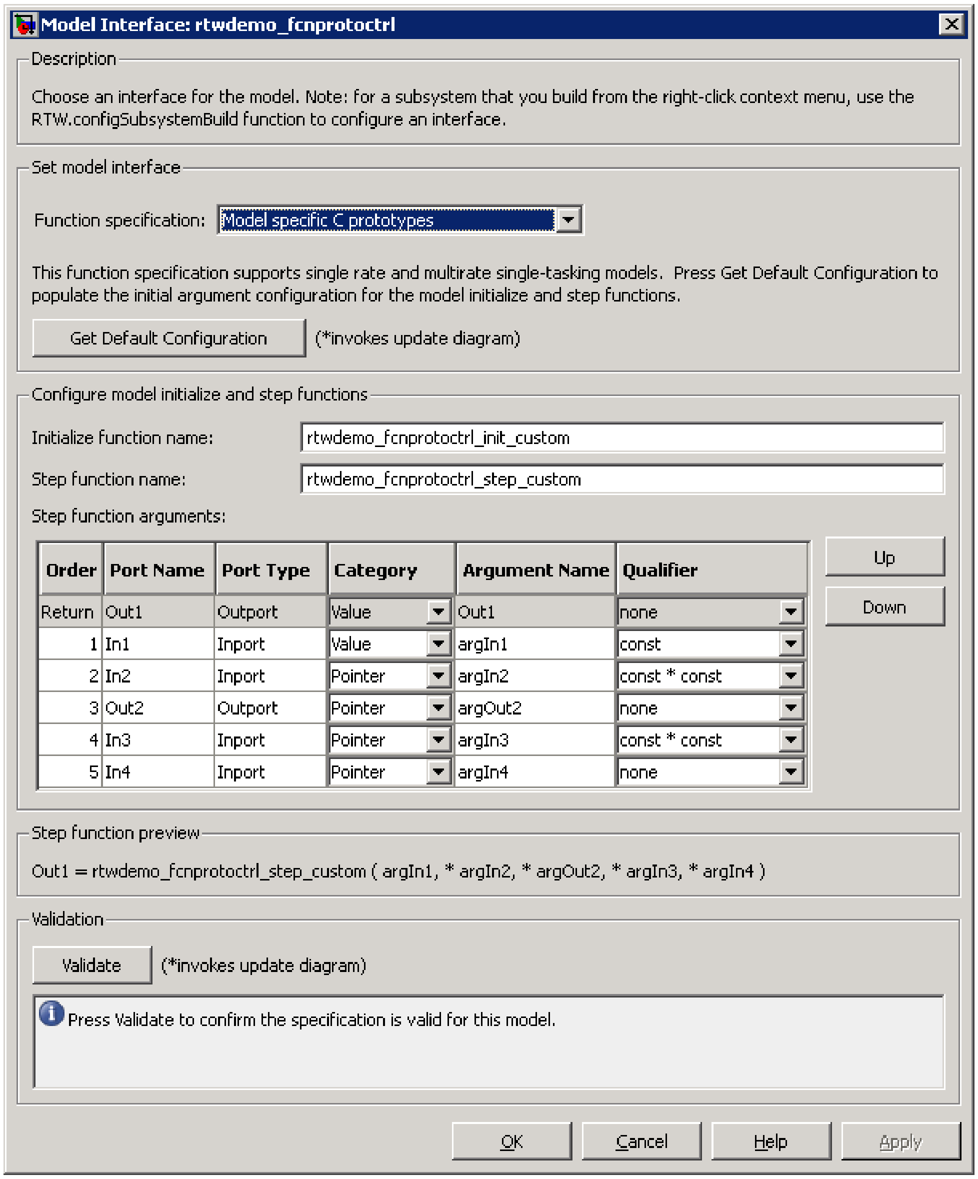
**Note** You cannot use the `Default model initialize and step functions` view to modify the function prototype configuration.

---

## Model Specific C Prototypes View

Selecting `Model specific C prototypes` for the **Function specification** parameter displays the `Model specific C prototypes` view of your model function prototypes. This view provides controls that you can use to customize the function names, the order of arguments, and argument attributes including name, passing mechanism, and type qualifier for each of the model's root-level I/O ports.

To begin configuring your function control prototype configuration, click the **Get Default Configuration** button. This activates and initializes the function names and properties in the **Configure model initialize and step functions** subpane, as shown below. If you click **Get Default Configuration** again later, only the properties of the step function arguments are reset to default values.



Description

Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set model interface

Function specification: Model specific C prototypes

This function specification supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial argument configuration for the model initialize and step functions.

(*invokes update diagram)

Configure model initialize and step functions

Initialize function name: rtwdemo_fcnprotoctrl_init_custom

Step function name: rtwdemo_fcnprotoctrl_step_custom

Step function arguments:

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| Return | Out1 | Outport | Value | Out1 | none |
| 1 | In1 | Inport | Value | argIn1 | const |
| 2 | In2 | Inport | Pointer | argIn2 | const * const |
| 3 | Out2 | Outport | Pointer | argOut2 | none |
| 4 | In3 | Inport | Pointer | argIn3 | const * const |
| 5 | In4 | Inport | Pointer | argIn4 | none |

Step function preview

Out1 = rtwdemo_fcnprotoctrl_step_custom ( argIn1, * argIn2, * argOut2, * argIn3, * argIn4 )

Validation

(*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

In the **Configure model initialize and step functions** subpane:

| Parameter | Description |
|---|---|
| **Step function name** | Name of the `model_step` function. |
| **Initialize function name** | Name of the `model_init` function. |
| **Order** | Order of the argument. A return argument is listed as `Return`. |
| **Port Name** | Name of the port. |
| **Port Type** | Type of the port. |
| **Category** | Specifies how an argument is passed in or out from the customized step function, either by copying a value (`Value`) or by a pointer to a memory space (`Pointer`). |
| **Argument Name** | Name of the argument. |
| **Qualifier** (optional) | Specifies a `const` type qualifier for a function argument. The available values are dependent on the **Category** specified. When you change the **Category**, if the specified type is no longer available, the **Qualifier** changes to `none`. The possible values are:<br>• `none`<br>• `const` (value)<br>• `const*` (value referenced by the pointer)<br>• `const*const` (value referenced by the pointer and the pointer itself) |

| Parameter | Description |
|---|---|
| | **Tip** When a model includes a referenced model, the `const` type qualifier for the root input argument of the referenced model's specified step function interface is set to `none`, and the qualifier for the source signal in the referenced model's parent is set to a value other than `none`, Real-Time Workshop honors the referenced model's interface specification by generating a type cast that discards the `const` type qualifier from the source signal. To override this behavior, add a `const` type qualifier to the referenced model. |

The **Step function preview** subpane provides a preview of how your step function prototype is interpreted in generated code. The preview is updated dynamically as you make modifications.

An argument `foo` whose **Category** is `Pointer` is previewed as `* foo`. If its **Category** is `Value`, it is previewed as `foo`. Notice that argument types and qualifiers are not represented in the **Step function preview** subpane.

## Configuring Function Prototypes for Nonvirtual Subsystems

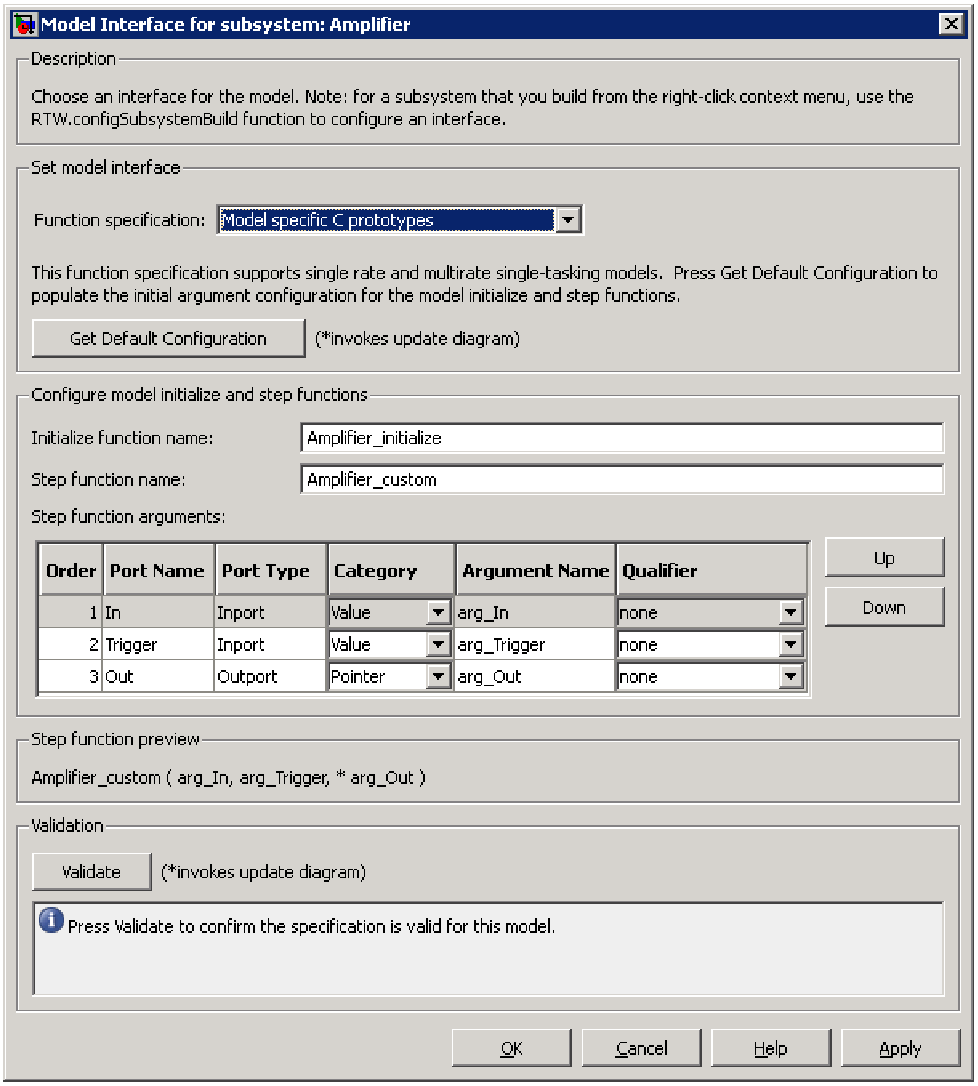
You can control step and initialization function prototypes for nonvirtual subsystems in ERT-based Simulink models, if you generate subsystem code using right-click build. Function prototype control is supported for the following types of nonvirtual subsystems:

- Triggered subsystems
- Enabled subsytems
- Enabled trigger subsystems
- While subsystems

- For subsystems
- Stateflow subsystems if atomic
- Embedded MATLAB subsystems if atomic

To launch the Model Interface for Subsystem dialog box, open the model containing the subsystem and invoke the `RTW.configSubsystemBuild` function.

The Model Interface dialog box for modifying the model-specific C prototypes for the `rtwdemo_counter/Amplifier` subsystem appears as follows:



Model Interface for subsystem: Amplifier

Description

Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set model interface

Function specification: Model specific C prototypes

This function specification supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial argument configuration for the model initialize and step functions.

Get Default Configuration (*invokes update diagram)

Configure model initialize and step functions

Initialize function name: Amplifier_initialize

Step function name: Amplifier_custom

Step function arguments:

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| 1 | In | Inport | Value | arg_In | none |
| 2 | Trigger | Inport | Value | arg_Trigger | none |
| 3 | Out | Outport | Pointer | arg_Out | none |

Step function preview

Amplifier_custom ( arg_In, arg_Trigger, * arg_Out )

Validation

Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

Right-click building the subsystem generates the step and initialization functions according to the customizations you make.

## Model Function Prototypes Example

The following procedure demonstrates how to use the **Configure Model Functions** button on the **Interface** pane of the Configuration Parameters dialog box to control the model function prototypes that the Real-Time Workshop Embedded Coder software generates for your Simulink model.

1 Open a MATLAB session and launch the `rtwdemo_counter` demo model.

2 In the `rtwdemo_counter` Model Editor, double-click the **Generate Code Using Real-Time Workshop Embedded Coder (double-click)** button to generate code for an ERT-based version of `rtwdemo_counter`. The code generation report for `rtwdemo_counter` appears.

3 In the code generation report, click the link for `rtwdemo_counter.c`.

4 In the `rtwdemo_counter.c` code display, locate and examine the generated code for the `rtwdemo_counter_step` and the `rtwdemo_counter_initialize` functions:

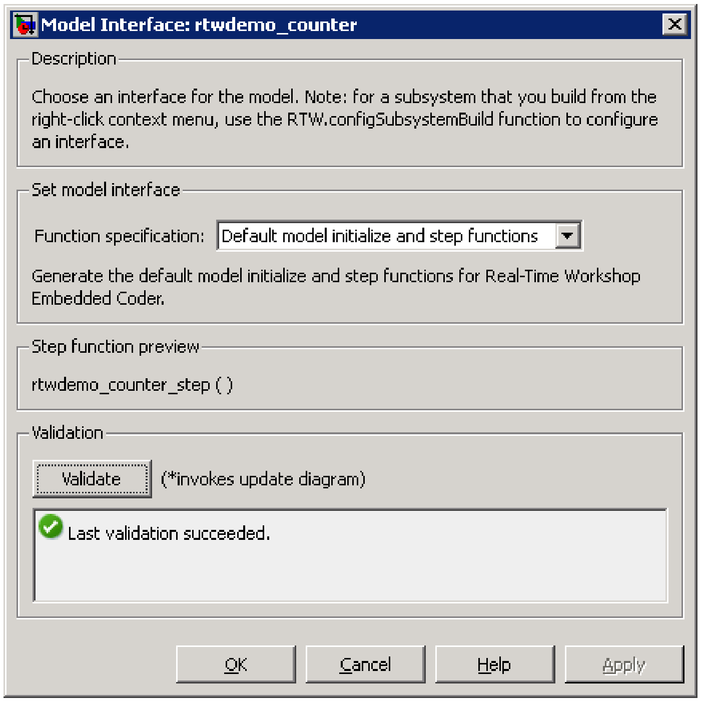
```
/* Model step function */
void rtwdemo_counter_step(void)
{
 ...
}

/* Model initialize function */
void rtwdemo_counter_initialize(void)
{
 ...
}
```

You can close the report window after you have examined the generated code. Optionally, you can save `rtwdemo_counter.c` and any other generated files of interest to a different location for later comparison.

5 From the `rtwdemo_counter` model, open the Configuration Parameters dialog box.

**6** Navigate to the **Real-Time Workshop** > **Interface** pane and click the **Configure Model Functions** button. The Model Interface dialog box appears.

**7** In the initial (`Default model initialize and step funtions`) view of the Model Interface dialog box, click the **Validate** button to validate and preview the default function prototype for the `rtwdemo_counter_step` function. The function prototype arguments under **Step function preview** should correspond to the default prototype in step 4.



Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Function specification: Default model initialize and step functions

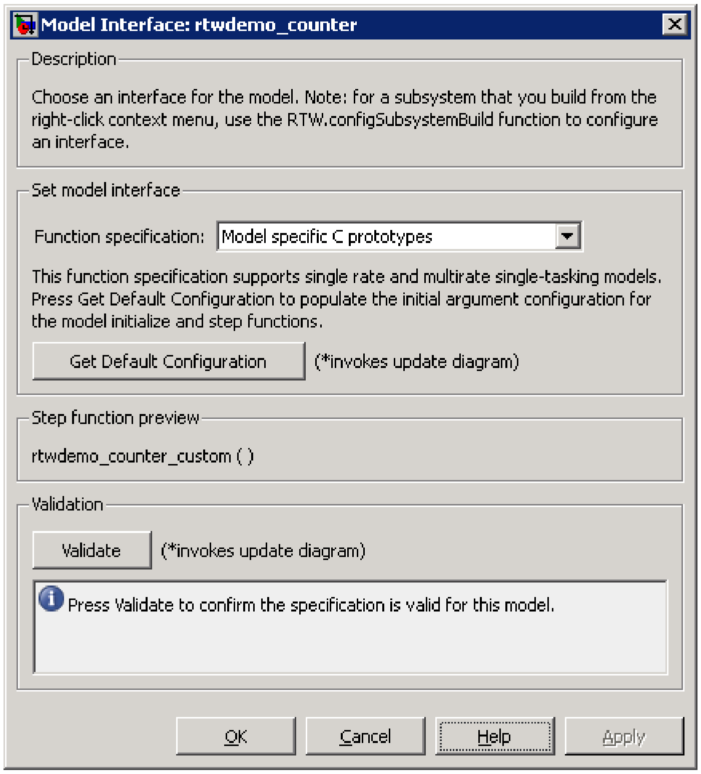
Generate the default model initialize and step functions for Real-Time Workshop Embedded Coder.

rtwdemo_counter_step ( )

(*invokes update diagram)

Last validation succeeded.

**8** In the Model Interface dialog box, set **Function specification** field to `Model specific C prototypes`. Making this selection switches the dialog box from the `Default model initialize and step functions` view to the `Model specific C prototypes` view.



Model Interface: rtwdemo_counter

Description

Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set model interface

Function specification: Model specific C prototypes

This function specification supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial argument configuration for the model initialize and step functions.

Get Default Configuration (*invokes update diagram)

Step function preview

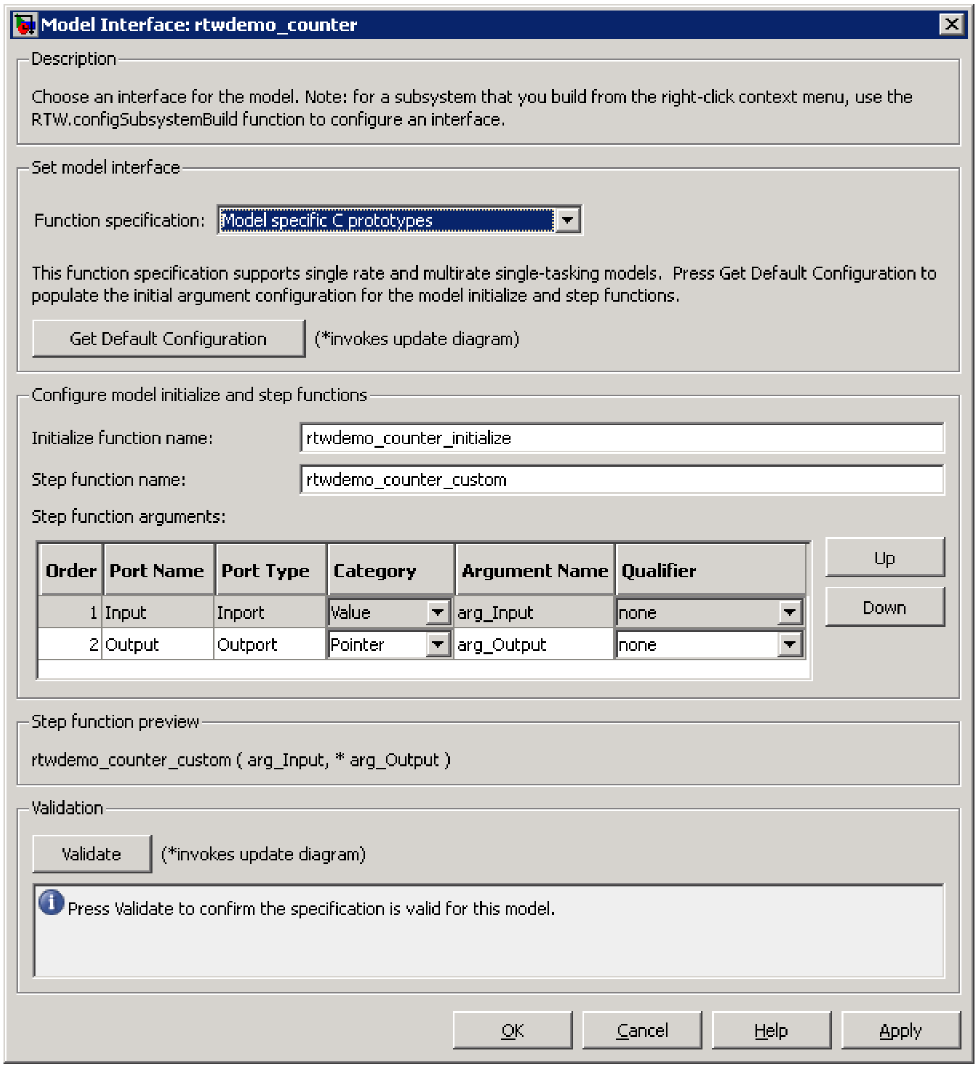
rtwdemo_counter_custom ( )

Validation

Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

**9** In the `Model specific C prototypes` view, click the **Get Default Configuration** button to activate the **Configure model initialize and step functions** subpane.



Model Interface: rtwdemo_counter

Description

Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set model interface

Function specification: Model specific C prototypes

This function specification supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial argument configuration for the model initialize and step functions.

Get Default Configuration (*invokes update diagram)

Configure model initialize and step functions

Initialize function name: rtwdemo_counter_initialize

Step function name: rtwdemo_counter_custom

Step function arguments:

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| 1 | Input | Inport | Value | arg_Input | none |
| 2 | Output | Outport | Pointer | arg_Output | none |

Step function preview

rtwdemo_counter_custom ( arg_Input, * arg_Output )

Validation

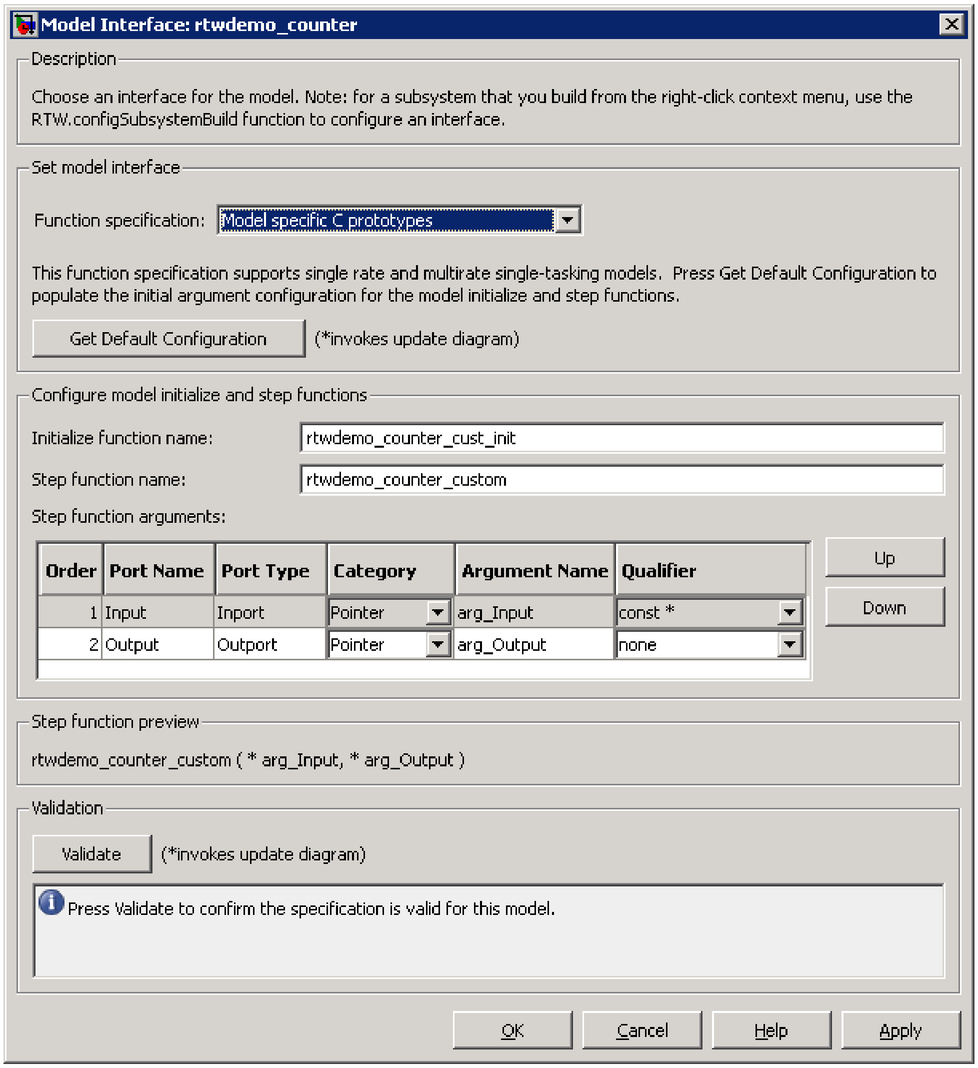
Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

**10** In the **Configure model initialize and step functions** subpane, change **Initialize function name** to `rtwdemo_counter_cust_init`.

**11** In the **Configure model initialize and step functions** subpane, in the row for the `Input` argument, change the value of **Category** from `Value` to

`Pointer` and change the value of **Qualifier** from `none` to `const *`. The preview reflects your changes.



Model Interface: rtwdemo_counter

Description

Choose an interface for the model. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set model interface

Function specification: Model specific C prototypes

This function specification supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial argument configuration for the model initialize and step functions.

Get Default Configuration (*invokes update diagram)

Configure model initialize and step functions

Initialize function name: rtwdemo_counter_cust_init

Step function name: rtwdemo_counter_custom

Step function arguments:

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| 1 | Input | Inport | Pointer | arg_Input | const * |
| 2 | Output | Outport | Pointer | arg_Output | none |

Step function preview

rtwdemo_counter_custom ( * arg_Input, * arg_Output )

Validation

Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

**12** Click the **Validate** button to validate the modified function prototype. The **Validation** subpane displays a message that the validation succeeded.

13 Click **OK** to exit the Model Interface dialog box.

14 Generate code for the model. When the build completes, the code generation report for `rtwdemo_counter` appears.

15 In the code generation report, click the link for `rtwdemo_counter.c`.

16 Locate and examine the generated code for the `rtwdemo_counter_custom` and `rtwdemo_counter_cust_init` functions:

```
/* Customized model step function */
void rtwdemo_counter_custom(const int32_T *arg_Input, int32_T *arg_Output)
{
 ...
}

 /* Model initialize function */
void rtwdemo_counter_cust_init(void)
{
 ...
}
```

17 Verify that the generated code is consistent with the function prototype modifications that you specified in the Model Interface dialog box.

## Configuring Model Function Prototypes Programmatically

You can use the function prototype control functions (listed in Function Prototype Control Functions on page 28-20), to programmatically control model function prototypes. Typical uses of these functions include:

- **Create and validate a new function prototype**
  1. Create a model-specific C function prototype with `*obj* = RTW.ModelSpecificCPrototype`, where *`obj`* returns a handle to a newly created, empty function prototype.
  2. Add argument configuration information for your model ports using `RTW.ModelSpecificCPrototype.addArgConf`.
  3. Attach the function prototype to your loaded ERT-based Simulink model using `RTW.ModelSpecificCPrototype.attachToModel`.
  4. Validate the function prototype using `RTW.ModelSpecificCPrototype.runValidation`.
  5. If validation succeeds, save your model and then generate code using the `rtwbuild` function.
- **Modify and validate an existing function prototype**
  1. Get the handle to an existing model-specific C function prototype that is attached to your loaded ERT-based Simulink model with `*obj* = RTW.getFunctionSpecification(*modelName*)`, where *`modelName`* is a string specifying the name of a loaded ERT-based Simulink model, and *`obj`* returns a handle to a function prototype attached to the specified model.

     You can use other function prototype control functions on the returned handle only if the test `isa(obj,'RTW.ModelSpecificCPrototype')` returns 1. If the model does not have a function prototype configuration, the function returns `[]`. If the function returns a handle to an object of type `RTW.FcnDefault`, you cannot modify the existing function prototype.
  2. Use the `Get` and `Set` functions listed in Function Prototype Control Functions on page 28-20 to test and reset such items as the function names, argument names, argument positions, argument categories, and argument type qualifiers.

3. Validate the function prototype using `RTW.ModelSpecificCPrototype.runValidation`.

4. If validation succeeds, save your model and then generate code using the `rtwbuild` function.

- **Create and validate a new function prototype, starting with default configuration information from your Simulink model**

  1. Create a model-specific C function prototype using *`obj`* `= RTW.ModelSpecificCPrototype`, where *`obj`* returns a handle to a newly created, empty function prototype.

  2. Attach the function prototype to your loaded ERT-based Simulink model using `RTW.ModelSpecificCPrototype.attachToModel`.

  3. Get default configuration information from your model using `RTW.ModelSpecificCPrototype.getDefaultConf`.

  4. Use the `Get` and `Set` functions listed in Function Prototype Control Functions on page 28-20 to test and reset such items as the function names, argument names, argument positions, argument categories, and argument type qualifiers.

  5. Validate the function prototype using `RTW.ModelSpecificCPrototype.runValidation`.

  6. If validation succeeds, save your model and then generate code using the `rtwbuild` function.

---

**Note** You should not use the same model-specific C function prototype object across multiple models. If you do, changes that you make to the step and initialization function prototypes in one model are propagated to other models, which is usually not desirable.

---

## Function Prototype Control Functions

| Function | Description |
|---|---|
| `RTW.ModelSpecificCPrototype.addArgConf` | Add step function argument configuration information for Simulink model port to model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.attachToModel` | Attach model-specific C function prototype to loaded ERT-based Simulink model |
| `RTW.ModelSpecificCPrototype.getArgCategory` | Get step function argument category for Simulink model port from model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.getArgName` | Get step function argument name for Simulink model port from model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.getArgPosition` | Get step function argument position for Simulink model port from model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.getArgQualifier` | Get step function argument type qualifier for Simulink model port from model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.getDefaultConf` | Get default configuration information for model-specific C function prototype from Simulink model to which it is attached |
| `RTW.ModelSpecificCPrototype.getFunctionName` | Get function names from model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.getNumArgs` | Get number of step function arguments from model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.getPreview` | Get model-specific C function prototype code previews |
| `RTW.configSubsystemBuild` | Launch GUI to configure C function prototype or C++ encapsulation interface for right-click build of specified subsystem |
| `RTW.getFunctionSpecification` | Get handle to model-specific C function prototype object |

**Function Prototype Control Functions (Continued)**

| Function | Description |
|---|---|
| `RTW.ModelSpecificCPrototype.runValidation` | Validate model-specific C function prototype against Simulink model to which it is attached |
| `RTW.ModelSpecificCPrototype.setArgCategory` | Set step function argument category for Simulink model port in model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.setArgName` | Set step function argument name for Simulink model port in model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.setArgPosition` | Set step function argument position for Simulink model port in model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.setArgQualifier` | Set step function argument type qualifier for Simulink model port in model-specific C function prototype |
| `RTW.ModelSpecificCPrototype.setFunctionName` | Set function names in model-specific C function prototype |

## Sample M-Script for Configuring Model Function Prototypes

The following sample M-script configures the model function prototypes for the `rtwdemo_counter` model, using the Function Prototype Control Functions on page 28-20.

```
%% Open the rtwdemo_counter model
rtwdemo_counter

%% Select ert.tlc as the System Target File for the model
set_param(gcs,'SystemTargetFile','ert.tlc')

%% Create a model-specific C function prototype
a=RTW.ModelSpecificCPrototype

%% Add argument configuration information for Input and Output ports
addArgConf(a,'Input','Pointer','inputArg','const *')
addArgConf(a,'Output','Pointer','outputArg','none')

%% Attach the model-specific C function prototype to the model
attachToModel(a,gcs)

%% Rename the initialization function
setFunctionName(a,'InitFunction','init')

%% Rename the step function and change some argument attributes
setFunctionName(a,'StepFunction','step')
setArgPosition(a,'Output',1)
setArgCategory(a,'Input','Value')
setArgName(a,'Input','InputArg')
setArgQualifier(a,'Input','none')

%% Validate the function prototype against the model
[status,message]=runValidation(a)

%% if validation succeeded, generate code and build
if status
    rtwbuild(gcs)
```

```
        end
```

## Verifying Generated Code for Customized Functions

You can use software-in-the-loop (SIL) testing to verify the generated code for your customized step and initialization functions. This involves generating an ERT S-function wrapper for your generated code, which then can be integrated into a Simulink model to verify that the generated code provides the same result as the original model or nonvirtual subsystem. For more information, see Chapter 25, “Generating S-Function Wrappers” and Chapter 37, “Verifying Generated Source Code With Software-In-the-Loop Simulation”.

## Model Function Prototype Control Limitations

The following limitations apply to controlling model function prototypes:

- Function prototype control supports only step and initialization functions generated from a Simulink model.
- Function prototype control supports only single-instance implementations. For standalone targets, you must clear the **Generate reusable code** check box (on the **Interface** pane of the Configuration Parameters dialog box). For model reference targets, you must select `One` for the **Total number of instances allowed per top model** parameter (on the **Model Referencing** pane of the Configuration Parameters dialog box).
- For model reference targets, the code generator ignores the **Generate reusable code** parameter (on the **Interface** pane of the Configuration Parameters dialog box).
- You must select the **Single output/update function** parameter (on the **Interface** pane of the Configuration Parameters dialog box).
- Function prototype control does not support multitasking models. Multirate models are supported, but you must configure the models for single-tasking.
- You must configure root-level inports and outports to use `Auto` storage classes.
- The generated code for a parent model does not call the function prototype control step functions generated from referenced models.
- Do not control function prototypes with the static `ert_main.c` provided by The MathWorks. Specifying a function prototype control configuration other than the default creates a mismatch between the generated code and the default static `ert_main.c`.
- The code generator removes the data structure for the root inports of the model unless a subsystem implemented by a nonreusable function uses the value of one or more of the inports.
- The code generator removes the data structure for the root outports of the model except when you enable MAT-file logging, or if the sample time of one or more of the outports is not the fundamental base rate (including a constant rate).

- If you copy a subsystem block and paste it to create a new block in either a new model or the same model, the function prototype control interface information from the original subsystem block does not copy to the new subsystem block.
- For a Stateflow chart that uses a model root inport value, or that calls a subsystem that uses a model root inport value, you must do one of the following to generate code:
  - Clear the **Execute (enter) Chart At Initialization** check box in the Stateflow chart.
  - Make the Stateflow function a nonreusable function.
  - Insert a Signal Conversion block immediately after the root inport and select the **Exclude this block from 'Block reduction' optimization** check box in the Signal Conversion block parameters.

# Controlling Generation of Encapsulated C++ Model Interfaces

## Overview of C++ Encapsulation

Using the Real-Time Workshop Embedded Coder language option `C++ (Encapsulated)`, you can generate a C++ class interface to model code. The generated interface encapsulates all required model data into C++ class attributes and all model entry point functions into C++ class methods. The benefits of encapsulation include:

- Greater control over access to model data
- Ability to multiply instantiate model classes
- Easier integration of model code into C++ programming environments

C++ encapsulation also works for right-click builds of nonvirtual subsystems. (For information on requirements that apply, see "Configuring C++ Encapsulation Interfaces for Nonvirtual Subsystems" on page 29-20.)

The general procedure for generating C++ encapsulation interfaces to model code is as follows:

1. Configure your model to use an `ert.tlc` system target file provided by The MathWorks.
2. Select the language option `C++ (Encapsulated)` for your model.
3. Optionally, configure related C++ encapsulation interface settings for your model code, using either a graphical user interface (GUI) or application programming interface (API).
4. Generate model code and examine the results.

To get started with an example, see "C++ Encapsulation Quick-Start Example" on page 29-4. For more details about configuring C++ encapsulation interfaces for your model code, see "Generating and Configuring C++ Encapsulation Interfaces to Model Code" on page 29-12 and "Configuring C++ Encapsulation Interfaces Programmatically" on page 29-22. For limitations that apply, see "C++ Encapsulation Interface Control Limitations" on page 29-27.

**Note** For a demonstration of the C++ encapsulation capability, see the demo model `rtwdemo_cppencap`.

## C++ Encapsulation Quick-Start Example

This example illustrates a simple use of the `C++ (Encapsulated)` option. It uses C++ encapsulation to generate interfaces for code from a Real-Time Workshop demo model, without extensive modifications to default settings.

---

**Note** For details about setting C++ encapsulation options, see the sections that follow this example, beginning with "Generating and Configuring C++ Encapsulation Interfaces to Model Code" on page 29-12.

---

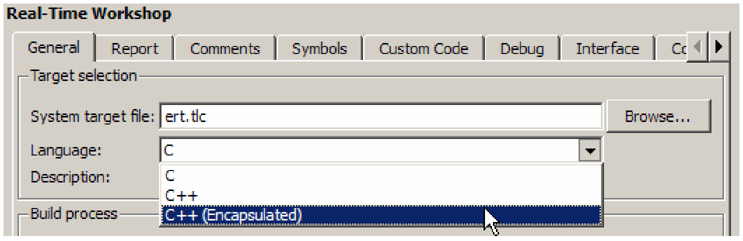
To generate C++ encapsulated interfaces for a Simulink model:

1 Open a model for which you would like to generate C++ encapsulation interfaces. This example uses the Real-Time Workshop demo model `rtwdemo_counter`.

2 Configure the model to use an `ert.tlc` system target file provided by The MathWorks. For example, open the Configuration Parameters dialog box, go to the **Real-Time Workshop** pane, select an appropriate target value from the **System target file** menu, and click **Apply**.

3 Optionally, as a baseline for later code comparison, generate code from the model using a different **Language** parameter setting, `C++` or `C`. (You can set up the build directory naming or location to distinguish your baseline build from later builds of the same model.)

4 On the **Real-Time Workshop** pane of the Configuration Parameters dialog box, select the `C++ (Encapsulated)` language option.



System target file: ert.tlc

Language: C

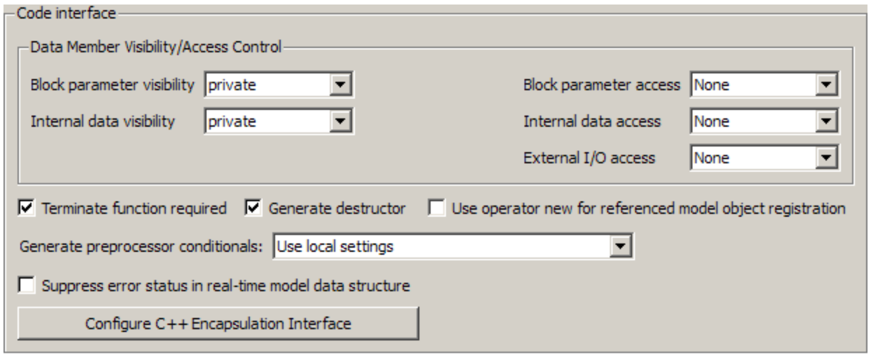
Click **Apply**.

---

**Note** To immediately generate the default style of encapsulated C++ code, without exploring the related model configuration options, skip steps 5–9 and go directly to step 10.

---

**5** Go to the **Interface** pane of the Configuration Parameters dialog box and examine the **Code interface** subpane.



Code interface

Data Member Visibility/Access Control

Block parameter visibility: private
Internal data visibility: private
Block parameter access: None
Internal data access: None
External I/O access: None

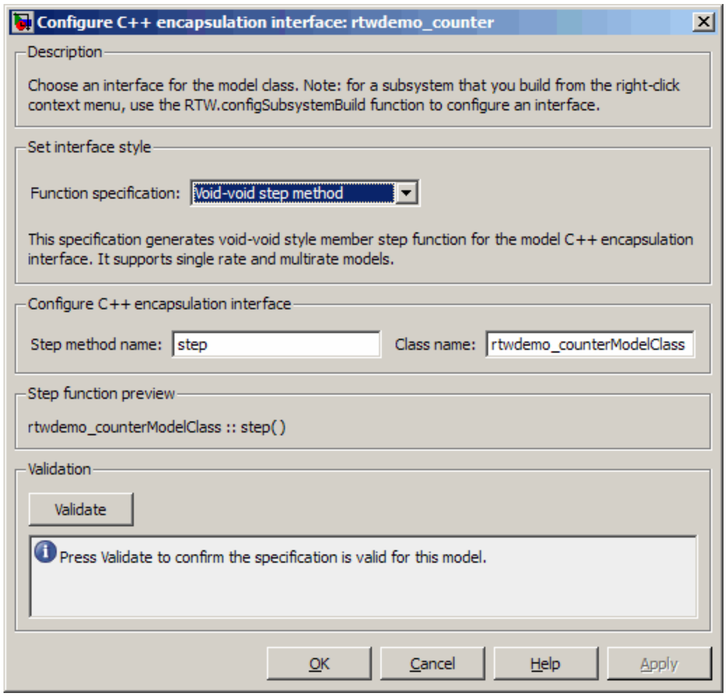
☑ Terminate function required ☑ Generate destructor ☐ Use operator new for referenced model object registration

Generate preprocessor conditionals: Use local settings

☐ Suppress error status in real-time model data structure

When you selected the `C++ (Encapsulated)` language option for your model, C++ encapsulation interface controls replaced the default options on the **Code interface** subpane. See "Configuring Code Interface Options" on page 29-13 for descriptions of these controls. Examine the default settings and modify as appropriate.

**6** Click the **Configure C++ Encapsulation Interface** button. This action opens the Configure C++ encapsulation interface dialog box, which allows you to configure the step method for your generated model class. The dialog box initially displays a view for configuring a `void-void` style step method (passing no I/O arguments) for the model class. In this view, you can rename the model class and the step method for your model.


Configure C++ encapsulation interface: rtwdemo_counter

Description

Choose an interface for the model class. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set interface style

Function specification: Void-void step method

This specification generates void-void style member step function for the model C++ encapsulation interface. It supports single rate and multirate models.

Configure C++ encapsulation interface

Step method name: step    Class name: rtwdemo_counterModelClass

Step function preview

rtwdemo_counterModelClass :: step( )

Validation

Press Validate to confirm the specification is valid for this model.

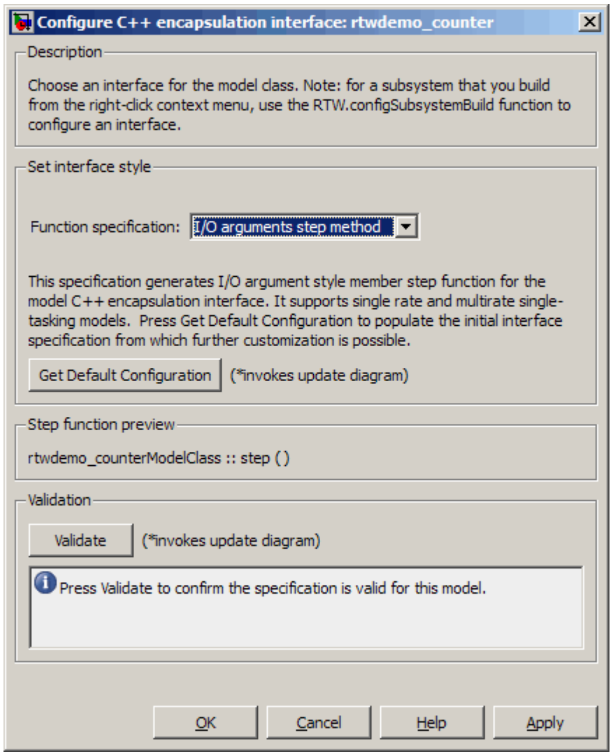
See "Configuring the Step Method for Your Model Class" on page 29-15 for descriptions of these controls.

---

**Note** If the `void-void` interface style meets your needs, you can skip steps 7–9 and go directly to step 10.

---

7 If you want root-level model input and output to be arguments on the step method, select the value `I/O arguments step method` from the **Function specification** menu. The dialog box displays a view for configuring an I/O arguments style step method for the model class.



Configure C++ encapsulation interface: rtwdemo_counter

Description

Choose an interface for the model class. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set interface style

Function specification: I/O arguments step method

This specification generates I/O argument style member step function for the model C++ encapsulation interface. It supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial interface specification from which further customization is possible.

Step function preview

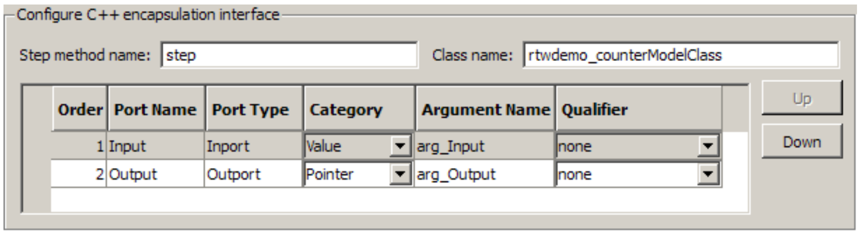
rtwdemo_counterModelClass :: step ( )

Validation

Press Validate to confirm the specification is valid for this model.

See "Configuring the Step Method for Your Model Class" on page 29-15 for descriptions of these controls.

**8** Click the **Get Default Configuration** button. This action causes a **Configure C++ encapsulation interface** subpane to appear in the dialog box. The subpane displays the initial interface configuration for your model, which provides a starting point for further customization.



Configure C++ encapsulation interface

Step method name: step    Class name: rtwdemo_counterModelClass

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| 1 | Input | Inport | Value | arg_Input | none |
| 2 | Output | Outport | Pointer | arg_Output | none |

See “Passing I/O Arguments” on page 29-17 for descriptions of these controls.

9 Perform this optional step only if you want to customize the configuration of the I/O arguments generated for your model step method.

---

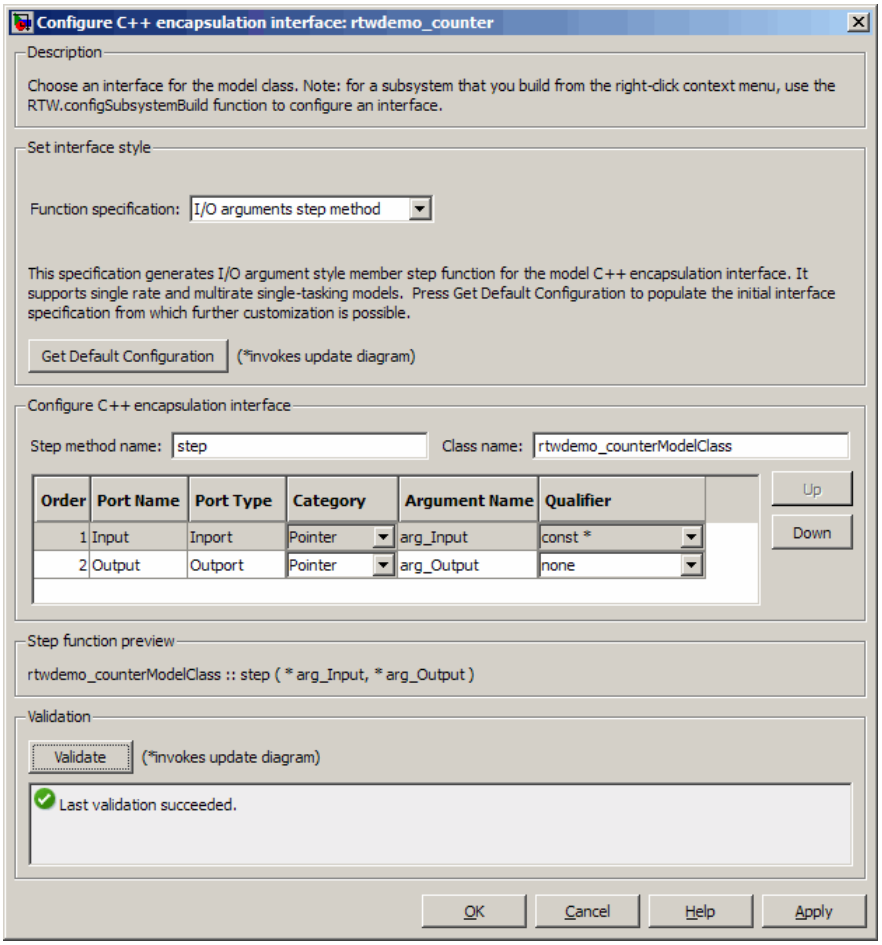
**Note** If you choose to skip this step, you should click **Cancel** to exit the dialog box.

---

If you choose to perform this step, first you must check that the required option **Remove root level I/O zero initialization** is selected on the **Optimization** pane, and then navigate back to the `I/O arguments step method` view of the Configure C++ encapsulation interface dialog box.

Now you can use the dialog box controls to configure I/O argument attributes. For example, in the **Configure C++ encapsulation interface** subpane, in the row for the `Input` argument, you can change the value of **Category** from `Value` to `Pointer` and change the value of **Qualifier** from `none` to `const *`. The preview updates to reflect your changes. Click the **Validate** button to validate the modified interface configuration.

Continue modifying and validating until you are satisfied with the step method configuration.



Configure C++ encapsulation interface: rtwdemo_counter

Description

Choose an interface for the model class. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set interface style

Function specification: I/O arguments step method

This specification generates I/O argument style member step function for the model C++ encapsulation interface. It supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial interface specification from which further customization is possible.

Get Default Configuration (*invokes update diagram)

Configure C++ encapsulation interface

Step method name: step    Class name: rtwdemo_counterModelClass

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| 1 | Input | Inport | Pointer | arg_Input | const * |
| 2 | Output | Outport | Pointer | arg_Output | none |

Step function preview

rtwdemo_counterModelClass :: step ( * arg_Input, * arg_Output )

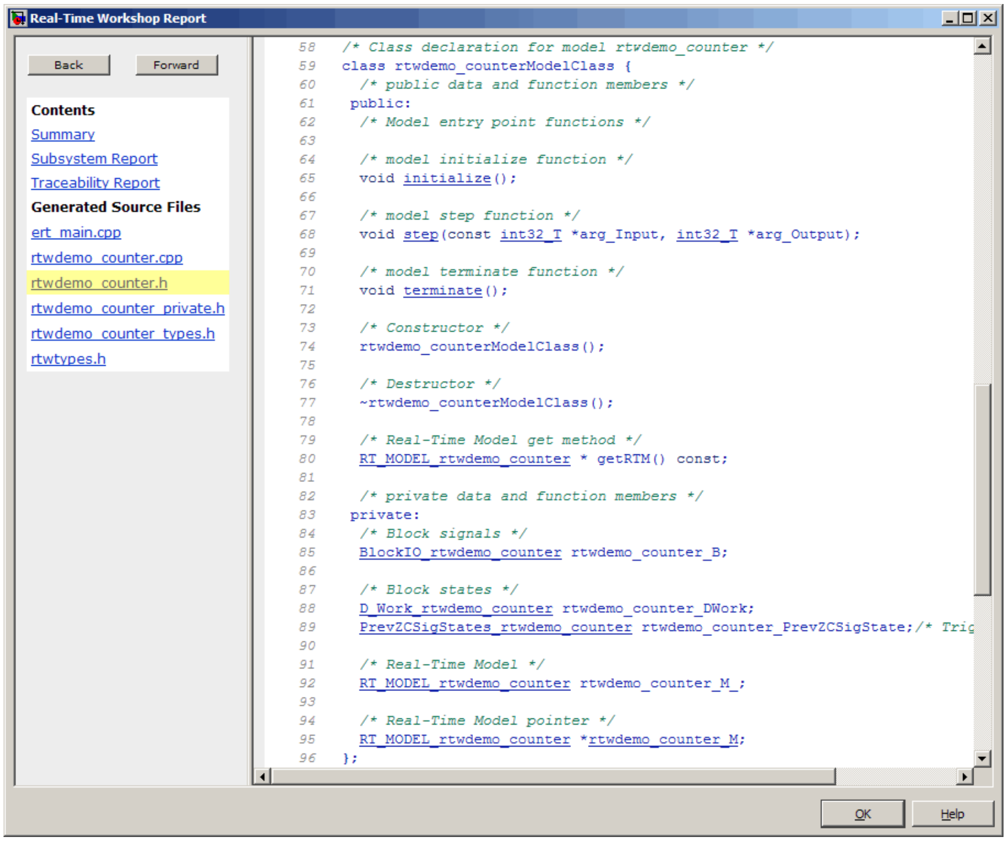
Validation

Validate (*invokes update diagram)

Last validation succeeded.

Click **Apply** and **OK**.

**10** Generate code for the model. When the build completes, the code generation report for `rtwdemo_counter` appears. Examine the report and observe that all required model data is encapsulated into C++ class attributes and all model entry point functions are encapsulated into C++ class methods. For example, click the link for `rtwdemo_counter.h` to see the class declaration for the model.



```
/* Class declaration for model rtwdemo_counter */
class rtwdemo_counterModelClass {
  /* public data and function members */
 public:
  /* Model entry point functions */

  /* model initialize function */
  void initialize();

  /* model step function */
  void step(const int32_T *arg_Input, int32_T *arg_Output);

  /* model terminate function */
  void terminate();

  /* Constructor */
  rtwdemo_counterModelClass();

  /* Destructor */
  ~rtwdemo_counterModelClass();

  /* Real-Time Model get method */
  RT_MODEL_rtwdemo_counter * getRTM() const;

  /* private data and function members */
 private:
  /* Block signals */
  BlockIO_rtwdemo_counter rtwdemo_counter_B;

  /* Block states */
  D_Work_rtwdemo_counter rtwdemo_counter_DWork;
  PrevZCSigStates_rtwdemo_counter rtwdemo_counter_PrevZCSigState;/* Trig

  /* Real-Time Model */
  RT_MODEL_rtwdemo_counter rtwdemo_counter_M_;

  /* Real-Time Model pointer */
  RT_MODEL_rtwdemo_counter *rtwdemo_counter_M;
};
```

**Note**

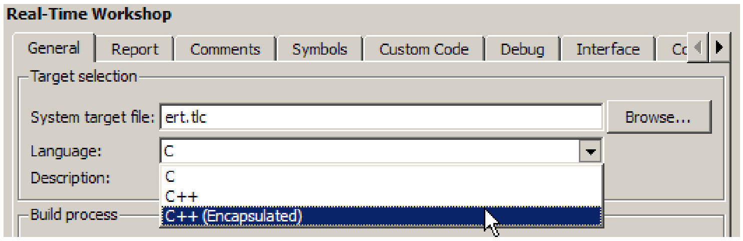
- If you configured custom I/O arguments for the model step method (optional step 9), examine the generated code for the step method in `rtwdemo_counter.h` and `rtwdemo_counter.cpp`. The arguments should reflect your changes. For example, if you performed the `Input` argument modifications in step 9, the input argument should appear as `const int32_T *arg_Input`.
- If you saved a baseline model build (optional step 3), you can traverse and compare the generated files in the corresponding build directories.

## Generating and Configuring C++ Encapsulation Interfaces to Model Code

**In this section...**

### Selecting the C++ (Encapsulated) Option

To select the `C++ (Encapsulated)` option, in the Configuration Parameters dialog box, on the **Real-Time Workshop** pane, use the **Language** menu:



System target file: ert.tlc

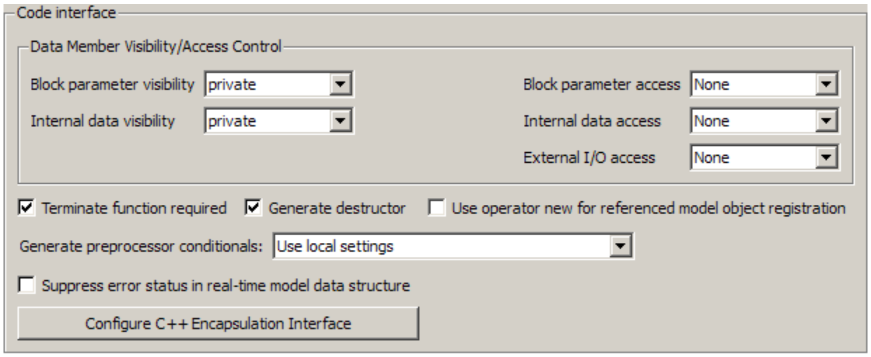
Language: C

When you select this option, you see the following effects on other panes in the Configuration Parameters dialog box:

- Disables model configuration options that `C++ (Encapsulated)` does not support. For details, see "C++ Encapsulation Interface Control Limitations" on page 29-27.
- Replaces the default options on the **Interface** pane, in the **Code interface** subpane, with C++ encapsulation interface controls, which are described in the next section.

## Configuring Code Interface Options

When you select the `C++ (Encapsulated)` option for your model, the C++ encapsulation interface controls shown below replace the **Code interface** default options on the **Interface** pane.



Code interface

Data Member Visibility/Access Control

Block parameter visibility: private

Internal data visibility: private

Block parameter access: None

Internal data access: None

External I/O access: None

☑ Terminate function required ☑ Generate destructor ☐ Use operator new for referenced model object registration

Generate preprocessor conditionals: Use local settings

☐ Suppress error status in real-time model data structure

- **Block parameter visibility**

  Specifies whether to generate the block parameter structure as a `public`, `private`, or `protected` data member of the C++ model class (`private` by default).

- **Internal data visibility**

  Specifies whether to generate internal data structures, such as Block I/O, DWork vectors, Runtime model, Zero-crossings, and continuous states, as `public`, `private`, or `protected` data members of the C++ model class (`private` by default).

- **Block parameter access**

  Specifies whether to generate access methods for block parameters for the C++ model class (`None` by default). You can select noninlined access methods (`Method`) or inlined access methods (`Inlined method`).

- **Internal data access**

  Specifies whether to generate access methods for internal data structures, such as Block I/O, DWork vectors, Runtime model, Zero-crossings, and continuous states, for the C++ model class (`None` by default). You can select noninlined access methods (`Method`) or inlined access methods (`Inlined method`).

- **External I/O access**

  Specifies whether to generate access methods for root-level I/O signals for the C++ model class (`None` by default). You can select noninlined access methods (`Method`) or inlined access methods (`Inlined method`).

  ---

  **Note** This parameter affects generated code only if you are using the default (`void-void` style) step method for your model class; *not* if you are explicitly passing arguments for root-level I/O signals using an I/O arguments style step method. For more information, see "Passing No Arguments (void-void)" on page 29-16 and "Passing I/O Arguments" on page 29-17.

  ---

- **Terminate function**

  Specifies whether to generate the `*model*_terminate` function (on by default). This function contains all model termination code and should be called as part of system shutdown.

- **Generate destructor**

  Specifies whether to generate a destructor for the C++ model class (on by default).

- **Use operator new for referenced model object registration**

  For a model containing Model blocks, specifies whether generated code should use dynamic memory allocation, during model object registration, to instantiate objects for referenced models configured with a C++ encapsulation interface (off by default). If you select this option, during instantiation of an object for the top model in a model reference hierarchy, the generated code uses the operator `new` to instantiate objects for referenced models.

  Selecting this option frees a parent model from having to maintain information about submodels beyond its direct children. Clearing this option means that a parent model maintains information about all of its submodels, including its direct and indirect children.

---

**Note** If you select this option, be aware that a `bad_alloc` exception might be thrown, per the C++ standard, if an out-of-memory error occurs during the use of `new`. You must provide code to catch and process the `bad_alloc` exception in case an out-of-memory error occurs for a `new` call during construction of a top model object.

---

- **Generate preprocessor conditionals**

  For a model containing Model blocks, specifies whether to generate preprocessor conditional directives globally for a model, locally for each variant Model block, or conditionally based on the **Generate preprocessor conditionals** setting in the Model Reference Parameter dialog for each variant Model block (`Use local settings` by default).

- **Suppress error status in real-time model data structure**

  Specifies whether to omit the error status field from the generated real-time model data structure `rtModel` (off by default). Selecting this option reduces memory usage.

  Be aware that selecting this option can cause the code generator to omit the `rtModel` data structure from generated code.

- **Configure C++ Encapsulation Interface**

  Opens the Configure C++ encapsulation interface dialog box, which allows you to configure the step method for your model class. For more information, see “Configuring the Step Method for Your Model Class” on page 29-15.

## Configuring the Step Method for Your Model Class

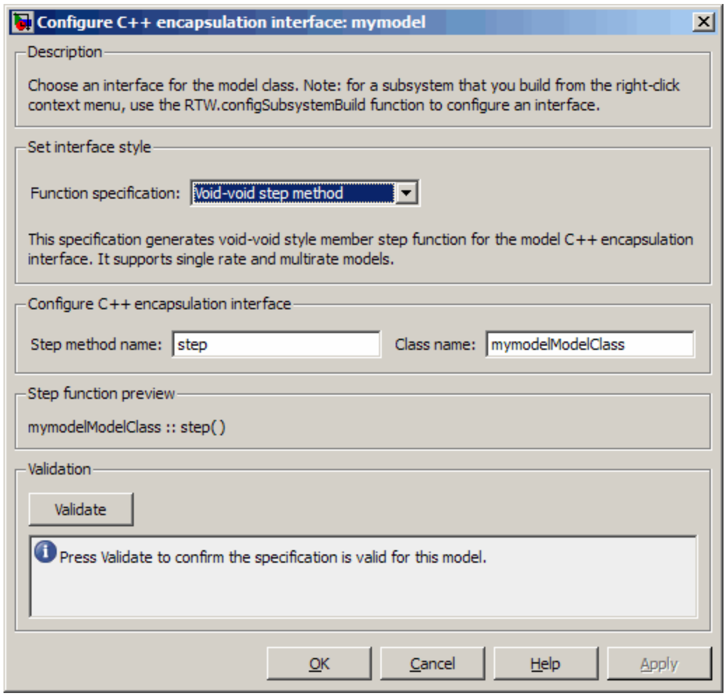
To configure the step method for your model class, on the **Interface** pane, click the **Configure C++ Encapsulation Interface** button, which is available when you select`C++ (Encapsulated)` for your model. This action opens the Configure C++ encapsulation interface dialog box, where you can configure the step method for your model class in either of two styles:

- “Passing No Arguments (void-void)” on page 29-16
- “Passing I/O Arguments” on page 29-17

**Note** The `void-void` style of step method specification supports single-rate models and multirate models, while the I/O arguments style supports single-rate models and multirate single-tasking models.

## Passing No Arguments (void-void)

The Configure C++ encapsulation interface dialog box initially displays a view for configuring a `void-void` style step method for the model class.


Configure C++ encapsulation interface: mymodel

Description

Choose an interface for the model class. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set interface style

Function specification: Void-void step method

This specification generates void-void style member step function for the model C++ encapsulation interface. It supports single rate and multirate models.

Configure C++ encapsulation interface

Step method name: step

Class name: mymodelModelClass

Step function preview

mymodelModelClass :: step( )

Validation

Press Validate to confirm the specification is valid for this model.

- **Step method name**

  Allows you to specify a step method name other than the default, `step`.

- **Class name**

  Allows you to specify a model class name other than the default, *`model`*`ModelClass`.

- **Step function preview**

  Displays a preview of the model step function prototype as currently configured. The preview display is dynamically updated as you make configuration changes.

- **Validate**

  Validates your current model step function configuration. The **Validation** pane displays success or failure status and an explanation of any failure.

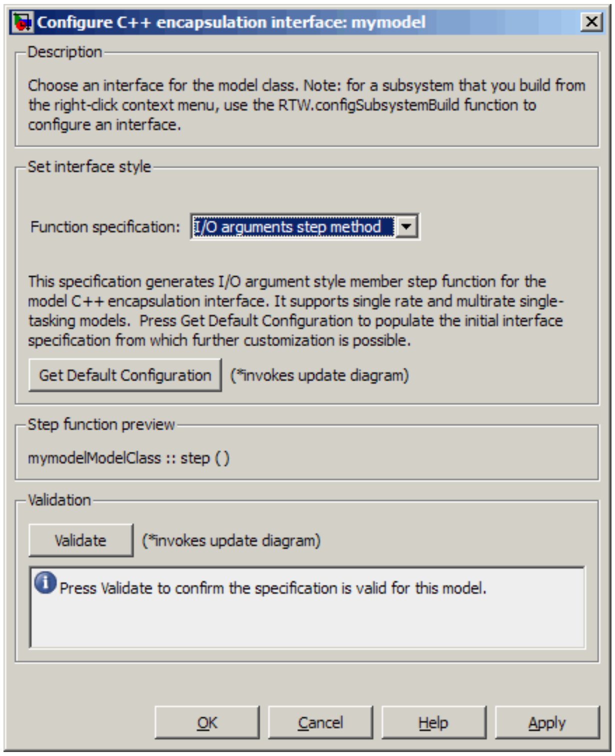
## Passing I/O Arguments

If you select `I/O arguments step method` from the **Function specification** menu, the dialog box displays a view for configuring an I/O arguments style step method for the model class.

---

**Note** To use the I/O arguments style step method, you must select the option **Remove root level I/O zero initialization** on the **Optimization** pane of the Configuration Parameters dialog box.

---



Configure C++ encapsulation interface: mymodel

Description

Choose an interface for the model class. Note: for a subsystem that you build from the right-click context menu, use the RTW.configSubsystemBuild function to configure an interface.

Set interface style

Function specification: I/O arguments step method

This specification generates I/O argument style member step function for the model C++ encapsulation interface. It supports single rate and multirate single-tasking models. Press Get Default Configuration to populate the initial interface specification from which further customization is possible.

Get Default Configuration (*invokes update diagram)

Step function preview

mymodelModelClass :: step ( )

Validation

Validate (*invokes update diagram)

Press Validate to confirm the specification is valid for this model.

- **Get Default Configuration**

  Click this button to get the initial interface configuration that provides a starting point for further customization.

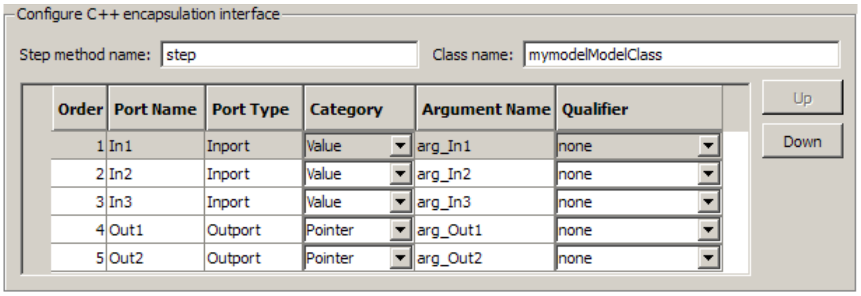
- **Step function preview**

  Displays a preview of the model step function prototype as currently configured. The preview dynamically updates as you make configuration changes.

- **Validate**

  Validates your current model step function configuration. The **Validation** pane displays success or failure status and an explanation of any failure.

When you click **Get Default Configuration**, the **Configure C++ encapsulation interface** subpane appears in the dialog box, displaying the initial interface configuration. For example:



Step method name: step

Class name: mymodelModelClass

| Order | Port Name | Port Type | Category | Argument Name | Qualifier |
|---|---|---|---|---|---|
| 1 | In1 | Inport | Value | arg_In1 | none |
| 2 | In2 | Inport | Value | arg_In2 | none |
| 3 | In3 | Inport | Value | arg_In3 | none |
| 4 | Out1 | Outport | Pointer | arg_Out1 | none |
| 5 | Out2 | Outport | Pointer | arg_Out2 | none |

- **Step method name**

  Allows you to specify a step method name other than the default, `step`.

- **Class name**

  Allows you to specify a model class name other than the default, `*model*ModelClass`.

- **Order**

  Displays the numerical position of each argument. Use the **Up** and **Down** buttons to change argument order.

- **Port Name**

  Displays the port name of each argument (not configurable using this dialog box).

- **Port Type**

  Displays the port type, `Inport` or `Outport`, of each argument (not configurable using this dialog box).

- **Category**

  Displays the passing mechanism for each argument. To change the passing mechanism for an argument, select `Value`, `Pointer`, or `Reference` from the argument's **Category** menu.

- **Argument Name**

Displays the name of each argument. To change an argument name, click in the argument's **Argument name** field, position the cursor for text entry, and enter the new name.

- **Qualifier**

  Displays the `const` type qualifier for each argument. To change the qualifier for an argument, select an available value from the argument's **Qualifier** menu. The possible values are:

  - `none`
  - `const` (value)
  - `const*` (value referenced by the pointer)
  - `const*const` (value referenced by the pointer and the pointer itself)
  - `const &` (value referenced by the reference)

---

**Tip** When a model includes a referenced model, the `const` type qualifier for the root input argument of the referenced model's specified step function interface is set to `none` and the qualifier for the source signal in the referenced model's parent is set to a value other than `none`, Real-Time Workshop honors the referenced model's interface specification by generating a type cast that discards the `const` type qualifier from the source signal. To override this behavior, add a `const` type qualifier to the referenced model.

---

## Configuring C++ Encapsulation Interfaces for Nonvirtual Subsystems

C++ encapsulation interfaces can be configured for right-click builds of nonvirtual subsystems in Simulink models, provided that:

- You select the system target file `ert.tlc` for the model.
- You select the **Language** parameter value `C++ (Encapsulated)` for the model.
- The subsystem is convertible to a Model block using the function `Simulink.SubSystem.convertToModelReference`. For referenced model conversion requirements, see the Simulink reference page `Simulink.SubSystem.convertToModelReference`.

To configure C++ encapsulation interfaces for a subsystem that meets the requirements:

1 Open the containing model and select the subsystem block.

2 Enter the following MATLAB command:

```
RTW.configSubsystemBuild(gcb)
```

where `gcb` is the Simulink function `gcb`, returning the full block path name of the current block.

This command opens a subsystem equivalent of the Configure C++ encapsulation interface dialog sequence that is described in detail in the preceding section, "Configuring the Step Method for Your Model Class" on page 29-15. (For more information about using the MATLAB command, see `RTW.configSubsystemBuild`.)

3 Use the Configure C++ encapsulation interface dialog boxes to configure C++ encapsulation settings for the subsystem.

4 Right-click the subsystem and select **Real-Time Workshop > Build Subsystem**.

5 When the subsystem build completes, you can examine the C++ encapsulation interfaces in the generated files and the HTML code generation report.

## Configuring C++ Encapsulation Interfaces Programmatically

If you select the **Language** option `C++ (Encapsulated)` for your model, you can use the C++ encapsulation interface control functions (listed in C++ Encapsulation Interface Control Functions on page 29-23) to programmatically configure the step method for your model class.

Typical uses of these functions include:

- **Create and validate a new step method interface, starting with default configuration information from your Simulink model**

  1. Create a model-specific C++ encapsulation interface with `*obj* = RTW.ModelCPPVoidClass` or `*obj* = RTW.ModelCPPArgsClass`, where *`obj`* returns a handle to an newly created, empty C++ encapsulation interface.
  2. Attach the C++ encapsulation interface to your loaded ERT-based Simulink model using `attachToModel`.
  3. Get default C++ encapsulation interface configuration information from your model using `getDefaultConf`.
  4. Use the `Get` and `Set` functions listed in C++ Encapsulation Interface Control Functions on page 29-23 to test or reset the model class name and model step method name. Additionally, if you are using the I/O arguments style step method, you can test and reset argument names, argument positions, argument categories, and argument type qualifiers.
  5. Validate the C++ encapsulation interface using `runValidation`. (If validation fails, use the error message information that`runValidation` returns to address the issues.)
  6. Save your model and then generate code using the `rtwbuild` function.

- **Modify and validate an existing step method interface for a Simulink model**

  1. Get the handle to an existing model-specific C++ encapsulation interface that is attached to your loaded ERT-based Simulink model using `*obj* = RTW.getEncapsulationInterfaceSpecification(*modelName*)`, where *`modelName`* is a string specifying the name of a loaded ERT-based

Simulink model, and `obj` returns a handle to a C++ encapsulation interface attached to the specified model. If the model does not have an attached C++ encapsulation interface configuration, the function returns `[]`.

**2** Use the `Get` and `Set` functions listed in C++ Encapsulation Interface Control Functions on page 29-23 to test or reset the model class name and model step method name. Additionally, if the returned interface uses the I/O arguments style step method, you can test and reset argument names, argument positions, argument categories, and argument type qualifiers.

**3** Validate the C++ encapsulation interface using `runValidation`. (If validation fails, use the error message information that `runValidation` returns to address the issues.)

**4** Save your model and then generate code using the `rtwbuild` function.

---

**Note** You should not use the same model-specific C++ encapsulation interface control object across multiple models. If you do, changes that you make to the step method configuration in one model propagate to other models, which is usually not desirable.

---

### C++ Encapsulation Interface Control Functions

| Function | Description |
|---|---|
| `attachToModel` | Attach model-specific C++ encapsulation interface to loaded ERT-based Simulink model |
| `getArgCategory` | Get argument category for Simulink model port from model-specific C++ encapsulation interface |
| `getArgName` | Get argument name for Simulink model port from model-specific C++ encapsulation interface |
| `getArgPosition` | Get argument position for Simulink model port from model-specific C++ encapsulation interface |
| `getArgQualifier` | Get argument type qualifier for Simulink model port from model-specific C++ encapsulation interface |

**C++ Encapsulation Interface Control Functions (Continued)**

| Function | Description |
|---|---|
| `getClassName` | Get class name from model-specific C++ encapsulation interface |
| `getDefaultConf` | Get default configuration information for model-specific C++ encapsulation interface from Simulink model to which it is attached |
| `getNumArgs` | Get number of step method arguments from model-specific C++ encapsulation interface |
| `getStepMethodName` | Get step method name from model-specific C++ encapsulation interface |
| `RTW.configSubsystemBuild` | Open GUI to configure C function prototype or C++ encapsulation interface for right-click build of specified subsystem |
| `RTW.getEncapsulation-InterfaceSpecification` | Get handle to model-specific C++ encapsulation interface control object |
| `runValidation` | Validate model-specific C++ encapsulation interface against Simulink model to which it is attached |
| `setArgCategory` | Set argument category for Simulink model port in model-specific C++ encapsulation interface |
| `setArgName` | Set argument name for Simulink model port in model-specific C++ encapsulation interface |
| `setArgPosition` | Set argument position for Simulink model port in model-specific C++ encapsulation interface |
| `setArgQualifier` | Set argument type qualifier for Simulink model port in model-specific C++ encapsulation interface |
| `setClassName` | Set class name in model-specific C++ encapsulation interface |
| `setStepMethodName` | Set step method name in model-specific C++ encapsulation interface |

## Sample M-Script for Configuring the Step Method for a Model Class

The following sample M-script configures the step method for the `rtwdemo_counter` model class, using the C++ Encapsulation Interface Control Functions on page 29-23.

```
%% Open the rtwdemo_counter model
rtwdemo_counter

%% Select ert.tlc as the System Target File for the model
set_param(gcs,'SystemTargetFile','ert.tlc')

%% Select C++ (Encapsulated) as the target language for the model
set_param(gcs,'TargetLang','C++ (Encapsulated)')

%% Set required option for I/O arguments style step method (cmd off = GUI on)
set_param(gcs,'ZeroExternalMemoryAtStartup','off')

%% Create a C++ encapsulated interface using an I/O arguments style step method
a=RTW.ModelCPPArgsClass

%% Attach the C++ encapsulated interface to the model
attachToModel(a,gcs)

%% Get the default C++ encapsulation interface configuration from the model
getDefaultConf(a)

%% Move the Output port argument from position 2 to position 1
setArgPosition(a,'Output',1)

%% Reset the model step method name from step to StepMethod
setStepMethodName(a,'StepMethod')

%% Change the Input port argument name, category, and qualifier
setArgName(a,'Input','inputArg')
setArgCategory(a,'Input','Pointer')
setArgQualifier(a,'Input','const *')
```

```
%% Validate the function prototype against the model
[status,message]=runValidation(a)

%% if validation succeeded, generate code and build
if status
    rtwbuild(gcs)
end
```

## C++ Encapsulation Interface Control Limitations

- The `C++ (Encapsulated)` option does not support some Simulink model configuration options. Selecting `C++ (Encapsulated)` disables the following items in the Configuration Parameters dialog box:
  - **Identifier format control** subpane on the **Symbols** pane
  - **Templates** pane
    - The **Templates** pane parameter **File customization template** is not supported for `C++ (Encapsulated)` code generation.
    - Selecting `C++ (Encapsulated)` turns on the **Templates** pane option **Generate an example main program** but removes it from the Configuration Parameters dialog box. If desired, you can disable it using the command line parameter `GenerateSampleERTMain`.
  - **Data Placement** pane
  - **Memory Sections** pane

**Note** Selecting `C++ (Encapsulated)` forces on the **Real-Time Workshop** pane model option **Ignore custom storage classes**. By design, `C++ (Encapsulated)` code generation treats data objects with custom storage classes as if their storage class attribute is set to `Auto`.

- Among the data exchange interfaces available on the **Interface** pane of the Configuration Parameters dialog box, only the `C API` interface is supported for `C++ (Encapsulated)` code generation. If you select `External mode` or `ASAP2`, code generation fails with a validation error.
- The I/O arguments style of step method specification supports single-rate models and multirate single-tasking models, but not multirate multitasking models.
- The `C++ (Encapsulated)` option does not support use of the `IncludeERTFirstTime` model option to include the `firstTime` argument in the *`model`*`_initialize` function generated for an ERT-based models. (The `IncludeERTFirstTime` option is off by default except for models created with R2006a.) Also, the `C++ (Encapsulated)` option requires that the target selected for the model support `firstTime` argument control by setting

the `ERTFirstTimeCompliant` target option, which all targets provided by The MathWorks do by default. In other words, the `C++ (Encapsulated)` option requires that the target option `ERTFirstTimeCompliant` is on and the model option `IncludeERTFirstTime` is off.

- The **Real-Time Workshop > Export Functions** capability does not support `C++ (Encapsulated)` as the target language.
- For a Stateflow chart that resides in a root model configured to use the `I/O arguments step method` function specification, and that uses a model root inport value or calls a subsystem that uses a model root inport value, you must do one of the following to generate code:
  - Clear the **Execute (enter) Chart At Initialization** check box in the Stateflow chart.
  - Insert a Signal Conversion block immediately after the root inport and select the **Exclude this block from 'Block reduction' optimization** check box in the Signal Conversion block parameters.
- When building a referenced model that is configured to generate a C++ encapsulation interface:
  - You must use the `I/O arguments step method` style of the C++ encapsulated interface. The `void-void step method` style is not supported for referenced models.
  - You cannot use a C++ encapsulation interface in cases when a referenced model cannot have a combined output/update function. Cases include a model that
    - Has multiple sample times
    - Has a continuous sample time
    - Saves states

# Replacing Math Functions and Operators Using Target Function Libraries

## Introduction to Target Function Libraries

**In this section...**

### Overview of Target Function Libraries

The Real-Time Workshop Embedded Coder software provides the target function library (TFL) API, which allows you to create and register function replacement tables. When selected for a model, these TFL tables provide the basis for replacing default math functions and operators in your model code with target-specific code. The ability to control function and operator replacements potentially allows you to optimize target performance (speed and memory) and better integrate model code with external and legacy code.

A *target function library* (TFL) is a set of one or more function replacement tables that define the target-specific implementations of math functions and operators to be used in generating code for your Simulink model. The Real-Time Workshop software provides three default TFLs, described in the following table. You select these TFLs from the **Target function library** drop-down list on the **Interface** pane of the Configuration Parameters dialog box.

| TFL | Description | Contains Tables... |
|---|---|---|
| `C89/C90 (ANSI)` | Generates calls to the ISO®/IEC 9899:1990 C standard math library for floating-point functions. | `ansi_tfl_table_tmw.mat` |
| `C99 (ISO)` | Generates calls to the ISO/IEC 9899:1999 C standard math library. | `iso_tfl_table_tmw.mat`<br>`ansi_tfl_table_tmw.mat` |
| `GNU99 (GNU)` | Generates calls to the GNU®[7] gcc math library, which provides C99 extensions as defined by compiler option `-std=gnu99`. | `gnu_tfl_table_tmw.mat`<br>`iso_tfl_table_tmw.mat`<br>`ansi_tfl_table_tmw.mat` |

7. GNU® is a registered trademark of the Free Software Foundation.

When a TFL contains multiple tables, the order in which they are listed reflects the order in which they are searched. The TFL API allows you to create your own TFLs, made up of your own function tables in combination with one of the three default TFLs. For example, you could create a TFL for an embedded processor that combines some special-purpose function customizations with a processor-specific library of function and operator implementations:

| | | |
|---|---|---|
| `MyProcessor (ANSI)` | Generates calls to my custom function implementations or a processor-specific library. | `tfl_table_sinfcns.m` `tfl_table_myprocessor.m` `ansi_tfl_table_tmw.mat` |

Each TFL function replacement table contains one or more table entries, with each table entry representing a potential replacement for a single math function or an operator. Each table entry provides a mapping between a *conceptual view* of the function or operator (similar to the Simulink block view of the function or operator) and a *target-specific implementation* of that function or operator.

The conceptual view of a function or operator is represented in a TFL table entry by the following elements, which identify the function or operator entry to the code generation process:

- A function or operator key (a function name such as `'cos'` or an operator ID string such as `'RTW_OP_ADD'`)
- A set of conceptual arguments that observe a Simulink naming scheme (`'y1'`, `'u1'`, `'u2'`, ...), along with their I/O types (output or input) and data types
- Other attributes, such as fixed-point saturation and rounding characteristics for operators, as needed to identify the function or operator to the code generation process as exactly as you require for matching purposes

The target-specific implementation of a function or operator is represented in a TFL table entry by the following elements:

- The name of your implementation function (such as `'cos_dbl'` or `'u8_add_u8_u8'`)

- A set of implementation arguments that you define (the order of which must correspond to the conceptual arguments), along with their I/O types (output or input) and data types
- Parameters providing the build information for your implementation function, including header file and source file names and paths

Additionally, a TFL table entry includes a priority value (0–100, with 0 as the highest priority), which defines the entry's priority relative to other entries in the table.

During code generation for your model, when the code generation process encounters a call site for a math function or operator, it creates and partially populates a TFL entry object, for the purpose of querying the TFL database for a replacement function. The information provided for the TFL query includes the function or operator key and the conceptual argument list. The TFL entry object is then passed to the TFL. If there is a matching table entry in the TFL, a fully-populated TFL entry, including the implementation function name, argument list, and build information, is returned to the call site and used to generate code.

Within the TFL that is selected for your model, the tables that comprise the TFL are searched in the order in which they are listed (by `RTW.viewTFL` or by the TFL's **Target function library** tool tip). Within each table, if multiple matches are found for a TFL entry object, priority level determines the match that is returned. A higher-priority (lower-numbered) entry is used over a similar entry with a lower priority (higher number).

The TFL API supports the following functions for replacement with custom library functions using TFL tables:

**Math Functions**

**Note** For detailed support information, see "Example: Mapping Math Functions to Target-Specific Implementations" on page 30-25).

| | | | |
|---|---|---|---|
| `abs` | `cos` | `log` | `saturate` |
| `acos` | `cosh` | `log10` | `sign` |

| | | | |
|---|---|---|---|
| `acosh` | `exactrSqrt` | `max` | `sin` |
| `asin` | `exp` | `min` | `sinh` |
| `asinh` | `fix` | `mod/fmod` | `sqrt` |
| `atan` | `floor` | `pow` | `tan` |
| `atan2` | `hypot` | `rem` | `tanh` |
| `atanh` | `ldexp` | `round` | |
| `ceil` | `ln` | `rSqrt` | |
| **Copy Utility Function** | | | |
| `memcpy` | | | |
| **Nonfinite Support Utility Functions** | | | |
| `getInf` | `getMinusInf` | `getNaN` | |

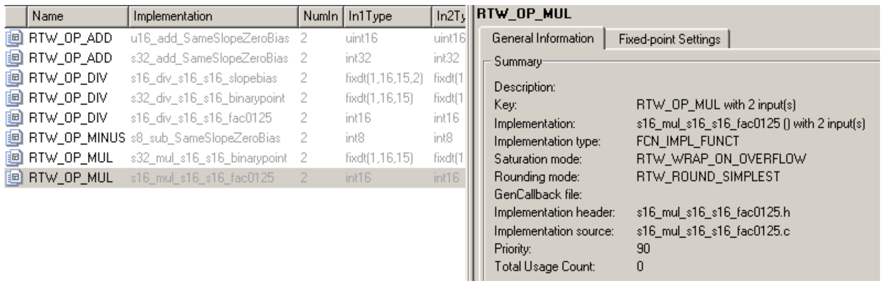
The TFL API also supports the following operations for replacement with custom library functions using TFL tables:

- Scalar operators
  - `+` (addition)
  - (subtraction)
  - `*` (multiplication)
  - `/` (division)
  - Data type conversion (cast)
  - Fixed-point << (shift left)
- Nonscalar operators
  - `+` (addition)
  - (subtraction)
  - `*` (matrix multiplication)
  - `.*` (array multiplication)
  - `'` (matrix transposition)
  - `.'` (array transposition)

## Target Function Libraries General Workflow

The general steps for creating and using a target function library are as follows:

**1** Create one or more TFL tables containing replacement entries for math operators (+, –, *, /) and functions using an API based on the MATLAB API. (The demo `rtwdemo_tfl_script` provides example tables that can be used as a starting point for customization.)



| Name | Implementation | NumIn | In1Type | In2Ty |
|---|---|---|---|---|
| RTW_OP_ADD | u16_add_SameSlopeZeroBias | 2 | uint16 | uint16 |
| RTW_OP_ADD | s32_add_SameSlopeZeroBias | 2 | int32 | int32 |
| RTW_OP_DIV | s16_div_s16_s16_slopebias | 2 | fixdt(1,16,15,2) | fixdt(1 |
| RTW_OP_DIV | s32_div_s16_s16_binarypoint | 2 | fixdt(1,16,15) | fixdt(1 |
| RTW_OP_DIV | s16_div_s16_s16_fac0125 | 2 | int16 | int16 |
| RTW_OP_MINUS | s8_sub_SameSlopeZeroBias | 2 | int8 | int8 |
| RTW_OP_MUL | s32_mul_s16_s16_binarypoint | 2 | fixdt(1,16,15) | fixdt(1 |
| RTW_OP_MUL | s16_mul_s16_s16_fac0125 | 2 | int16 | int16 |

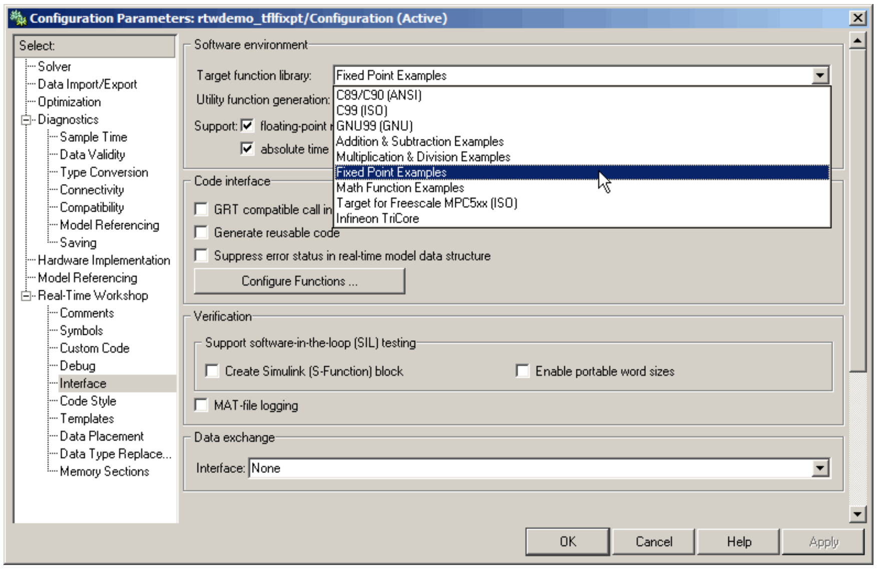
RTW_OP_MUL

| | |
|---|---|
| Description: | |
| Key: | RTW_OP_MUL with 2 input(s) |
| Implementation: | s16_mul_s16_s16_fac0125 () with 2 input(s) |
| Implementation type: | FCN_IMPL_FUNCT |
| Saturation mode: | RTW_WRAP_ON_OVERFLOW |
| Rounding mode: | RTW_ROUND_SIMPLEST |
| GenCallback file: | |
| Implementation header: | s16_mul_s16_s16_fac0125.h |
| Implementation source: | s16_mul_s16_s16_fac0125.c |
| Priority: | 90 |
| Total Usage Count: | 0 |

**2** Register a target function library, consisting of one or more replacement tables, for use with Simulink or Embedded MATLAB Coder software. The M APIs `sl_customization` and `rtwTargetInfo` are provided for this purpose.

**3** Open your Simulink model and select the desired target function library from the **Target function library** drop-down list located on the **Interface** pane of the Configuration Parameters dialog box. For Embedded MATLAB Coder applications, instantiate a Real-Time Workshop configuration object, set the Target Function Library, and provide the configuration object in a call to the `emlc` function, as follows:

```
rtwConfig = emlcoder.RTWConfig('ert');
rtwConfig.TargetFunctionLibrary = 'Addition & Subtraction Examples';
emlc -T rtw -s rtwConfig -c addsub_two_int16 -eg {t, t};
```


Configuration Parameters: rtwdemo_tflfixpt/Configuration (Active)

Software environment

Target function library: Fixed Point Examples

Utility function generation:

Support: ☑ floating-point ☑ absolute time

Code interface

☐ GRT compatible call in

☐ Generate reusable code

☐ Suppress error status in real-time model data structure

Verification

Support software-in-the-loop (SIL) testing

☐ Create Simulink (S-Function) block ☐ Enable portable word sizes

☐ MAT-file logging

Data exchange

Interface: None

**4** Build your Simulink model or Embedded MATLAB Coder application.

See the demo `rtwdemo_tfl_script`, which illustrates how to use TFLs to replace operators and functions in generated code. With each example model included in this demo, a separate TFL is provided to illustrate the creation of operator and function replacements and how to register the replacements with Simulink software.

## Target Function Libraries Quick-Start Example

This section steps you through a simple example of the complete TFL workflow. (The materials for this example can easily be created based on the file and model displays in this section.)

**1** Create and save a TFL table definition file that instantiates and populates a TFL table entry, such as the file `tfl_table_sinfcn.m` shown below. This file creates function table entries for the `sin` function. For detailed information on creating table definition files for math functions and operators, see "Creating Function Replacement Tables" on page 30-15.

```
function hTable = tfl_table_sinfcn()
%TFL_TABLE_SINFCN - Describe function entries for a Target Function Library table.
```

```
hTable = RTW.TflTable;

% Create entry for double data type sine function replacement
hTable.registerCFunctionEntry(100, 1, 'sin', 'double', 'sin_dbl', ...
                                             'double', '<sin_dbl.h>','','');

% Create entry for single data type sine function replacement
hTable.registerCFunctionEntry(100, 1, 'sin', 'single', 'sin_sgl', ...
                                             'double', '<sin_sgl.h>','','');
```

**Note** See "Example: Mapping Math Functions to Target-Specific Implementations" on page 30-25 for another example of `sin` function replacement, in which function arguments are created individually.

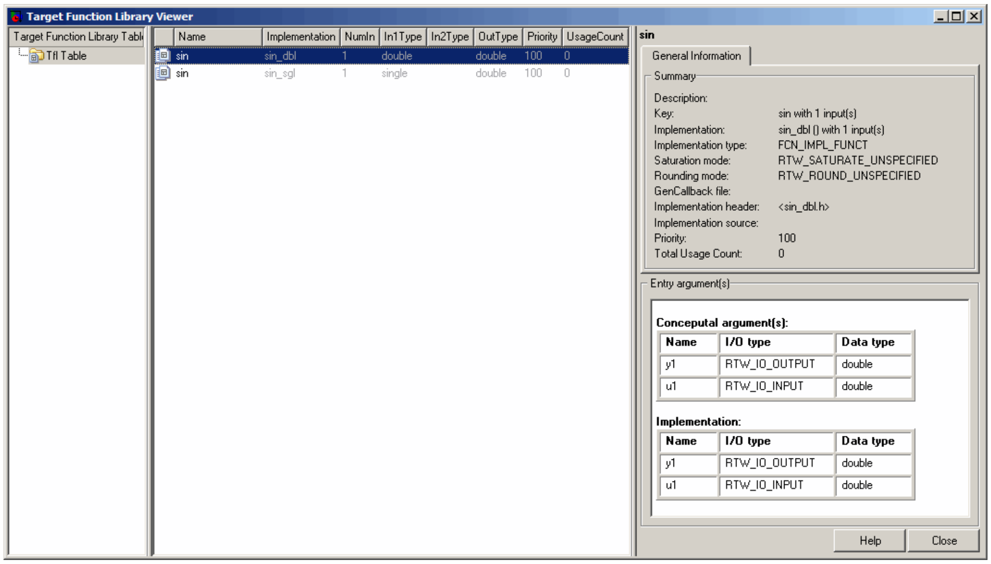
**2** As a first check of the validity of your table entries, invoke the TFL table definition file as follows:

```
>> tbl = tfl_table_sinfcn

tbl =

RTW.TflTable
            Version: '1.0'
         AllEntries: [2x1 RTW.TflCFunctionEntry]
    ReservedSymbols: []

>>
```

Any errors found during the invocation are displayed.

**3** As a further check of your table entries, invoke the TFL Viewer using the following MATLAB command:

```
>> RTW.viewTfl(tfl_table_sinfcn)
```



| Name | Implementation | NumIn | In1Type | In2Type | OutType | Priority | UsageCount |
|---|---|---|---|---|---|---|---|
| sin | sin_dbl | 1 | double | | double | 100 | 0 |
| sin | sin_sgl | 1 | single | | double | 100 | 0 |

sin

Summary

| | |
|---|---|
| Description: | |
| Key: | sin with 1 input(s) |
| Implementation: | sin_dbl () with 1 input(s) |
| Implementation type: | FCN_IMPL_FUNCT |
| Saturation mode: | RTW_SATURATE_UNSPECIFIED |
| Rounding mode: | RTW_ROUND_UNSPECIFIED |
| GenCallback file: | |
| Implementation header: | <sin_dbl.h> |
| Implementation source: | |
| Priority: | 100 |
| Total Usage Count: | 0 |

Entry argument(s)

**Conceptual argument(s):**

| Name | I/O type | Data type |
|---|---|---|
| y1 | RTW_IO_OUTPUT | double |
| u1 | RTW_IO_INPUT | double |

**Implementation:**

| Name | I/O type | Data type |
|---|---|---|
| y1 | RTW_IO_OUTPUT | double |
| u1 | RTW_IO_INPUT | double |

Select entries in your table and verify that the graphical display of the contents of your table meets your expectations. (The TFL Viewer can also help you debug issues with the order of entries in a table, the order of tables in a TFL, and function signature mismatches. For more information, see "Examining and Validating Function Replacement Tables" on page 30-119.)

**4** Create and save a TFL registration file that includes the `tfl_table_sinfcn` table, such as the `sl_customization.m` file shown below. The file specifies that the TFL to be registered is named `'Sine Function Example'` and consists of `tfl_table_sinfcn`, with the default ANSI[8] math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION
```

8. ANSI® is a registered trademark of the American National Standards Institute, Inc.

```
% Local function to define a TFL containing tfl_table_sinfcn
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Sine Function Example';
  thisTfl.Description = 'Demonstration of sine function replacement';
  thisTfl.TableList = {'tfl_table_sinfcn'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

If you place this `sl_customization.m` file in the MATLAB search path or in the current working directory, the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

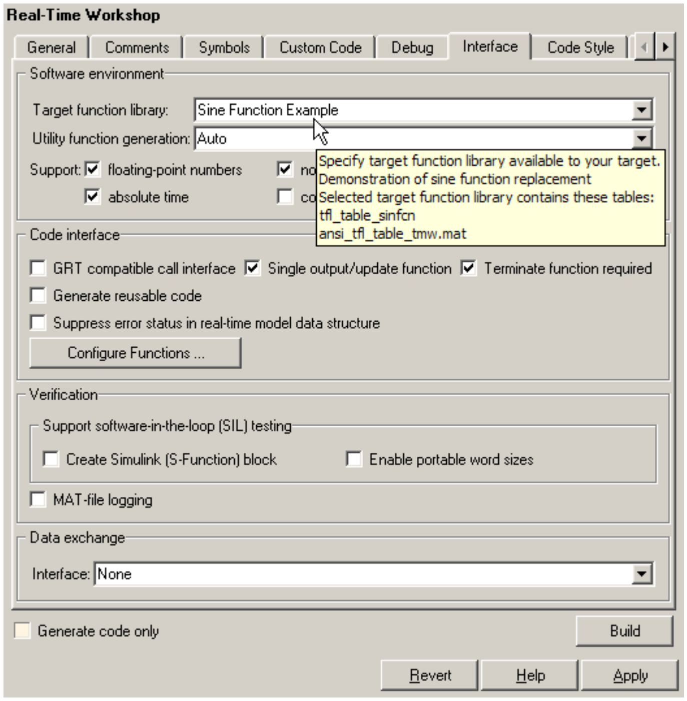
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see "Registering Target Function Libraries" on page 30-128.

5 With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip contains information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



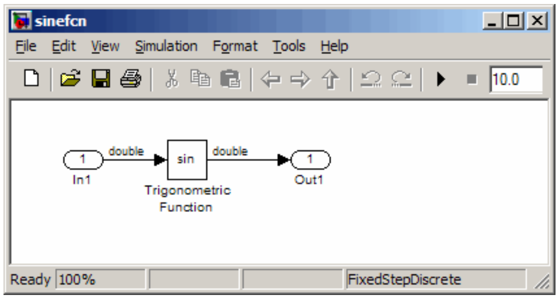
Target function library: Sine Function Example
Utility function generation: Auto
Support: [✓] floating-point numbers [✓] no
[✓] absolute time [ ] co

Specify target function library available to your target.
Demonstration of sine function replacement
Selected target function library contains these tables:
tfl_table_sinfcn
ansi_tfl_table_tmw.mat

[ ] GRT compatible call interface [✓] Single output/update function [✓] Terminate function required
[ ] Generate reusable code
[ ] Suppress error status in real-time model data structure
[ ] Create Simulink (S-Function) block [ ] Enable portable word sizes
[ ] MAT-file logging
Interface: None
[ ] Generate code only

Optionally, you can relaunch the TFL Viewer, using the command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `Sine Function Example`.

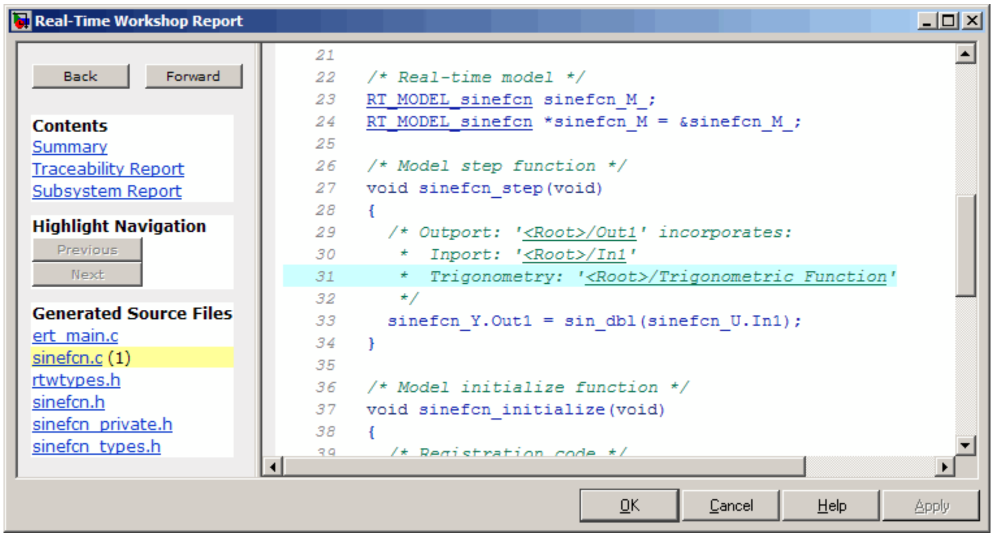
**6** Create an ERT-based model with a Trigonometric Function block set to the sine function, such as the following:



Make sure that the TFL you registered, `Sine Function Example`, is selected for this model.

7 Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

8 Go to the model window and use model-to-code highlighting to trace the code generated using your TFL entry. For example, right-click the Trigonometric Function block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the `sin` function code within the model step function in `sinefcn.c`. In this case, `sin` has been replaced with `sin_dbl` in the generated code.



```

/* Real-time model */
RT_MODEL_sinefcn sinefcn_M_;
RT_MODEL_sinefcn *sinefcn_M = &sinefcn_M_;

/* Model step function */
void sinefcn_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Trigonometry: '<Root>/Trigonometric Function'
   */
  sinefcn_Y.Out1 = sin_dbl(sinefcn_U.In1);
}

/* Model initialize function */
void sinefcn_initialize(void)
{
  /* Registration code */
```

**9** If functions were not replaced as you intended, you can use the techniques described in "Examining and Validating Function Replacement Tables" on page 30-119 to help you determine why the code generation process was unable to match a function signature with the TFL table entry you created for it.

For example, you can view the TFL cache hits and misses logged during the most recent build. For the code generation step in this example, there was one cache hit and zero cache misses, as shown in the following `HitCache` and `MissCache` entries:

```
>> a=get_param('sinefcn','TargetFcnLibHandle')

a =

RTW.TflControl
        Version: '1.0'
       HitCache: [1x1 RTW.TflCFunctionEntry]
      MissCache: [0x1 handle]
    TLCCallList: [0x1 handle]
      TflTables: [2x1 RTW.TflTable]

>> a.HitCache(1)
```

```
ans =

RTW.TflCFunctionEntry
                         Key: 'sin'
                    Priority: 100
              ConceptualArgs: [2x1 RTW.TflArgNumeric]
              Implementation: [1x1 RTW.CImplementation]
.
.
.
>>
```

## Creating Function Replacement Tables

**In this section...**

### Overview of Function Replacement Table Creation

To create a TFL table containing replacement information for supported functions and operators, you perform the following steps:

**1** Create a table definition M-file containing a function definition in the following general form:

```
function hTable = tfl_table_name()
%TFL_TABLE_NAME - Describe entries for a Target Function Library table.
.
.
```

.

For example, the following sample function definition is from the "Target Function Libraries Quick-Start Example" on page 30-7:

```
function hTable = tfl_table_sinfcn()
%TFL_TABLE_SINFCN - Describe function entries for a Target Function Library table.
.
.
.
```

2 Within the function body, instantiate a TFL table with a command such as the following:

```
hTable = RTW.TflTable;
```

3 Use the TFL table creation functions (listed in the table below) to add table entries representing your replacements for supported functions and operators. For each individual function or operator entry, you issue one or more function calls to

   a Instantiate a table entry.

   b Add conceptual arguments, implementation arguments, and other attributes to the entry.

   c Add the entry to the table.

   "Creating Table Entries" on page 30-18 describes this procedure in detail, including two methods for creating function entries. The following sample function entry is from the "Target Function Libraries Quick-Start Example" on page 30-7:

```
% Create entry for double data type sine function replacement
hTable.registerCFunctionEntry(100, 1, 'sin', 'double', 'sin_dbl', ...
                                          'double', '<sin_dbl.h>','','');
```

4 Save the table definition M-file using the name of the table definition function, for example, `tfl_table_sinfcn.m`.

After you have created a table definition M-file, you can do the following:

- Examine and validate the table, as described in “Examining and Validating Function Replacement Tables” on page 30-119.
- Register a TFL containing the table with the Simulink software, as described in “Registering Target Function Libraries” on page 30-128.

After you register a TFL with the Simulink software, it appears in the Simulink GUI and can be selected for use in building models.

The following table provides a functional grouping of the TFL table creation functions.

| Function | Description |
|---|---|
| **Table entry creation** | |
| `addEntry` | Add table entry to collection of table entries registered in TFL table |
| `copyConceptualArgsToImplementation` | Copy conceptual argument specifications to matching implementation arguments for TFL table entry |
| `createAndAddConceptualArg` | Create conceptual argument from specified properties and add to conceptual arguments for TFL table entry |
| `createAndAddImplementationArg` | Create implementation argument from specified properties and add to implementation arguments for TFL table entry |
| `createAndSetCImplementationReturn` | Create implementation return argument from specified properties and add to implementation for TFL table entry |
| `setTflCFunctionEntryParameters` | Set specified parameters for function entry in TFL table |
| `setTflCOperationEntryParameters` | Set specified parameters for operator entry in TFL table |
| **Alternative method for conceptual argument creation** | |
| `addConceptualArg` | Add conceptual argument to array of conceptual arguments for TFL table entry |
| `getTflArgFromString` | Create TFL argument based on specified name and built-in data type |

| Function | Description |
|---|---|
| **Alternative method for function entry creation** | |
| `registerCFunctionEntry` | Create TFL function entry based on specified parameters and register in TFL table |
| `registerCPromotableMacroEntry` | Create TFL promotable macro entry based on specified parameters and register in TFL table (for `abs` function replacement only) |
| **Build information** | |
| `addAdditionalHeaderFile` | Add additional header file to array of additional header files for TFL table entry |
| `addAdditionalIncludePath` | Add additional include path to array of additional include paths for TFL table entry |
| `addAdditionalLinkObj` | Add additional link object to array of additional link objects for TFL table entry |
| `addAdditionalLinkObjPath` | Add additional link object path to array of additional link object paths for TFL table entry |
| `addAdditionalSourceFile` | Add additional source file to array of additional source files for TFL table entry |
| `addAdditionalSourcePath` | Add additional source path to array of additional source paths for TFL table entry |
| **Reserved identifiers** | |
| `setReservedIdentifiers` | Register specified reserved identifiers to be associated with TFL table |

## Creating Table Entries

- "Overview of Table Entry Creation" on page 30-19
- "General Method for Creating Function and Operator Entries" on page 30-20
- "Alternative Method for Creating Function Entries" on page 30-24

### Overview of Table Entry Creation

You define TFL table entries by issuing TFL table creation function calls inside a table definition M-file. The function calls must follow a function declaration and a TFL table instantiation, such as the following:

```
function hTable = tfl_table_sinfcn()
%TFL_TABLE_SINFCN - Describe function entries for a Target Function Library table.

hTable = RTW.TflTable;
```

Within the function body, you use the TFL table creation functions to add table entries representing your replacements for supported functions and operators. For each individual function or operator entry, you issue one or more function calls to

1. Instantiate a table entry.

2. Add conceptual arguments, implementation arguments, and other attributes to the entry.

3. Add the entry to the table.

The general method for creating function and operator entries, described in "General Method for Creating Function and Operator Entries" on page 30-20, uses the functions shown in the following table.

| Function | Description |
|---|---|
| **Table entry creation** | |
| `addEntry` | Add table entry to collection of table entries registered in TFL table |
| `copyConceptualArgsToImplementation` | Copy conceptual argument specifications to matching implementation arguments for TFL table entry |
| `createAndAddConceptualArg` | Create conceptual argument from specified properties and add to conceptual arguments for TFL table entry |
| `createAndAddImplementationArg` | Create implementation argument from specified properties and add to implementation arguments for TFL table entry |

| Function | Description |
|---|---|
| `createAndSetCImplementationReturn` | Create implementation return argument from specified properties and add to implementation for TFL table entry |
| `setTflCFunctionEntryParameters` | Set specified parameters for function entry in TFL table |
| `setTflCOperationEntryParameters` | Set specified parameters for operator entry in TFL table |
| **Alternative method for conceptual argument creation** | |
| `addConceptualArg` | Add conceptual argument to array of conceptual arguments for TFL table entry |
| `getTflArgFromString` | Create TFL argument based on specified name and built-in data type |

A simpler alternative creation method is available for function entries, with the constraints that input types must be uniform and implementation arguments must use default Simulink naming. The alternative method uses the following functions and is described in “Alternative Method for Creating Function Entries” on page 30-24.

| Function | Description |
|---|---|
| **Alternative method for function entry creation** | |
| `registerCFunctionEntry` | Create TFL function entry based on specified parameters and register in TFL table |
| `registerCPromotableMacroEntry` | Create TFL promotable macro entry based on specified parameters and register in TFL table (for `abs` function replacement only) |

## General Method for Creating Function and Operator Entries

The general workflow for creating TFL table entries applies equally to function and operator replacements, and involves the following steps.

**Note**

- You can remap operator outputs to implementation function inputs for operator replacement entries (see "Remapping Operator Outputs to Implementation Function Input Positions" on page 30-111). However, for function replacement entries, implementation argument order must match the conceptual argument order. Remapping the argument order in a function implementation is not supported.
- For function entries, if your implementations additionally meet the requirements that all input arguments are of the same type and your implementation arguments use default Simulink naming (return argument `y1` and input arguments `u`*`n`*), you can use a simpler alternative method for creating the entries, as described in "Alternative Method for Creating Function Entries" on page 30-24.

1 Within the function body of your table definition M-file, instantiate a TFL table entry for a function or operator, using one of the following lines of code:

| | |
|---|---|
| `fcn_entry = RTW.TflCFunctionEntry;` | Supports function replacement |
| `op_entry = RTW.TflCOperationEntry;` | Supports operator replacement |
| `op_entry = RTW.TflCOperationEntry-Generator;` | Provides relative scaling factor (RSF) fixed-point parameters, described in "Mapping Fixed-Point Operators to Target-Specific Implementations" on page 30-77, that are not available in `RTW.TflCOperationEntry` |
| `op_entry = RTW.TflCOperationEntry-Generator_NetSlope;` | Provides net slope parameters, described in "Mapping Fixed-Point Operators to Target-Specific Implementations" on page 30-77, that are not available in `RTW.TflCOperationEntry` |

| | |
|---|---|
| `op_entry = RTW.TflBlasEntry-Generator;` | Supports replacement of nonscalar operators with MathWorks BLAS functions, described in "Mapping Nonscalar Operators to Target-Specific Implementations" on page 30-47 |
| `op_entry = RTW.TflCBlasEntry-Generator;` | Supports replacement of nonscalar operators with ANSI/ISO C BLAS functions, described in "Mapping Nonscalar Operators to Target-Specific Implementations" on page 30-47 |

**2** Set the table entry parameters, which are passed in parameter/value pairs to one of the following functions:

- `setTflCFunctionEntryParameters`
- `setTflCOperationEntryParameters`

For example:

```
setTflCFunctionEntryParameters(fcn_entry, ...
                               'Key',                    'sin', ...
                               'Priority',               30, ...
                               'ImplementationName',     'mySin', ...
                               'ImplementationHeaderFile', 'basicMath.h',...
                               'ImplementationSourceFile', 'basicMath.c');
```

For detailed descriptions of the settable function and operator attributes, see the `setTflCFunctionEntryParameters` and `setTflCOperationEntryParameters` reference pages in the Real-Time Workshop Embedded Coder documentation.

**3** Create and add conceptual arguments to the function or operator entry. Output arguments must precede input arguments, and the function signature (including argument naming, order, and attributes) must fulfill the signature match sought by function or operator callers. Conceptual argument names follow the default Simulink naming convention:

- For return argument, `y1`
- For input argument names, `u1`, `u2`, ..., `u`*n*

You can create and add conceptual arguments in either of two ways:

- Call the `createAndAddConceptualArg` function to create the argument and add it to the table entry. For example:

  ```
  createAndAddConceptualArg(fcn_entry, 'RTW.TflArgNumeric', ...
                            'Name',         'y1',...
                            'IOType',       'RTW_IO_OUTPUT',...
                            'DataTypeMode', 'double');
  ```

- Call the `getTflArgFromString` function to create an argument based on a built-in data type, and then call the `addConceptualArg` function to add the argument to the table entry.

  ---

  **Note** If you use `getTflArgFromString`, the `IOType` property of the created argument defaults to `'RTW_IO_INPUT'`, indicating an input argument. For an output argument, you must change the `IOType` value to `'RTW_IO_OUTPUT'` by directly assigning the argument property, as shown in the following example.

  ---

  ```
  arg = getTflArgFromString(hTable, 'y1', 'int16');
  arg.IOType = 'RTW_IO_OUTPUT';
  addConceptualArg(op_entry, arg);
  ```

**4** Create and add implementation arguments, representing the signature of your implementation function, to the function or operator entry. The implementation argument order must match the conceptual argument order. You can create and add implementation arguments in either of two ways:

- Call the `copyConceptualArgsToImplementation` function to populate all of the implementation arguments as copies of the previously created conceptual arguments. For example:

  ```
  copyConceptualArgsToImplementation(fcn_entry);
  ```

- Call the `createAndSetCImplementationReturn` function to create the implementation return argument and add it to the table entry, and then call the `createAndAddImplementationArg` function to individually create and add each of your implementation arguments. This method allows you to vary argument attributes, including argument naming, as long as conceptual argument order is maintained. For example:

```
createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                                   'Name',       'y1', ...
                                   'IOType',     'RTW_IO_OUTPUT', ...
                                   'IsSigned',   true, ...
                                   'WordLength', 32, ...
                                   'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                               'Name',       'u1', ...
                               'IOType',     'RTW_IO_INPUT',...
                               'IsSigned',   true,...
                               'WordLength', 32, ...
                               'FractionLength', 0 );

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                               'Name',       'u2', ...
                               'IOType',     'RTW_IO_INPUT',...
                               'IsSigned',   true,...
                               'WordLength', 32, ...
                               'FractionLength', 0 );
```

5 Add the function or operator entry to the TFL table using the `addEntry` function. For example:

```
addEntry(hTable, fcn_entry);
```

For complete examples of function entries and operator entries created using the general method, see “Example: Mapping Math Functions to Target-Specific Implementations” on page 30-25 and “Example: Mapping Scalar Operators to Target-Specific Implementations” on page 30-42. For syntax examples, see the examples in the TFL table creation function reference pages in the Real-Time Workshop Embedded Coder documentation.

### Alternative Method for Creating Function Entries

You can use a simpler alternative method for creating TFL function entries if your function implementation meets the following criteria:

- The implementation argument order matches the conceptual argument order.
- All input arguments are of the same type.
- The return argument name and all input argument names follow the default Simulink naming convention:
  - For the return argument, `y1`
  - For input argument names, `u1`, `u2`, ..., `u`*n*

The alternative method for creating function entries involves a single step. Call one of the following functions to create and add conceptual and implementation arguments and register the function entry:

- `registerCFunctionEntry`
- `registerCPromotableMacroEntry` (use only for the `abs` function)

For example:

```
hTable = RTW.TflTable;

registerCFunctionEntry(hTable, 100, 1, 'sqrt', 'double', ...
                       'sqrt', 'double', '<math.h>', '', '');
```

For detailed descriptions of the function arguments, see the `registerCFunctionEntry` and `registerCPromotableMacroEntry` reference pages in the Real-Time Workshop Embedded Coder documentation.

## Example: Mapping Math Functions to Target-Specific Implementations

The Real-Time Workshop Embedded Coder software supports the following math functions for replacement with custom library functions using target function library (TFL) tables.

| Math Function | Simulink Support | Stateflow Support | Embedded MATLAB and Embedded MATLAB Coder Support |
|---|---|---|---|
| `abs` | • Floating-point<br>• Integer | • Floating-point<br>• Integer | Floating-point |
| `acos` | Floating-point | Floating-point | Floating-point |
| `acosh` | Floating-point | Not available (NA) | Not replaceable (NR) |
| `asin` | Floating-point | Floating-point | Floating-point |
| `asinh` | Floating-point | NA | NR |
| `atan` | Floating-point | Floating-point | Floating-point |
| `atan2` | Floating-point | Floating-point | Floating-point |
| `atanh` | Floating-point | NA | NR |
| `ceil` | Floating-point | Floating-point | Floating-point |
| `cos` | Floating-point | Floating-point | Floating-point |
| `cosh` | Floating-point | Floating-point | Floating-point |
| `exactrSqrt` | • Floating-point<br>• Integer | NA | NA |
| `exp` | Floating-point | Floating-point | Floating-point |
| `fix` | Floating-point | NA | NR |
| `floor` | Floating-point | Floating-point | Floating-point |
| `hypot` | Floating-point | NA | NR |
| `ldexp` | Floating-point | Floating-point | Floating-point |
| `ln` | Floating-point | NA | NA |
| `log` | Floating-point | Floating-point | Floating-point |
| `log10` | Floating-point | Floating-point | Floating-point |
| `max` | • Floating-point<br>• Integer | • Floating-point<br>• Integer | • Floating-point<br>• Integer |

| Math Function | Simulink Support | Stateflow Support | Embedded MATLAB and Embedded MATLAB Coder Support |
|---|---|---|---|
| `min` | • Floating-point<br>• Integer | • Floating-point<br>• Integer | • Floating-point<br>• Integer |
| `mod/fmod` | • Floating-point (`mod`)<br>• Integer (`mod`) | Floating-point (`fmod`) | NR |
| `pow` | Floating-point | Floating-point | Floating-point |
| `rem` | Floating-point | NA | Floating-point |
| `round` | Floating-point | NA | NR |
| `rSqrt` | • Floating-point<br>• Integer | NA | NA |
| `saturate` | • Floating-point<br>• Integer | NA | NA |
| `sign` | • Floating-point<br>• Integer | NA | NR |
| `sin` | Floating-point | Floating-point | Floating-point |
| `sinh` | Floating-point | Floating-point | Floating-point |
| `sqrt` | Floating-point | Floating-point | Floating-point |
| `tan` | Floating-point | Floating-point | Floating-point |
| `tanh` | Floating-point | Floating-point | Floating-point |

The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry for the `sin` function.

---

**Note** See “Target Function Libraries Quick-Start Example” on page 30-7 for another example of `sin` function replacement, in which function arguments are created using the simpler method described in “Alternative Method for Creating Function Entries” on page 30-24.

---

1 Create and save the following TFL table definition file, `tfl_table_sinfcn2.m`. This file defines a TFL table containing a function replacement entry for the `sin` function.

   The function body sets selected sine function entry parameters, creates the `y1` and `u1` conceptual arguments individually, and then copies the conceptual arguments to the implementation arguments. Finally the function entry is added to the table.

```
function hTable = tfl_table_sinfcn2()
%TFL_TABLE_SINFCN2 - Describe function entry for a Target Function Library table.

hTable = RTW.TflTable;

% Create entry for sine function replacement
fcn_entry = RTW.TflCFunctionEntry;
setTflCFunctionEntryParameters(fcn_entry, ...
                               'Key',                 'sin', ...
                               'Priority',            30, ...
                               'ImplementationName',  'mySin', ...
                               'ImplementationHeaderFile', 'basicMath.h',...
                               'ImplementationSourceFile', 'basicMath.c');

createAndAddConceptualArg(fcn_entry, 'RTW.TflArgNumeric', ...
                          'Name',         'y1',...
                          'IOType',       'RTW_IO_OUTPUT',...
                          'DataTypeMode', 'double');

createAndAddConceptualArg(fcn_entry, 'RTW.TflArgNumeric', ...
                          'Name',         'u1', ...
                          'IOType',       'RTW_IO_INPUT',...
                          'DataTypeMode', 'double');
```

```
copyConceptualArgsToImplementation(fcn_entry);

addEntry(hTable, fcn_entry);
```

2 Optionally, perform a quick check of the validity of the function entry by invoking the table definition file at the MATLAB command line (`>> tbl = tfl_table_sinfcn2`) and by viewing it in the TFL Viewer (`>> RTW.viewTfl(tfl_table_sinfcn2)`). For more information about validating TFL tables, see "Examining and Validating Function Replacement Tables" on page 30-119.

3 Create and save the following TFL registration file, which references the `tfl_table_sinfcn2` table.

The file specifies that the TFL to be registered is named `'Sine Function Example 2'` and consists of `tfl_table_sinfcn2`, with the default ANSI[9] math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_sinfcn2
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Sine Function Example 2';
  thisTfl.Description = 'Demonstration of sine function replacement';
  thisTfl.TableList = {'tfl_table_sinfcn2'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};
```

9. ANSI® is a registered trademark of the American National Standards Institute, Inc.

```
end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

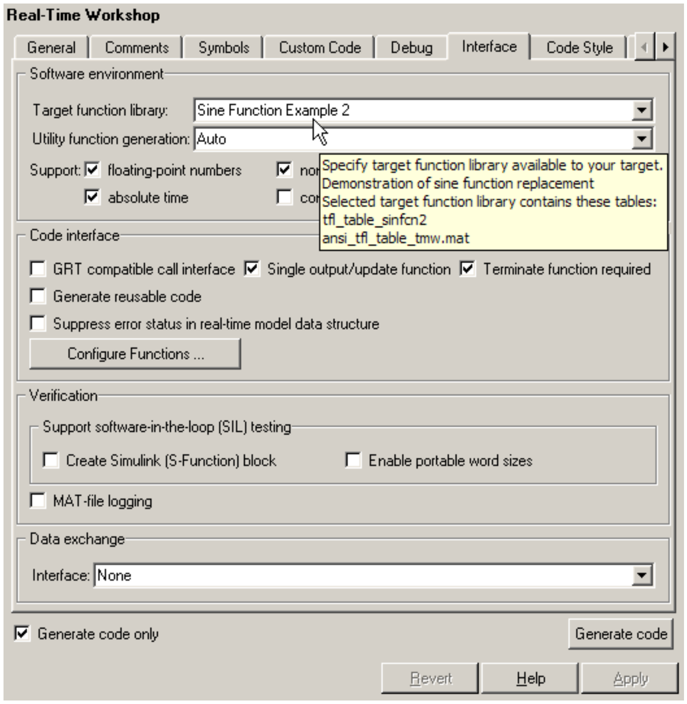
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see "Registering Target Function Libraries" on page 30-128.

4 With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



Real-Time Workshop

General | Comments | Symbols | Custom Code | Debug | Interface | Code Style

Software environment

Target function library: Sine Function Example 2

Utility function generation: Auto

Support: [✓] floating-point numbers [✓] non [✓] absolute time [ ] con

Specify target function library available to your target.
Demonstration of sine function replacement
Selected target function library contains these tables:
tfl_table_sinfcn2
ansi_tfl_table_tmw.mat

Code interface

[ ] GRT compatible call interface [✓] Single output/update function [✓] Terminate function required

[ ] Generate reusable code

[ ] Suppress error status in real-time model data structure

Configure Functions ...

Verification

Support software-in-the-loop (SIL) testing

[ ] Create Simulink (S-Function) block [ ] Enable portable word sizes

[ ] MAT-file logging

Data exchange

Interface: None

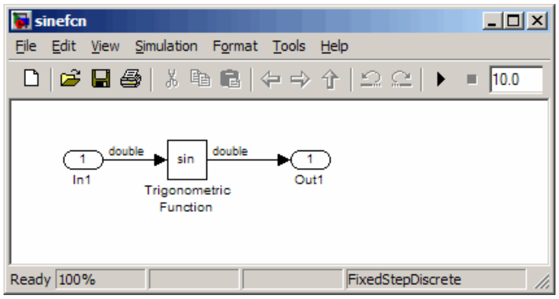
[✓] Generate code only

Generate code

Revert | Help | Apply

Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `Sine Function Example 2`.

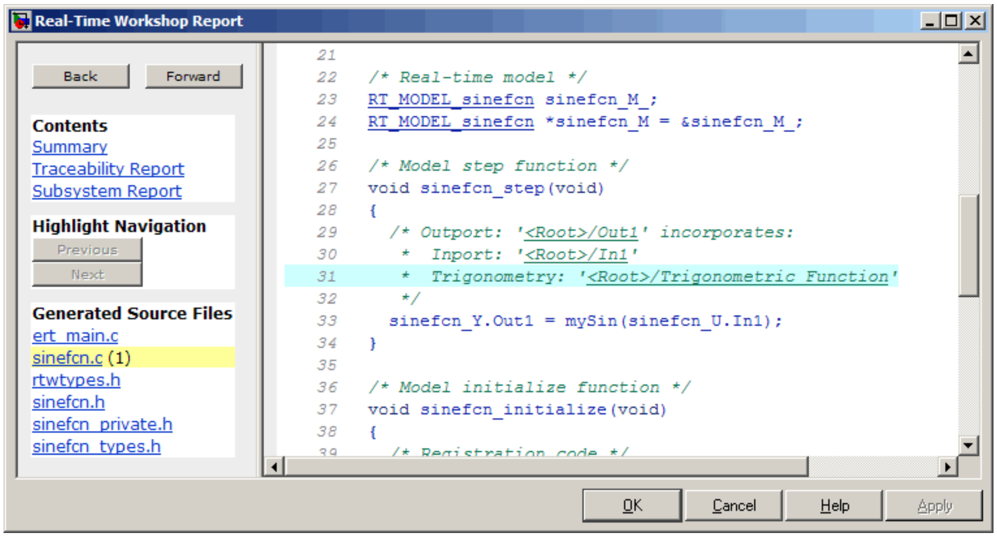
**5** Create an ERT-based model with a Trigonometric Function block set to the sine function, such as the following:



Make sure that the TFL you registered, `Sine Function Example 2`, is selected for this model.

6 Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

7 Go to the model window and use model-to-code highlighting to trace the code generated using your TFL entry. For example, right-click the Trigonometric Function block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the `sin` function code within the model step function in `sinefcn.c`. In this case, `sin` has been replaced with `mySin` in the generated code.



```

/* Real-time model */
RT_MODEL_sinefcn sinefcn_M_;
RT_MODEL_sinefcn *sinefcn_M = &sinefcn_M_;

/* Model step function */
void sinefcn_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Trigonometry: '<Root>/Trigonometric Function'
   */
  sinefcn_Y.Out1 = mySin(sinefcn_U.In1);
}

/* Model initialize function */
void sinefcn_initialize(void)
{
  /* Registration code */
```

## Example: Mapping the memcpy Function to a Target-Specific Implementation

The Real-Time Workshop Embedded Coder software supports the `memcpy` function for replacement with custom library functions using target function library (TFL) tables.

The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry for the `memcpy` function.

1 Create and save the following TFL table definition file, `tfl_table_memcpy.m`. This file defines a TFL table containing a function replacement entry for the `memcpy` function.

   The function body sets selected `memcpy` function entry parameters, creates the `y1`, `u1`, `u2`, and `u3` conceptual arguments individually, adds each argument to the conceptual arguments array for the function, and then copies the conceptual arguments to the implementation arguments. Finally the function entry is added to the table.

```
function hTable = tfl_table_memcpy()
%TFL_TABLE_MEMCPY - Describe memcpy function entry for a TFL table.

hTable = RTW.TflTable;

% Create function replacement entry for void* memcpy(void*, void*, size_t)
fcn_entry = RTW.TflCFunctionEntry;
setTflCFunctionEntryParameters(fcn_entry, ...
                               'Key',                  'memcpy', ...
                               'Priority',             90, ...
                               'ImplementationName',   'memcpy_int', ...
                               'ImplementationHeaderFile', 'memcpy_int.h',...
                               'SideEffects',          true);
% Set SideEffects to 'true' for function returning void to prevent it being
% optimized away

arg = getTflArgFromString(hTable, 'y1', 'void*');
arg.IOType = 'RTW_IO_OUTPUT';
addConceptualArg(fcn_entry, arg);

arg = getTflArgFromString(hTable, 'u1', 'void*');
addConceptualArg(fcn_entry, arg);

arg = getTflArgFromString(hTable, 'u2', 'void*');
addConceptualArg(fcn_entry, arg);
```

```
arg = getTflArgFromString(hTable, 'u3', 'size_t');
addConceptualArg(fcn_entry, arg);

copyConceptualArgsToImplementation(fcn_entry);
addEntry(hTable, fcn_entry);
```

**2** Optionally, perform a quick check of the validity of the `memcpy` entry by invoking the table definition file at the MATLAB command line (>> `tbl = tfl_table_memcpy`) and by viewing it in the TFL Viewer (>> `RTW.viewTfl(tfl_table_memcpy)`). For more information about validating TFL tables, see "Examining and Validating Function Replacement Tables" on page 30-119.

**3** Create and save the following TFL registration file, which references the `tfl_table_memcpy` table.

The file specifies that the TFL to be registered is named `'Memcpy Function Example'` and consists of `tfl_table_memcpy`, with the default ANSI[10] math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_memcpy
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Memcpy Function Example';
  thisTfl.Description = 'Demonstration of memcpy function replacement';
  thisTfl.TableList = {'tfl_table_memcpy'};
```

10. ANSI® is a registered trademark of the American National Standards Institute, Inc.

```
        thisTfl.BaseTfl = 'C89/C90 (ANSI)';
        thisTfl.TargetHWDeviceType = {'*'};

    end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

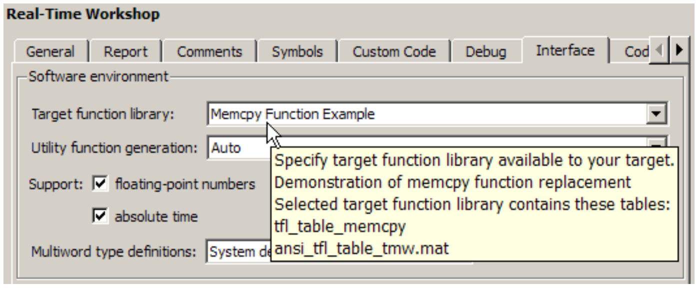
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see "Registering Target Function Libraries" on page 30-128.

4. With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



Software environment

Target function library: Memcpy Function Example

Utility function generation: Auto

Support: ☑ floating-point numbers ☑ absolute time

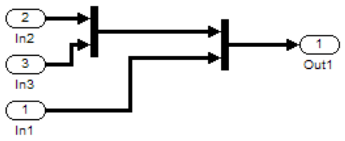
Multiword type definitions: System de

Specify target function library available to your target.
Demonstration of memcpy function replacement
Selected target function library contains these tables:
tfl_table_memcpy
ansi_tfl_table_tmw.mat

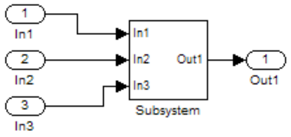
Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `Memcpy Function Example`.

**5** Create an ERT-based model that uses `memcpy` for vector assignments. For example,

**a** Use In, Out, and Mux blocks to create the following model. (Alternatively, you can open `rtwdemo_tflmath/Subsystem1` and copy the subsystem contents to a new model.)



**b** Select the diagram and use **Edit > Subsystem** to make it a subsystem.

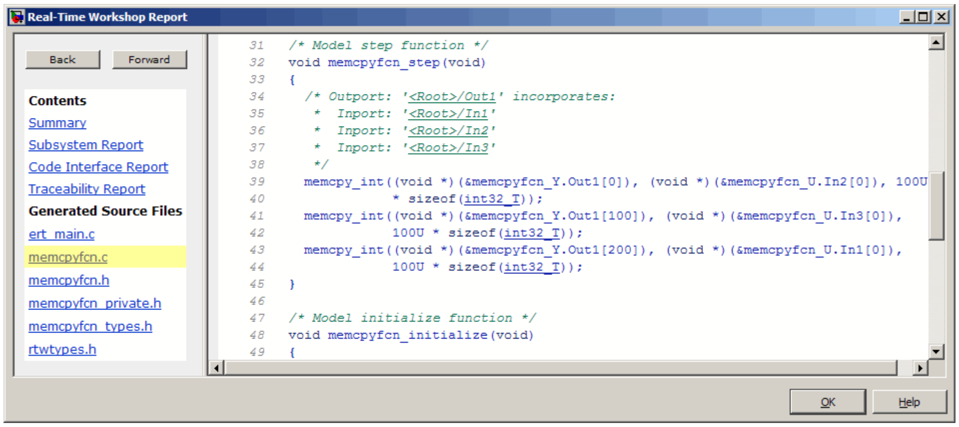


**c** Select an ERT-based system target file on the **Real-Time Workshop** pane of the Configuration Parameters dialog box, and select the TFL you registered, `Memcpy Function Example`, on the **Interface** pane. You should also select a fixed-step solver on the **Solver** pane. Leave the `memcpy` options on the **Optimization** pane at their default settings, that is, **Use memcpy for vector assignment** selected, and **Memcpy threshold (bytes)** at `64`. Apply the changes.

**d** Open Model Explorer and configure the **Signal Attributes** for the `In1`, `In2`, and `In3` source blocks. For each, set **Port dimensions** to `[1,100]`, and set **Data type** to `int32`. Apply the changes. Save the model. In this example, the model is saved to the name `memcpyfcn.mdl`.

**6** Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the **Create code generation report**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model. When code generation completes, the HTML code generation report is displayed.

**7** In the HTML code generation report, click on the *`model`*`.c` section (for example, `memcpyfcn.c`) and inspect the model step function to confirm that `memcpy` has been replaced with `memcpy_int` in the generated code.



```
/* Model step function */
void memcpyfcn_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Inport: '<Root>/In2'
   *  Inport: '<Root>/In3'
   */
  memcpy_int((void *)(&memcpyfcn_Y.Out1[0]), (void *)(&memcpyfcn_U.In2[0]), 100U
             * sizeof(int32_T));
  memcpy_int((void *)(&memcpyfcn_Y.Out1[100]), (void *)(&memcpyfcn_U.In3[0]),
             100U * sizeof(int32_T));
  memcpy_int((void *)(&memcpyfcn_Y.Out1[200]), (void *)(&memcpyfcn_U.In1[0]),
             100U * sizeof(int32_T));
}

/* Model initialize function */
void memcpyfcn_initialize(void)
{
```

## Example: Mapping Nonfinite Support Utility Functions to Target-Specific Implementations

The Real-Time Workshop Embedded Coder software supports the following nonfinite support utility functions for replacement with custom library functions using target function library (TFL) tables.

```
GetInf
GetMinusInf
GetNaN
```

The following example uses the method described in “General Method for Creating Function and Operator Entries” on page 30-20 to create TFL table entries for the nonfinite functions.

1 Create and save the following TFL table definition file, `tfl_table_nonfinite.m`. This file defines a TFL table containing function replacement entries for the nonfinite functions.

   For each nonfinite function, the function body uses the local function `locAddFcnEnt` to create entries for `single` and `double` replacement. For each entry, the local function sets selected function entry parameters, creates the `y1` and `u1` conceptual arguments individually, and then copies the conceptual arguments to the implementation arguments. Finally the function entry is added to the table.

```
function hTable = tfl_table_nonfinite()
%TFL_TABLE_NONFINITE - Describe function entries for a TFL table.

hTable = RTW.TflTable;

%% Create entries for nonfinite support utility functions
%locAddFcnEnt(hTable, key,          implName,        out,      in1,    hdr )
locAddFcnEnt(hTable, 'getNaN',      'getNaN',       'double', 'void', 'nonfin.h');
locAddFcnEnt(hTable, 'getNaN',      'getNaNF',      'single', 'void', 'nonfin.h');
locAddFcnEnt(hTable, 'getInf',      'getInf',       'double', 'void', 'nonfin.h');
locAddFcnEnt(hTable, 'getInf',      'getInfF',      'single', 'void', 'nonfin.h');
locAddFcnEnt(hTable, 'getMinusInf', 'getMinusInf',  'double', 'void', 'nonfin.h');
locAddFcnEnt(hTable, 'getMinusInf', 'getMinusInfF', 'single', 'void', 'nonfin.h');

%% Local Function
function locAddFcnEnt(hTable, key, implName, out, in1, hdr)
  if isempty(hTable)
    return;
  end

  fcn_entry = RTW.TflCFunctionEntry;
  setTflCFunctionEntryParameters(fcn_entry, ...
                                 'Key', key, ...
                                 'Priority', 90, ...
                                 'ImplementationName', implName, ...
```

```
                                  'ImplementationHeaderFile', hdr);

  arg = getTflArgFromString(hTable, 'y1', out);
  arg.IOType = 'RTW_IO_OUTPUT';
  addConceptualArg(fcn_entry, arg);

  arg = getTflArgFromString(hTable, 'u1', in1);
  addConceptualArg(fcn_entry, arg);

  copyConceptualArgsToImplementation(fcn_entry);

  addEntry(hTable, fcn_entry);

  %EOF
```

**2** Optionally, perform a quick check of the validity of the nonfinite function entries by invoking the table definition file at the MATLAB command line (>> `tbl = tfl_table_nonfinite`) and by viewing it in the TFL Viewer (>> `RTW.viewTfl(tfl_table_nonfinite)`). For more information about validating TFL tables, see “Examining and Validating Function Replacement Tables” on page 30-119.

**3** Create and save the following TFL registration file, which references the `tfl_table_nonfinite` table.

The file specifies that the TFL to be registered is named `'Nonfinite Functions Example'` and consists of `tfl_table_nonfinite`, with the default ANSI[11] math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_nonfinite
```

11. ANSI® is a registered trademark of the American National Standards Institute, Inc.

```
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Nonfinite Functions Example';
  thisTfl.Description = 'Demonstration of nonfinite functions replacement';
  thisTfl.TableList = {'tfl_table_nonfinite'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

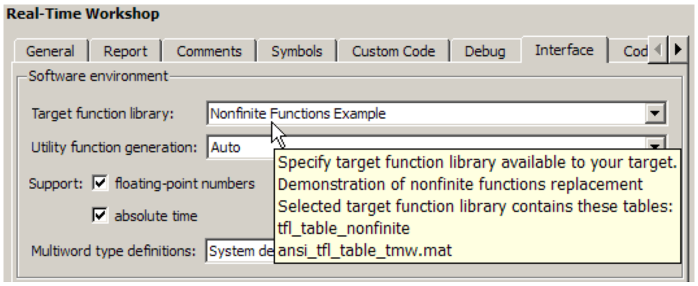
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see "Registering Target Function Libraries" on page 30-128.

4. With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



Software environment

Target function library: Nonfinite Functions Example

Utility function generation: Auto

Support: ☑ floating-point numbers

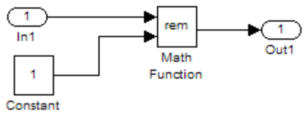
☑ absolute time

Multiword type definitions: System de

Specify target function library available to your target.
Demonstration of nonfinite functions replacement
Selected target function library contains these tables:
tfl_table_nonfinite
ansi_tfl_table_tmw.mat

Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `Nonfinite Functions Example`.

**5** Create an ERT-based model with a Math Function block set to the `rem` function, such as the following:

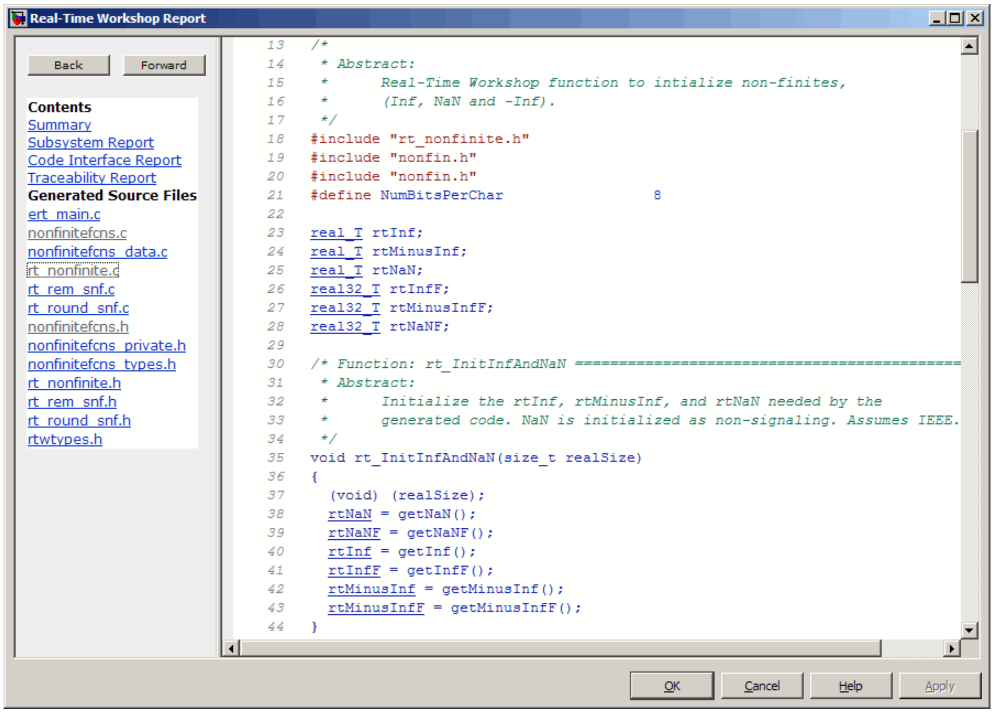


Open Model Explorer. Select the **Support: non-finite numbers** parameter on the **Real-Time Workshop > Interface** pane of the Configuration Parameters dialog box and configure the **Signal Attributes** for the `In1` and `Constant` source blocks. For each source block, set **Data type** to `double`. Apply the changes. Save the model. In this example, the model is saved to the name `nonfinitefcns.mdl`.

Make sure that the TFL you registered, `Nonfinite Functions Example`, is selected for this model.

**6** Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the option **Create code generation report**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

**7** In the HTML code generation report, click on the `rtnonfinite.c` link and inspect the `rt_InitInfAndNaN` function to confirm that your replacements for nonfinite support functions are present in the generated code.



```
/*
 * Abstract:
 *      Real-Time Workshop function to intialize non-finites,
 *      (Inf, NaN and -Inf).
 */
#include "rt_nonfinite.h"
#include "nonfin.h"
#include "nonfin.h"
#define NumBitsPerChar                 8

real_T rtInf;
real_T rtMinusInf;
real_T rtNaN;
real32_T rtInfF;
real32_T rtMinusInfF;
real32_T rtNaNF;

/* Function: rt_InitInfAndNaN ============================================
 * Abstract:
 *      Initialize the rtInf, rtMinusInf, and rtNaN needed by the
 *      generated code. NaN is initialized as non-signaling. Assumes IEEE.
 */
void rt_InitInfAndNaN(size_t realSize)
{
  (void) (realSize);
  rtNaN = getNaN();
  rtNaNF = getNaNF();
  rtInf = getInf();
  rtInfF = getInfF();
  rtMinusInf = getMinusInf();
  rtMinusInfF = getMinusInfF();
}
```

## Example: Mapping Scalar Operators to Target-Specific Implementations

The Real-Time Workshop Embedded Coder software supports the following scalar operators for replacement with custom library functions using target function library (TFL) tables:

- + (addition)
-   (subtraction)
- * (multiplication)
- / (division)
- Data type conversion (cast)
- Fixed-point << (shift left)

The following example uses the method described in “General Method for Creating Function and Operator Entries” on page 30-20 to create a TFL table entry for the + (addition) operator.

1 Create and save the following TFL table definition file, `tfl_table_add_uint8.m`. This file defines a TFL table containing an operator replacement entry for the + (addition) operator.

   The function body sets selected addition operator entry parameters, creates the `y1`, `u1`, and `u2` conceptual arguments individually, and then copies the conceptual arguments to the implementation arguments. Finally, the operator entry is added to the table.

```
function hTable = tfl_table_add_uint8
%TFL_TABLE_ADD_UINT8 - Describe operator entry for a Target Function Library table.

hTable = RTW.TflTable;

% Create entry for addition of built-in uint8 data type
% Saturation on, Rounding no preference
op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
                    'Key',                        'RTW_OP_ADD', ...
                    'Priority',                   90, ...
                    'SaturationMode',             'RTW_SATURATE_ON_OVERFLOW', ...
                    'RoundingMode',               'RTW_ROUND_UNSPECIFIED', ...
                    'ImplementationName',         'u8_add_u8_u8', ...
                    'ImplementationHeaderFile', 'u8_add_u8_u8.h', ...
                    'ImplementationSourceFile', 'u8_add_u8_u8.c' );

arg = getTflArgFromString(hTable, 'y1', 'uint8');
arg.IOType = 'RTW_IO_OUTPUT';
addConceptualArg(op_entry, arg);

arg = getTflArgFromString(hTable, 'u1', 'uint8');
addConceptualArg(op_entry, arg );

arg = getTflArgFromString(hTable, 'u2', 'uint8');
addConceptualArg(op_entry, arg );
```

```
copyConceptualArgsToImplementation(op_entry);

addEntry(hTable, op_entry);
```

2 Optionally, perform a quick check of the validity of the operator entry by invoking the table definition file at the MATLAB command line (>> `tbl = tfl_table_add_uint8`) and by viewing it in the TFL Viewer (>> `RTW.viewTfl(tfl_table_add_uint8)`).

   For more information about validating TFL tables, see "Examining and Validating Function Replacement Tables" on page 30-119.

3 Create and save the following TFL registration file, which references the `tfl_table_add_uint8` table.

   The file specifies that the TFL to be registered is named `'Addition Operator Example'` and consists of `tfl_table_add_uint8`, with the default ANSI math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_add_uint8
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Addition Operator Example';
  thisTfl.Description = 'Demonstration of addition operator replacement';
  thisTfl.TableList = {'tfl_table_add_uint8'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};
```

```
end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

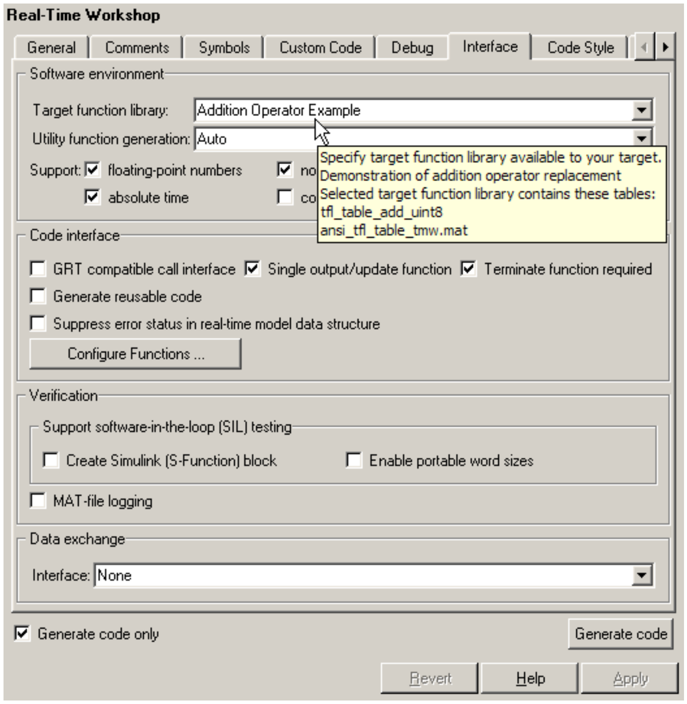
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see “Registering Target Function Libraries” on page 30-128.

4 With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---


Real-Time Workshop

General | Comments | Symbols | Custom Code | Debug | Interface | Code Style

Software environment

Target function library: Addition Operator Example

Utility function generation: Auto

Support: ☑ floating-point numbers ☑ no

☑ absolute time ☐ co

Specify target function library available to your target.
Demonstration of addition operator replacement
Selected target function library contains these tables:
tfl_table_add_uint8
ansi_tfl_table_tmw.mat

Code interface

☐ GRT compatible call interface ☑ Single output/update function ☑ Terminate function required

☐ Generate reusable code

☐ Suppress error status in real-time model data structure

Configure Functions ...

Verification

Support software-in-the-loop (SIL) testing

☐ Create Simulink (S-Function) block ☐ Enable portable word sizes

☐ MAT-file logging

Data exchange

Interface: None

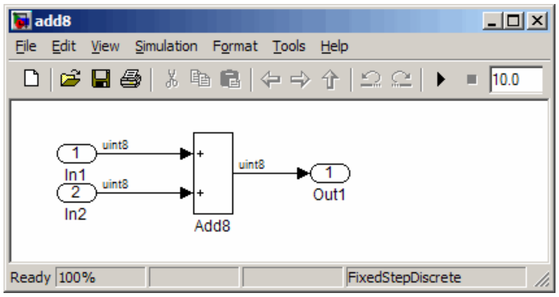
☑ Generate code only

Generate code

Revert Help Apply

Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `Addition Operator Example`.

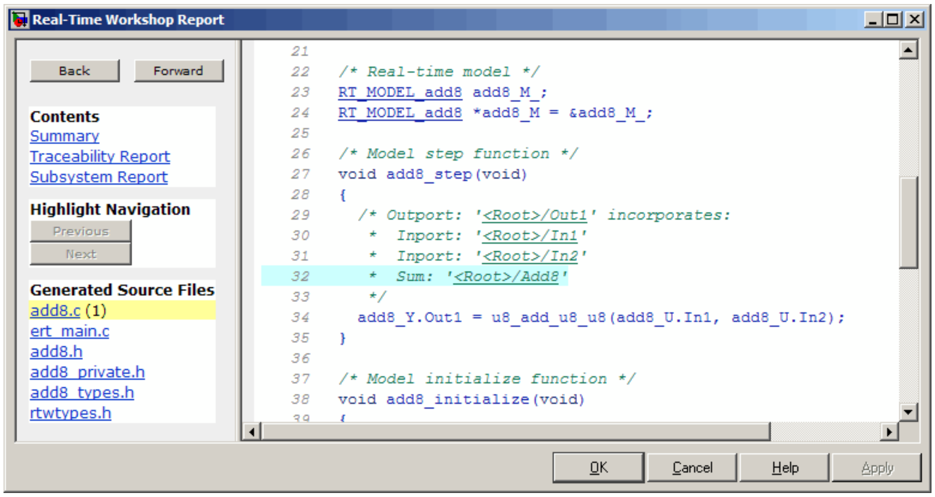
**5** Create an ERT-based model with an Add block, such as the following:



Make sure that the TFL you registered, `Addition Operator Example`, is selected for this model.

**6** Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

**7** Go to the model window and use model-to-code highlighting to trace the code generated using your TFL entry. For example, right-click the Add block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the Sum block code within the model step function in `add8.c`. In this case, code containing the + operator has been replaced with `u8_add_u8_u8` in the generated code.



```

/* Real-time model */
RT_MODEL_add8 add8_M_;
RT_MODEL_add8 *add8_M = &add8_M_;

/* Model step function */
void add8_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Inport: '<Root>/In2'
   *  Sum: '<Root>/Add8'
   */
  add8_Y.Out1 = u8_add_u8_u8(add8_U.In1, add8_U.In2);
}

/* Model initialize function */
void add8_initialize(void)
{
```

## Mapping Nonscalar Operators to Target-Specific Implementations

- "Example: Mapping Small Matrix Operations to Processor-Specific Intrinsic Functions" on page 30-48
- "Example: Mapping Matrix Multiplication to MathWorks BLAS Functions" on page 30-55

- "Example: Mapping Matrix Multiplication to ANSI/ISO C BLAS Functions" on page 30-66

The Real-Time Workshop Embedded Coder software supports the following nonscalar operators for replacement with custom library functions using target function library (TFL) tables:

`+` (addition)
(subtraction)
`*` (matrix multiplication)
`.*` (array multiplication)
`'` (matrix transposition)
`.'` (array transposition)

Supported data types include `single`, `double`, `int8`, `uint8`, `int16`, `uint16`, `int32`, and `uint32`, their complex equivalents (for example, `cint32`), and fixed-point integers.

---

**Note**

- TFL table entries for nonscalar addition and subtraction support only homogeneous input data types. For example, you cannot use both `int8` and `int16`.
- Saturation and rounding mode are ignored for floating-point nonscalar addition and subtraction. In TFL table entries for nonscalar addition and subtraction, if the argument data types are all floating-point, you should register `'RTW_ROUND_UNSPECIFIED'` for the `RoundingMode` and `SaturationMode` parameters to `setTflCOperationEntryParameters`.

---

## Example: Mapping Small Matrix Operations to Processor-Specific Intrinsic Functions

You can efficiently implement small matrix operations by invoking processor-specific intrinsic functions. The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry mapping small matrix sum operations to implementation functions that could invoke processor-specific intrinsic functions.

---

**Note** For examples of replacing other matrix operations and handling other data types, see the Matrix Operator Replacement section of the TFL demos page `rtwdemo_tfl_script`, including the demo model `rtwdemo_tflmatops` and its associated files.

---

**1** Create and save the following TFL table definition file, `tfl_table_matrix_add_double.m`. This file defines a TFL table containing two matrix operator replacement entries for the `+` (addition) operator and the `double` data type.

The function body sets selected addition operator entry parameters, creates the `y1`, `u1`, and `u2` conceptual arguments individually, and then configures the implementation arguments. Finally, the operator entry is added to the table.

To specify a matrix argument to `createAndAddConceptualArg`, use the TFL argument class `RTW.TflArgMatrix` and specify the base type and the dimensions for which the argument is valid. In this example, the first table entry specifies `[2 2]` and the second table entry specifies `[3 3]`.

```
function hTable = tfl_table_matrix_add_double
%TFL_TABLE_MATRIX_ADD_DOUBLE - Describe two matrix operator entries for a TFL table.

hTable = RTW.TflTable;

LibPath = fullfile(matlabroot, 'toolbox', 'rtw', 'rtwdemos', 'tfl_demo');

% Create table entry for matrix_sum_2x2_double
op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
    'Key',                      'RTW_OP_ADD', ...
    'Priority',                 30, ...
    'SaturationMode',           'RTW_WRAP_ON_OVERFLOW', ...
    'ImplementationName',       'matrix_sum_2x2_double', ...
    'ImplementationHeaderFile', 'MatrixMath.h', ...
    'ImplementationSourceFile', 'MatrixMath.c', ...
    'ImplementationHeaderPath', LibPath, ...
    'ImplementationSourcePath', LibPath, ...
    'AdditionalIncludePaths',   {LibPath}, ...
    'GenCallback',              'RTW.copyFileToBuildDir', ...
    'SideEffects',              true);

% Specify operands and result
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix',...
                          'Name',         'u1', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix',...
                          'Name',         'u2', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2]);

% Specify replacement function signature
arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);
arg = getTflArgFromString(hTable, 'u1', ['double' '*']);
op_entry.Implementation.addArgument(arg);
arg = getTflArgFromString(hTable, 'u2', ['double' '*']);
op_entry.Implementation.addArgument(arg);
arg = getTflArgFromString(hTable, 'y1', ['double' '*']);
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);

% Create table entry for matrix_sum_3x3_double
op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
    'Key',                      'RTW_OP_ADD', ...
    'Priority',                 30, ...
    'SaturationMode',           'RTW_WRAP_ON_OVERFLOW', ...
    'ImplementationName',       'matrix_sum_3x3_double', ...
    'ImplementationHeaderFile', 'MatrixMath.h', ...
    'ImplementationSourceFile', 'MatrixMath.c', ...
    'ImplementationHeaderPath', LibPath, ...
    'ImplementationSourcePath', LibPath, ...
    'AdditionalIncludePaths',   {LibPath}, ...
    'GenCallback',              'RTW.copyFileToBuildDir', ...
    'SideEffects',              true);

% Specify operands and result
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'BaseType',     'double', ...
                          'DimRange',     [3 3]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix',...
                          'Name',         'u1', ...
                          'BaseType',     'double', ...
                          'DimRange',     [3 3]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix',...
                          'Name',         'u2', ...
                          'BaseType',     'double', ...
                          'DimRange',     [3 3]);

% Specify replacement function signature
arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);
arg = getTflArgFromString(hTable, 'u1', ['double' '*']);
op_entry.Implementation.addArgument(arg);
arg = getTflArgFromString(hTable, 'u2', ['double' '*']);
op_entry.Implementation.addArgument(arg);
arg = getTflArgFromString(hTable, 'y1', ['double' '*']);
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);
```

2 Optionally, perform a quick check of the validity of the operator entries by invoking the table definition file at the MATLAB command line (`>> tbl = tfl_table_matrix_add_double`) and by viewing it in the TFL Viewer (`>> RTW.viewTfl(tfl_table_matrix_add_double)`).

   For more information about validating TFL tables, see "Examining and Validating Function Replacement Tables" on page 30-119.

3 Create and save the following TFL registration file, which references the `tfl_table_matrix_add_double` table.

   The file specifies that the TFL to be registered is named `'Matrix Addition Operator Example'` and consists of `tfl_table_matrix_add_double`, with the default ANSI math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_matrix_add_double
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Matrix Addition Operator Example';
  thisTfl.Description = 'Demonstration of matrix addition operator replacement';
  thisTfl.TableList = {'tfl_table_matrix_add_double'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

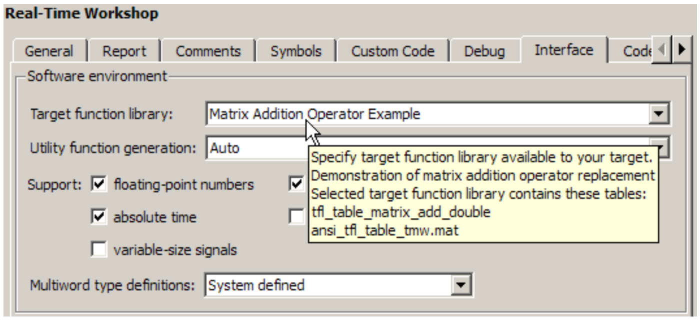
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see "Registering Target Function Libraries" on page 30-128.

4 With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



Target function library: Matrix Addition Operator Example

Utility function generation: Auto

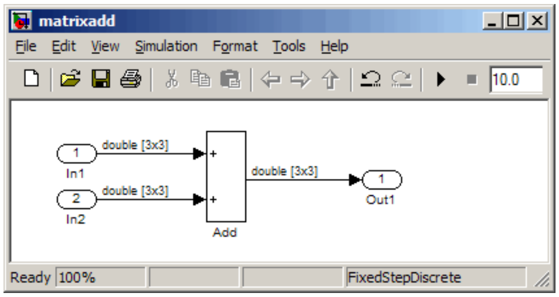
Specify target function library available to your target.
Demonstration of matrix addition operator replacement
Selected target function library contains these tables:
tfl_table_matrix_add_double
ansi_tfl_table_tmw.mat

Support: ✓ floating-point numbers ✓ absolute time ☐ variable-size signals

Multiword type definitions: System defined

Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `Matrix Addition Operator Example`.

5 Create an ERT-based model with an Add block, such as the following:

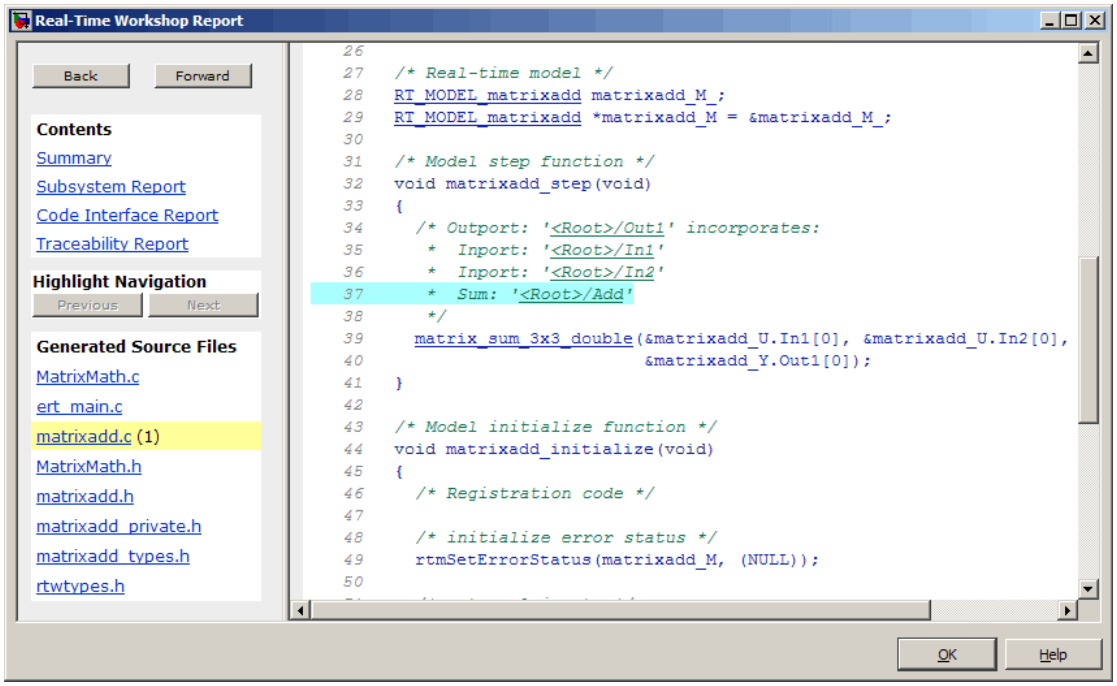


Configure the **Signal Attributes** for the `In1` and `In2` source blocks. For each source block, set **Port dimensions** to `[3 3]` and set the **Data type** to `double`. Also, go to the **Solver** pane of the Configuration Parameters dialog box and select a fixed-step, discrete solver with a fixed-step size such as `0.1`. Apply the changes. Save the model. In this example, the model is saved to the name `matrixadd.mdl`.

Make sure that the TFL you registered, `Matrix Addition Operator Example`, is selected for this model.

6 Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

7 Go to the model window and use model-to-code highlighting to trace the code generated using your TFL entry. For example, right-click the Add block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the Sum block code within the model step function in `matrixadd.c`. In this case, code containing the + operator has been replaced with `matrix_sum_3x3_double` in the generated code.



```

/* Real-time model */
RT_MODEL_matrixadd matrixadd_M_;
RT_MODEL_matrixadd *matrixadd_M = &matrixadd_M_;

/* Model step function */
void matrixadd_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Inport: '<Root>/In2'
   *  Sum: '<Root>/Add'
   */
  matrix_sum_3x3_double(&matrixadd_U.In1[0], &matrixadd_U.In2[0],
                        &matrixadd_Y.Out1[0]);
}

/* Model initialize function */
void matrixadd_initialize(void)
{
  /* Registration code */

  /* initialize error status */
  rtmSetErrorStatus(matrixadd_M, (NULL));

```

**Note** Optionally, you can reconfigure the In1 and In2 block **Port dimensions** to `[2 2]`, regenerate code, and observe that code containing the + operator is replaced with `matrix_sum_2x2_double`.

## Example: Mapping Matrix Multiplication to MathWorks BLAS Functions

You can use TFL tables to map nonscalar multiplication operations to the Basic Linear Algebra Subroutine (BLAS) multiplication functions `xgemm` and `xgemv`. The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry mapping floating-point matrix/matrix and matrix/vector multiplication operations to MathWorks BLAS library multiplication functions.

**Note** For examples of handling other data types, see the BLAS Support section of the TFL demos page `rtwdemo_tfl_script`, including the demo model `rtwdemo_tflblas` and its associated files.

Although BLAS libraries support matrix/matrix multiplication in the form of $C = aA*B + bC$, TFLs support only the limited case of $C = A*B\ (a = 1.0, b = 0.0)$. Correspondingly, although BLAS libraries support matrix/vector multiplication in the form of $y=aAx + by$, TFLs support only the limited case of $y = Ax\ (a = 1.0, b = 0.0)$.

1 Create and save the following TFL table definition file, `tfl_table_tmwblas_mmult_double.m`. This file defines a TFL table containing `dgemm` and `dgemv` replacement entries for the matrix multiplication operator and the `double` data type.

  For each entry, the function body sets selected matrix multiplication operator entry parameters, creates the `y1`, `u1`, and `u2` conceptual arguments individually, and then configures special implementation arguments that are required for `dgemm` and `dgemv` replacements. Finally, each operator entry is added to the table.

  To specify a matrix argument to `createAndAddConceptualArg`, use the TFL argument class `RTW.TflArgMatrix` and specify the base type and the dimensions for which the argument is valid. This type of table entry supports a range of dimensions specified in the format `[Dim1Min Dim2Min ... DimNMin; Dim1Max Dim2Max ... DimNMax]`. For example, `[2 2; inf inf]` means any two-dimensional matrix of size 2x2 or larger. In this example, the conceptual output argument for the `dgemm32` entry for matrix/matrix multiplication replacement specifies dimensions `[2 2; inf inf]`, while the conceptual output argument for the `dgemv32` entry for matrix/vector multiplication replacement specifies dimensions `[2 1; inf 1]`.

```
function hTable = tfl_table_tmwblas_mmult_double
%TFL_TABLE_TMWBLAS_MMULT_DOUBLE - Describe two mmult operator entries for TFL table.

hTable = RTW.TflTable;
```

```
% Define library path for Windows or UNIX
arch = computer('arch');
if ~ispc
    LibPath = fullfile('$(MATLAB_ROOT)', 'bin', arch);
else
    % Use Stateflow to get the compiler info
    compilerInfo = sf('Private','compilerman','get_compiler_info');
    compilerName = compilerInfo.compilerName;
    if strcmp(compilerName, 'msvc90') || ...
            strcmp(compilerName, 'msvc80') || ...
            strcmp(compilerName, 'msvc71') || ...
            strcmp(compilerName, 'msvc60'), ...
            compilerName = 'microsoft';
    end
    LibPath = fullfile('$(MATLAB_ROOT)', 'extern', 'lib', arch, compilerName);
end

% Create table entry for dgemm32
op_entry = RTW.TflBlasEntryGenerator;
if ispc
    libExt = 'lib';
elseif ismac
    libExt = 'dylib';
else
    libExt = 'so';
end
setTflCOperationEntryParameters(op_entry, ...
    'Key',                      'RTW_OP_MUL', ...
    'Priority',                 100, ...
    'ImplementationName',       'dgemm32', ...
    'ImplementationHeaderFile', 'blascompat32.h', ...
    'ImplementationHeaderPath', fullfile('$(MATLAB_ROOT)','extern','include'), ...
    'AdditionalLinkObjs',       {['libmwblascompat32.' libExt]}, ...
    'AdditionalLinkObjsPaths',  {LibPath}, ...
    'SideEffects',              true);

% Specify operands and result
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2; inf inf]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'u1', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2; inf inf]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'u2', ...
                          'BaseType',     'double', ...
                          'DimRange',     [1 1; inf inf]);

% Using RTW.TflBlasEntryGenerator for xgemm requires the following
% implementation signature:
%
% void f(char* TRANSA, char* TRANSB, int* M, int* N, int* K,
%        type* ALPHA, type* u1, int* LDA, type* u2, int* LDB,
%        type* BETA, type* y, int* LDC)
%
% Upon a successful match, the TFL entry will compute the correct
% values for M, N, K, LDA, LDB, and LDC and insert them into the
% generated code. TRANSA and TRANSB both will be set to 'N'.

% Specify replacement function signature

arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);

arg = RTW.TflArgCharConstant('TRANSA');
% Possible values for PassByType property are
%  RTW_PASSBY_AUTO, RTW_PASSBY_POINTER,
%  RTW_PASSBY_VOID_POINTER, RTW_PASSBY_BASE_POINTER
arg.PassByType = 'RTW_PASSBY_POINTER';
op_entry.Implementation.addArgument(arg);

arg = RTW.TflArgCharConstant('TRANSB');
arg.PassByType = 'RTW_PASSBY_POINTER';
op_entry.Implementation.addArgument(arg);
```

```
arg = getTflArgFromString(hTable, 'M', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'N', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'K', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'ALPHA', 'double', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u1', ['double' '*']);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDA', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u2', ['double' '*']);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDB', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);
```

```
arg = getTflArgFromString(hTable, 'BETA', 'double', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'y1', ['double' '*']);
arg.IOType = 'RTW_IO_OUTPUT';
arg.PassByType = 'RTW_PASSBY_POINTER';
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDC', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);

% Create table entry for dgemv32
op_entry = RTW.TflBlasEntryGenerator;
if ispc
    libExt = 'lib';
elseif ismac
    libExt = 'dylib';
else
    libExt = 'so';
end
setTflCOperationEntryParameters(op_entry, ...
    'Key',                      'RTW_OP_MUL', ...
    'Priority',                 100, ...
    'ImplementationName',       'dgemv32', ...
    'ImplementationHeaderFile', 'blascompat32.h', ...
    'ImplementationHeaderPath', fullfile('$(MATLAB_ROOT)','extern','include'), ...
    'AdditionalLinkObjs',       {['libmwblascompat32.' libExt]}, ...
    'AdditionalLinkObjsPaths',  {LibPath},...
    'SideEffects',              true);

% Specify operands and result
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
```

```
                           'BaseType',      'double', ...
                           'DimRange',      [2 1; inf 1]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                           'Name',          'u1', ...
                           'BaseType',      'double', ...
                           'DimRange',      [2 2; inf inf]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix',...
                           'Name',          'u2', ...
                           'BaseType',      'double', ...
                           'DimRange',      [1 1; inf 1]);

% Using RTW.TflBlasEntryGenerator for xgemv requires the following
% implementation signature:
%
% void f(char* TRANS, int* M, int* N,
%        type* ALPHA, type* u1, int* LDA, type* u2, int* INCX,
%        type* BETA, type* y, int* INCY)
%
% Upon a successful match, the TFL entry will compute the correct
% values for M, N, LDA, INCX, and INCY, and insert them into the
% generated code. TRANS will be set to 'N'.

% Specify replacement function signature

arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);

arg = RTW.TflArgCharConstant('TRANS');
arg.PassByType = 'RTW_PASSBY_POINTER';
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'M', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'N', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
```

```
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'ALPHA', 'double', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u1', ['double' '*']);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDA', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u2', ['double' '*']);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'INCX','integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'BETA', 'double', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'y1', ['double' '*']);
arg.IOType = 'RTW_IO_OUTPUT';
arg.PassByType = 'RTW_PASSBY_POINTER';
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'INCY', 'integer', 0);
arg.PassByType = 'RTW_PASSBY_POINTER';
arg.Type.ReadOnly = true;
```

```
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);
```

2 Optionally, perform a quick check of the validity of the operator entries by invoking the table definition file at the MATLAB command line (`>> tbl = tfl_table_tmwblas_mmult_double`) and by viewing it in the TFL Viewer (`>> RTW.viewTfl(tfl_table_tmwblas_mmult_double)`).

   For more information about validating TFL tables, see "Examining and Validating Function Replacement Tables" on page 30-119.

3 Create and save the following TFL registration file, which references the `tfl_table_tmwblas_mmult_double` table.

   The file specifies that the TFL to be registered is named `'MathWorks BLAS Matrix Multiplication Operator Example'` and consists of `tfl_table_tmwblas_mmult_double`, with the default ANSI math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_tmwblas_mmult_double
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'MathWorks BLAS Matrix Multiplication Operator Example';
  thisTfl.Description = 'Demonstration of MathWorks BLAS mmult operator replacement';
  thisTfl.TableList = {'tfl_table_tmwblas_mmult_double'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};
```

```
    end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

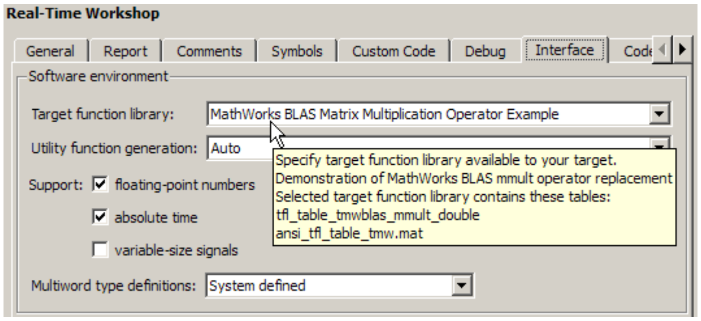
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see "Registering Target Function Libraries" on page 30-128.

4 With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



Target function library: MathWorks BLAS Matrix Multiplication Operator Example

Utility function generation: Auto

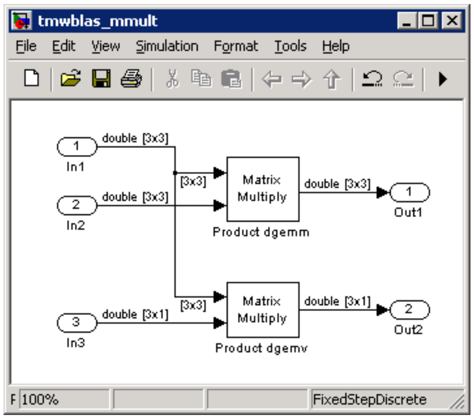
Support: ☑ floating-point numbers ☑ absolute time ☐ variable-size signals

Multiword type definitions: System defined

Specify target function library available to your target.
Demonstration of MathWorks BLAS mmult operator replacement
Selected target function library contains these tables:
tfl_table_tmwblas_mmult_double
ansi_tfl_table_tmw.mat

Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `MathWorks BLAS Matrix Multiplication Operator Example`.

**5** Create an ERT-based model with two Product blocks, such as the following:



**a** For each Product block, set the block parameter **Multiplication** to the value `Matrix(*)`.

**b** Configure the **Signal Attributes** for the `In1`, `In2`, and `In3` source blocks. For `In1` and `In2`, set **Port dimensions** to `[3 3]` and set the **Data type** to `double`. For `In3`, set **Port dimensions** to `[3 1]` and set the **Data type** to `double`.

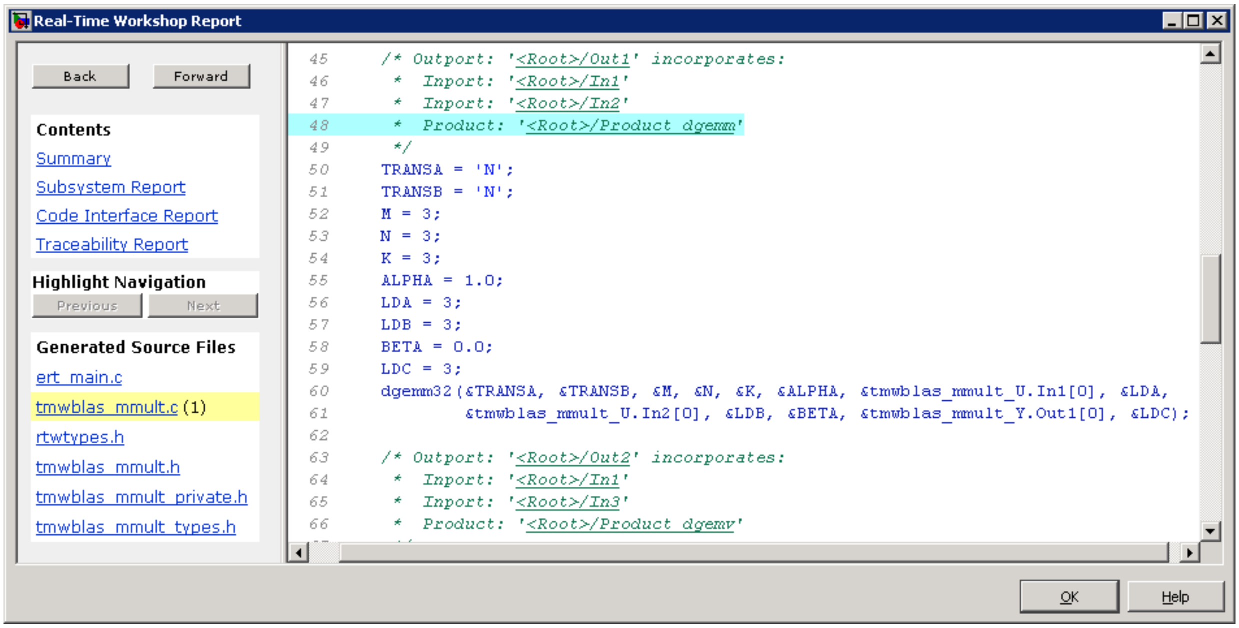
**c** Also, go to the **Solver** pane of the Configuration Parameters dialog box and select a fixed-step, discrete solver with a fixed-step size such as `0.1`. Apply the changes.

**d** Save the model. In this example, the model is saved to the name `tmwblas_mmult.mdl`.

**e** Make sure that the TFL you registered, `MathWorks BLAS Matrix Multiplication Operator Example`, is selected for this model.

**6** Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

**7** Go to the model window and use model-to-code highlighting to trace the code generated using your TFL entry. For example, right-click the top Product block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the Product block code within the model step function in `tmwblas_mmult.c`. In this case, code containing the matrix multiplication operator has been replaced with a call to `dgemm32` in the generated code.



```
    /* Outport: '<Root>/Out1' incorporates:
     *  Import: '<Root>/In1'
     *  Import: '<Root>/In2'
     *  Product: '<Root>/Product dgemm'
     */
    TRANSA = 'N';
    TRANSB = 'N';
    M = 3;
    N = 3;
    K = 3;
    ALPHA = 1.0;
    LDA = 3;
    LDB = 3;
    BETA = 0.0;
    LDC = 3;
    dgemm32(&TRANSA, &TRANSB, &M, &N, &K, &ALPHA, &tmwblas_mmult_U.In1[0], &LDA,
            &tmwblas_mmult_U.In2[0], &LDB, &BETA, &tmwblas_mmult_Y.Out1[0], &LDC);

    /* Outport: '<Root>/Out2' incorporates:
     *  Import: '<Root>/In1'
     *  Import: '<Root>/In3'
     *  Product: '<Root>/Product dgemv'
```

## Example: Mapping Matrix Multiplication to ANSI/ISO C BLAS Functions

You can use TFL tables to map nonscalar multiplication operations to the ANSI/ISO C BLAS multiplication functions `xgemm` and `xgemv`. The following example uses the method described in “General Method for Creating Function and Operator Entries” on page 30-20 to create a TFL table entry mapping floating-point matrix/matrix and matrix/vector multiplication operations to ANSI/ISO C BLAS library multiplication functions.

**Note** For examples of handling other data types, see the BLAS Support section of the TFL demos page `rtwdemo_tfl_script`, including the demo model `rtwdemo_tflblas` and its associated files.

Although BLAS libraries support matrix/matrix multiplication in the form of $C = aA*B + bC$, TFLs support only the limited case of $C = A*B\ (a = 1.0, b = 0.0)$. Correspondingly, although BLAS libraries support matrix/vector multiplication in the form of $y=aAx + by$, TFLs support only the limited case of $y = Ax\ (a = 1.0, b = 0.0)$.

1 Create and save the following TFL table definition file, `tfl_table_cblas_mmult_double.m`. This file defines a TFL table containing `dgemm` and `dgemv` replacement entries for the matrix multiplication operator and the `double` data type.

   For each entry, the function body sets selected matrix multiplication operator entry parameters, creates the `y1`, `u1`, and `u2` conceptual arguments individually, and then configures special implementation arguments that are required for `dgemm` and `dgemv` replacements. Finally, each operator entry is added to the table.

   To specify a matrix argument to `createAndAddConceptualArg`, use the TFL argument class `RTW.TflArgMatrix` and specify the base type and the dimensions for which the argument is valid. This type of table entry supports a range of dimensions specified in the format `[Dim1Min Dim2Min ...  DimNMin; Dim1Max Dim2Max ...  DimNMax]`. For example, `[2 2; inf inf]` means any two-dimensional matrix of size 2x2 or larger. In this example, the conceptual output argument for the `cblas_dgemm` entry for matrix/matrix multiplication replacement specifies dimensions `[2 2; inf inf]`, while the conceptual output argument for the `cblas_dgemv` entry for matrix/vector multiplication replacement specifies dimensions `[2 1; inf 1]`.

```
function hTable = tfl_table_cblas_mmult_double
%TFL_TABLE_CBLAS_MMULT_DOUBLE - Describe two mmult operator entries for TFL table.

hTable = RTW.TflTable;
```

```
LibPath = fullfile(matlabroot, 'toolbox', 'rtw', 'rtwdemos', 'tfl_demo');

% Create table entry for cblas_dgemm
op_entry = RTW.TflCBlasEntryGenerator;
setTflCOperationEntryParameters(op_entry, ...
    'Key',                      'RTW_OP_MUL', ...
    'Priority',                 100, ...
    'ImplementationName',       'cblas_dgemm', ...
    'ImplementationHeaderFile', 'cblas.h', ...
    'ImplementationHeaderPath', LibPath, ...
    'AdditionalIncludePaths',   {LibPath}, ...
    'GenCallback',              'RTW.copyFileToBuildDir', ...
    'SideEffects',              true);

% Specify operands and result
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2; inf inf]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'u1', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2; inf inf]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'u2', ...
                          'BaseType',     'double', ...
                          'DimRange',     [1 1; inf inf]);

% Using RTW.TflCBlasEntryGenerator for xgemm requires the following
% implementation signature:
%
% void f(enum ORDER, enum TRANSA, enum TRANSB, int M, int N, int K,
%        type ALPHA, type* u1, int LDA, type* u2, int LDB,
%        type BETA, type* y, int LDC)
%
% Since TFLs do not have the ability to specify enums, you must
% use integer.  (This will cause problems with C++ code generation,
% so for C++, use a wrapper function to cast each int to the
% appropriate enumeration type.)
%
% Upon a successful match, the TFL entry will compute the correct
% values for M, N, K, LDA, LDB, and LDC and insert them into the
% generated code.

% Specify replacement function signature

arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);

arg = getTflArgFromString(hTable, 'ORDER', 'integer', 102);
%arg.Type.ReadOnly=true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'TRANSA', 'integer', 111);
%arg.Type.ReadOnly=true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'TRANSB', 'integer', 111);
%arg.Type.ReadOnly=true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'M', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'N', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'K', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'ALPHA', 'double', 1);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u1', ['double' '*']);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDA', 'integer', 0);
```

```
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u2', ['double' '*']);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDB', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'BETA', 'double', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'y1', ['double' '*']);
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDC', 'integer', 0);
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);

% Create table entry for cblas_dgemv
op_entry = RTW.TflCBlasEntryGenerator;
setTflCOperationEntryParameters(op_entry, ...
    'Key',                        'RTW_OP_MUL', ...
    'Priority',                   100, ...
    'ImplementationName',         'cblas_dgemv', ...
    'ImplementationHeaderFile',   'cblas.h', ...
    'ImplementationHeaderPath',   LibPath, ...
    'AdditionalIncludePaths',     {LibPath}, ...
    'GenCallback',                'RTW.copyFileToBuildDir', ...
    'SideEffects',                true);

% Specify operands and result
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 1; inf 1]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix', ...
                          'Name',         'u1', ...
                          'BaseType',     'double', ...
                          'DimRange',     [2 2; inf inf]);
createAndAddConceptualArg(op_entry, 'RTW.TflArgMatrix',...
                          'Name',         'u2', ...
                          'BaseType',     'double', ...
                          'DimRange',     [1 1; inf 1]);

% Using RTW.TflCBlasEntryGenerator for xgemv requires the following
% implementation signature:
%
% void f(enum ORDER, enum TRANSA, int M, int N,
%        type ALPHA, type* u1, int LDA, type* u2, int INCX,
%        type BETA, type* y, int INCY)
%
% Since TFLs do not have the ability to specify enums, you must
% use integer.  (This will cause problems with C++ code generation,
% so for C++, use a wrapper function to cast each int to the
% appropriate enumeration type.)
%
% Upon a successful match, the TFL entry will compute the correct
% values for M, N, LDA, INCX, and INCY and insert them into the
% generated code.

% Specify replacement function signature

arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);

arg = getTflArgFromString(hTable, 'ORDER', 'integer', 102);
%arg.Type.ReadOnly=true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'TRANSA', 'integer', 111);
%arg.Type.ReadOnly=true;
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'M','integer', 0);
op_entry.Implementation.addArgument(arg);
```

```
arg = getTflArgFromString(hTable, 'N', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'ALPHA', 'double', 1);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u1', ['double' '*']);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'LDA', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u2', ['double' '*']);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'INCX', 'integer', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'BETA', 'double', 0);
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'y1', ['double' '*']);
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'INCY', 'integer', 0);
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);
```

2 Optionally, perform a quick check of the validity of the operator entries by invoking the table definition file at the MATLAB command line (`>> tbl = tfl_table_cblas_mmult_double`) and by viewing it in the TFL Viewer (`>> RTW.viewTFL(tfl_table_cblas_mmult_double)`).

   For more information about validating TFL tables, see "Examining and Validating Function Replacement Tables" on page 30-119.

3 Create and save the following TFL registration file, which references the `tfl_table_cblas_mmult_double` table.

The file specifies that the TFL to be registered is named `'ANSI/ISO C BLAS Matrix Multiplication Operator Example'` and consists of `tfl_table_cblas_mmult_double`, with the default ANSI math library as the base TFL table.

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_cblas_mmult_double
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'ANSI/ISO C BLAS Matrix Multiplication Operator Example';
  thisTfl.Description = 'Demonstration of C BLAS mmult operator replacement';
  thisTfl.TableList = {'tfl_table_cblas_mmult_double'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

Place this `sl_customization.m` file in the MATLAB search path or in the current working directory, so that the TFL is registered at each Simulink startup.

---

**Tip** To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`. (To refresh Embedded MATLAB Coder TFL registration information within a MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.)

---

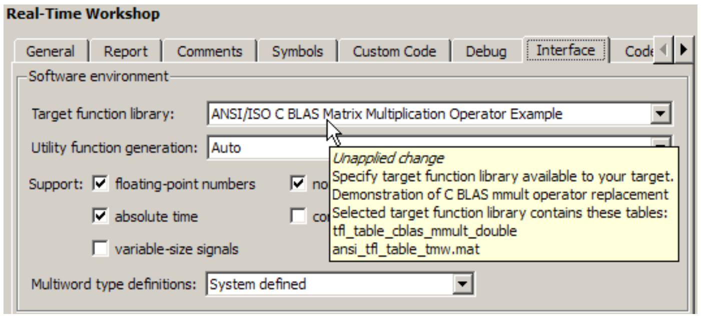
For more information about registering TFLs with Simulink or Embedded MATLAB Coder software, see “Registering Target Function Libraries” on page 30-128.

4 With your `sl_customization.m` file in the MATLAB search path or in the current working directory, open an ERT-based Simulink model and navigate to the **Interface** pane of the Configuration Parameters dialog box. Verify that the **Target function library** option lists the TFL name you specified and select it.

---

**Note** If you hover over the selected library with the cursor, a tool tip appears. This tip provides information derived from your TFL registration file, such as the TFL description and the list of tables it contains.

---



Real-Time Workshop

Software environment

Target function library: ANSI/ISO C BLAS Matrix Multiplication Operator Example

Utility function generation: Auto

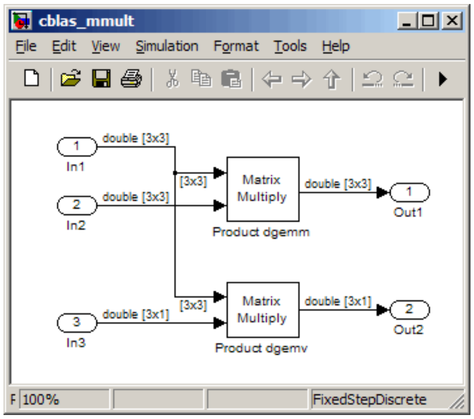
Support: ☑ floating-point numbers ☑ absolute time ☐ variable-size signals

Multiword type definitions: System defined

*Unapplied change*
Specify target function library available to your target.
Demonstration of C BLAS mmult operator replacement
Selected target function library contains these tables:
tfl_table_cblas_mmult_double
ansi_tfl_table_tmw.mat

Optionally, you can relaunch the TFL Viewer, using the MATLAB command `RTW.viewTFL` with no argument, to examine all registered TFLs, including `ANSI/ISO C BLAS Matrix Multiplication Operator Example`.

5 Create an ERT-based model with two Product blocks, such as the following:

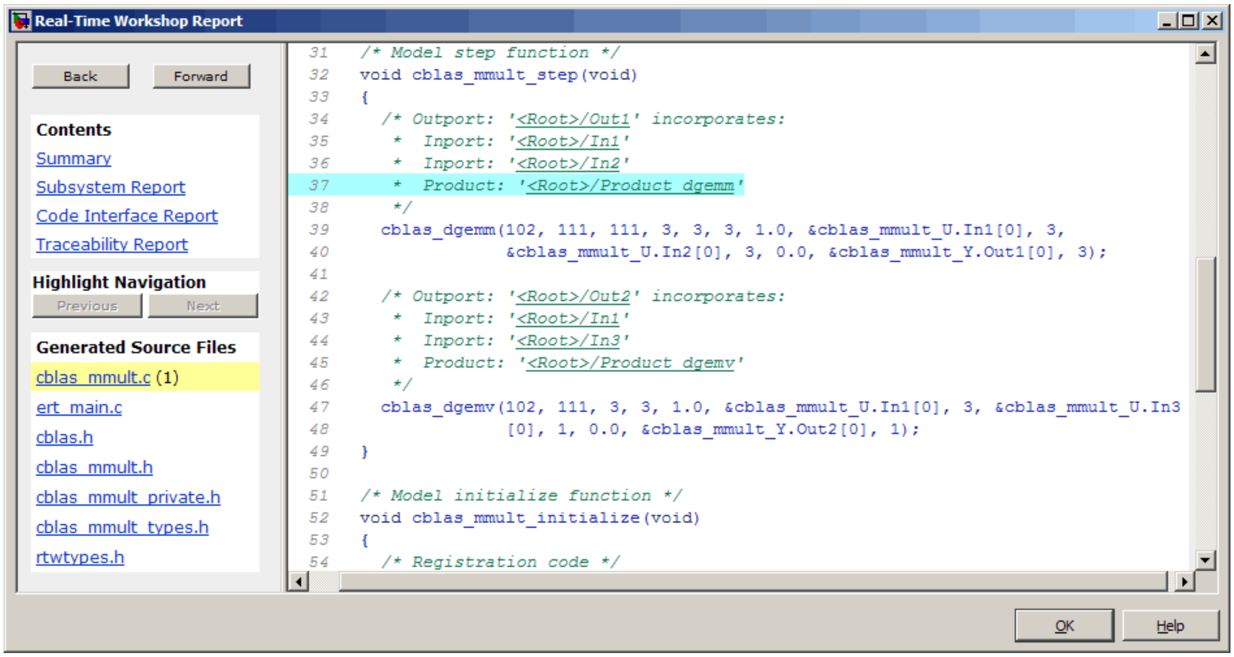


- **a** For each Product block, set the block parameter **Multiplication** to the value `Matrix(*)`.
- **b** Configure the **Signal Attributes** for the `In1`, `In2`, and `In3` source blocks. For `In1` and `In2`, set **Port dimensions** to `[3 3]` and set the **Data type** to `double`. For `In3`, set **Port dimensions** to `[3 1]` and set the **Data type** to `double`.
- **c** Also, go to the **Solver** pane of the Configuration Parameters dialog box and select a fixed-step, discrete solver with a fixed-step size such as `0.1`. Apply the changes.
- **d** Save the model. In this example, the model is saved to the name `cblas_mmult.mdl`.
- **e** Make sure that the TFL you registered, `ANSI/ISO C BLAS Matrix Multiplication Operator Example`, is selected for this model.

6. Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**. Then go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

7. Go to the model window and use model-to-code highlighting to trace the code generated using your TFL entry. For example, right-click the top Product block and select **Real-Time Workshop > Navigate to Code**. This selection highlights the Product block code within the model step function in `cblas_mmult.c`. In this case, code containing the matrix

multiplication operator has been replaced with a call to `cblas_dgemm` in the generated code.



```
/* Model step function */
void cblas_mmult_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Inport: '<Root>/In2'
   *  Product: '<Root>/Product_dgemm'
   */
  cblas_dgemm(102, 111, 111, 3, 3, 3, 1.0, &cblas_mmult_U.In1[0], 3,
              &cblas_mmult_U.In2[0], 3, 0.0, &cblas_mmult_Y.Out1[0], 3);

  /* Outport: '<Root>/Out2' incorporates:
   *  Inport: '<Root>/In1'
   *  Inport: '<Root>/In3'
   *  Product: '<Root>/Product_dgemv'
   */
  cblas_dgemv(102, 111, 3, 3, 1.0, &cblas_mmult_U.In1[0], 3, &cblas_mmult_U.In3
              [0], 1, 0.0, &cblas_mmult_Y.Out2[0], 1);
}

/* Model initialize function */
void cblas_mmult_initialize(void)
{
  /* Registration code */
```

## Mapping Fixed-Point Operators to Target-Specific Implementations

### Overview of Fixed-Point Operator Replacement

The Real-Time Workshop Embedded Coder software supports TFL-based function replacement for the following scalar operations on fixed-point data types:

- + (addition)
- (subtraction)
- * (multiplication)
- / (division)
- Data type conversion (cast)
- Fixed-point << (shift left)

Fixed-point operator table entries can be defined as matching:

- A specific binary-point-only scaling combination on the operator inputs and output.
- A specific [slope bias] scaling combination on the operator inputs and output.
- Relative scaling or net slope between multiplication or division operator inputs and output.

  Use these methods to map a range of slope and bias values to a replacement function for multiplication or division.
- Equal slope and zero net bias across addition or subtraction operator inputs and output.

  Use this method to disregard specific slope and bias values and map relative slope and bias values to a replacement function for addition or subtraction.

---

**Note**

- The demo `rtwdemo_tflfixpt` demonstrates these replacements and provides example tables that can be used as a starting point for customization.
- Using fixed-point data types in a model requires a Simulink Fixed Point license.
- The fixed-point terminology used in this section is defined and explained in the *Simulink Fixed Point User's Guide*. See especially "Fixed-Point Numbers" and "Arithmetic Operations".

---

## Fixed-Point Numbers and Arithmetic

Fixed-point numbers use integers and integer arithmetic to represent real numbers and arithmetic with the following encoding scheme:

$$V = \tilde{V} = SQ + B$$

where

- $V$ is an arbitrarily precise real-world value.
- $\tilde{V}$ is the approximate real-world value that results from fixed-point representation.
- $Q$ is an integer that encodes $\tilde{V}$, referred to as the *quantized integer*.
- $S$ is a coefficient of $Q$, referred to as the *slope*.
- $B$ is an additive correction, referred to as the *bias*.

The general equation for an operation between fixed-point operands is as follows:

$$(S_O Q_O + B_O) = (S_1 Q_1 + B_1) < op > (S_2 Q_2 + B_2)$$

The objective of TFL fixed-point operator replacement is to replace an operator that accepts and returns fixed-point or integer inputs and output with a function that accepts and returns built-in C numeric data types (not fixed-point data types). The following sections provide additional programming information for each supported operator.

## Addition

The operation $V_0 = V_1 + V_2$ implies that

$$Q_0 = \left(\frac{S_1}{S_0}\right) Q_1 + \left(\frac{S_2}{S_0}\right) Q_2 + \left(\frac{B_1 + B_2 - B_0}{S_0}\right)$$

If an addition replacement function is defined such that the scaling on the operands and sum are equal and the net bias

$$\left(\frac{B_1 + B_2 - B_0}{S_0}\right)$$

is zero (for example, a function `s8_add_s8_s8` that adds two signed 8-bit values and produces a signed 8-bit result), then the TFL operator entry must set the operator entry parameters `SlopesMustBeTheSame` and `MustHaveZeroNetBias` to `true`. (For parameter descriptions, see the reference page for the function `setTflCOperationEntryParameters`.)

## Subtraction

The operation $V_0 = V_1 - V_2$ implies that

$$Q_0 = \left(\frac{S_1}{S_0}\right)Q_1 - \left(\frac{S_2}{S_0}\right)Q_2 + \left(\frac{B_1 - B_2 - B_0}{S_0}\right)$$

If a subtraction replacement function is defined such that the scaling on the operands and difference are equal and the net bias

$$\left(\frac{B_1 - B_2 - B_0}{S_0}\right)$$

is zero (for example, a function `s8_sub_s8_s8` that subtracts two signed 8-bit values and produces a signed 8-bit result), then the TFL operator entry must set the operator entry parameters `SlopesMustBeTheSame` and `MustHaveZeroNetBias` to `true`. (For parameter descriptions, see the reference page for the function `setTflCOperationEntryParameters`.)

## Multiplication

There are different ways to specify multiplication replacements. The most direct way is to specify an exact match of the input and output types. This is feasible if a model contains only a few (known) slope and bias combinations. For this, use the `TflCOperationEntry` class and specify the exact values of slope and bias on each argument. For scenarios where there are numerous slope/bias combinations, it is not feasible to specify each value with a different TFL entry. For this, use a relative scaling factor (RSF) entry or a net slope entry:

- **Relative scaling factor (RSF) entry:**

  The operation $V_0 = V_1 * V_2$ implies, for binary-point-only scaling, that

  $$S_0Q_0 = (S_1Q_1)(S_2Q_2)$$
  $$Q_0 = \left(\frac{S_1S_2}{S_0}\right)Q_1Q_1$$
  $$Q_0 = S_nQ_1Q$$

  where $S_n$ is the net slope.

  Multiplication replacement functions may be defined such that all scaling is contained by a single operand. For example, a replacement function `s8_mul_s8_u8_rsf0p125` can multiply a signed 8-bit value by a factor of `[0 ... 0.1245]` and produce a signed 8-bit result. The following discussion describes how to convert the slope on each operand into a net factor.

  To match a multiplication operation to the `s8_mul_s8_u8_rsf0p125` replacement function, $0 <= S_nQ_2 <= 2^{-3}$. Substituting the maximum integer value for $Q_2$ results in the following match criteria: When $S_n2^8 = 2^{-3}$, or $S_n = 2^{-11}$, TFL replacement processing maps the multiplication operation to the `s8_mul_s8_u8_rsf0p125` function.

  To accomplish this mapping, the TFL operator entry must define a *relative scaling factor*, $F2^E$, where the values for $F$ and $E$ are provided using operator entry parameters `RelativeScalingFactorF` and `RelativeScalingFactorE`. (For parameter descriptions, see the reference page for the function `setTflCOperationEntryParameters`.) For the `s8_mul_s8_u8_rsf0p125` function, the `RelativeScalingFactorF` would be set to 1 and the `RelativeScalingFactorE` would be set to -3.

  ---

  **Note** When an operator entry specifies `RelativeScalingFactorF` and `RelativeScalingFactorE`, zero bias is implied for the inputs and output.

  ---

- **Net slope entry:**

  Net slope entries are similar to the relative scaling factor entry described above. The difference is the match criteria. For a net slope entry, the net slope of the call-site operation, $S_n$, must match the specified net slope, $S_n = F2^E$, without regard to the maximum integer value. Specify the desired net slope $F$ and $E$ values using operator entry parameters `NetSlopeAdjustmentFactor` and `NetFixedExponent`. (For parameter descriptions, see the reference page for the function `setTflCOperationEntryParameters`.)

**Note** When an operator entry specifies `NetSlopeAdjustmentFactor` and `NetFixedExponent`, matching entries must have arguments with zero bias.

## Division

There are different ways to specify division replacements. The most direct way is to specify an exact match of the input and output types. This is feasible if a model contains only a few (known) slope and bias combinations. For this, use the `TflCOperationEntry` class and specify the exact values of slope and bias on each argument. For scenarios where there are numerous slope/bias combinations, it is not feasible to specify each value with a different TFL entry. For this, use a relative scaling factor (RSF) entry or a net slope entry:

- **Relative scaling factor (RSF) entry:**

  The operation $V_0 = (V_1 \,/\, V_2)$ implies, for binary-point-only scaling, that

$$S_0 Q_0 = \left( \frac{S_1 Q_1}{S_2 Q_2} \right)$$

$$Q_0 = S_n \left( \frac{Q_1}{Q_2} \right)$$

  where $S_n$ is the net slope.

  As with multiplication, division replacement functions may be defined such that all scaling is contained by a single operand. For example, a replacement function `s16_rsf0p5_div_s16_s16` can divide a signed 16<<16 value by a signed 16-bit value and produce a signed 16-bit result.

The following discussion describes how to convert the slope on each operand into a net factor.

To match a division operation to the `s16_rsf0p5_div_s16_s16` replacement function, $0 <= S_n Q_1 <= 2^{-1}$. Substituting the maximum integer value for $Q_1$ results in the following match criteria: When $S_n 2^{15} = 2^{-1}$, or $S_n = 2^{-16}$, TFL replacement processing maps the division operation to the `s8_mul_s8_u8_rsf0p125` function.

To accomplish this mapping, the TFL operator entry must define a *relative scaling factor*, $F2^E$, where the values for $F$ and $E$ are provided using operator entry parameters `RelativeScalingFactorF` and `RelativeScalingFactorE`. (For parameter descriptions, see the reference page for the function `setTflCOperationEntryParameters`.) For the `s16_rsf0p5_div_s16_s16` function, the `RelativeScalingFactorF` would be set to 1 and the `RelativeScalingFactorE` would be set to -1.

**Note** When an operator entry specifies `RelativeScalingFactorF` and `RelativeScalingFactorE`, zero bias is implied for the inputs and output.

- **Net slope entry:**

  Net slope entries are similar to the relative scaling factor entry described above. The difference is the match criteria. For a net slope entry, the net slope of the call-site operation, $S_n$, must match the specified net slope, $S_n = F2^E$, without regard to the maximum integer value. Specify the desired net slope $F$ and $E$ values using operator entry parameters `NetSlopeAdjustmentFactor` and `NetFixedExponent`. (For parameter descriptions, see the reference page for the function `setTflCOperationEntryParameters`.)

**Note** When an operator entry specifies `NetSlopeAdjustmentFactor` and `NetFixedExponent`, matching entries must have arguments with zero bias.

### Data Type Conversion (Cast)

The data type conversion operation $V_0 = V_1$ implies, for binary-point-only scaling, that

$$Q_0 = \left(\frac{S_1}{S_0}\right)Q_1$$
$$Q_0 = S_n Q_1$$

where $S_n$ is the net slope.

### Shift Left

The shift left operation $V_0 = (V_1 \ / \ 2^n)$ implies, for binary-point-only scaling, that

$$S_0 Q_0 = \left(\frac{S_1 Q_1}{2^n}\right)$$
$$Q_0 = \left(\frac{S_1}{S_0}\right) + \left(\frac{Q_1}{2^n}\right)$$
$$Q_0 = S_n\left(\frac{Q_1}{2^n}\right)$$

where $S_n$ is the net slope.

## Creating Fixed-Point Operator Entries

To create TFL table entries for fixed-point operators, you use the "General Method for Creating Function and Operator Entries" on page 30-20 and specify fixed-point parameter/value pairs to the functions shown in the following table.

| Function | Description |
|---|---|
| `createAndAddConceptualArg` | Create conceptual argument from specified properties and add to conceptual arguments for TFL table entry |
| `createAndAddImplementationArg` | Create implementation argument from specified properties and add to implementation arguments for TFL table entry |
| `createAndSetCImplementationReturn` | Create implementation return argument from specified properties and add to implementation for TFL table entry |
| `setTflCOperationEntryParameters` | Set specified parameters for operator entry in TFL table |

The following table maps some common methods of matching TFL fixed-point operator table entries to the associated fixed-point parameters that you need to specify in your TFL table definition file.

| To match... | Instantiate class... | Minimally specify parameters... |
|---|---|---|
| A specific binary-point-only scaling combination on the operator inputs and output<br><br>See "Example: Creating Fixed-Point Operator Entries for Binary-Point-Only Scaling" on page 30-87. | `RTW.TflCOperationEntry` | `createAndAddConceptualArg` function:<br>• `CheckSlope`: Specify the value `true`.<br>• `CheckBias`: Specify the value `true`.<br>• `DataTypeMode` (or `DataType/Scaling` equivalent): Specify fixed-point binary-point-only scaling.<br>• `FractionLength`: Specify a fraction length (for example, 3). |
| A specific [slope bias] scaling combination on the operator inputs and output<br><br>See "Example: Creating | `RTW.TflCOperationEntry` | `createAndAddConceptualArg` function:<br>• `CheckSlope`: Specify the value `true`.<br>• `CheckBias`: Specify the value `true`.<br>• `DataTypeMode` (or `DataType/Scaling` equivalent): Specify fixed-point [slope bias] scaling. |

| To match... | Instantiate class... | Minimally specify parameters... |
|---|---|---|
| Fixed-Point Operator Entries for [Slope Bias] Scaling" on page 30-90. | | • `Slope` (or `SlopeAdjustmentFactor/-FixedExponent` equivalent): Specify a slope value (for example, `15`).<br>• `Bias`: Specify a bias value (for example, `2`). |
| Relative scaling between operator inputs and output (multiplication and division)<br><br>See "Example: Creating Fixed-Point Operator Entries for Relative Scaling (Multiplication and Division)" on page 30-94. | `RTW.TflCOperationEntry-Generator` | `setTflCOperationEntryParameters` function:<br>• `RelativeScalingFactorF`: Specify the slope adjustment factor (`F`) part of the relative scaling factor, `F2`$^{E}$ (for example, `1.0`).<br>• `RelativeScalingFactorE`: Specify the fixed exponent (`E`) part of the relative scaling factor, `F2`$^{E}$ (for example, `-3.0`).<br><br>`createAndAddConceptualArg` function:<br>• `CheckSlope`: Specify the value `false`.<br>• `CheckBias`: Specify the value `false`.<br>• `DataType`: Specify the value `'Fixed'`. |
| Net slope between operator inputs and output (multiplication and division)<br><br>See "Example: Creating Fixed-Point Operator Entries for Net Slope | `RTW.TflCOperationEntry-Generator_NetSlope` | `setTflCOperationEntryParameters` function:<br>• `NetSlopeAdjustmentFactor`: Specify the slope adjustment factor (`F`) part of the net slope, `F2`$^{E}$ (for example, `1.0`).<br>• `NetFixedExponent`: Specify the fixed exponent (`E`) part of the net slope, `F2`$^{E}$ (for example, `-3.0`).<br><br>`createAndAddConceptualArg` function: |

| To match... | Instantiate class... | Minimally specify parameters... |
|---|---|---|
| (Multiplication and Division)” on page 30-97. | | • `CheckSlope`: Specify the value `false`.<br>• `CheckBias`: Specify the value `false`.<br>• `DataType`: Specify the value `'Fixed'`. |
| Equal slope and zero net bias across operator inputs and output (addition and subtraction)<br><br>See “Example: Creating Fixed-Point Operator Entries for Equal Slope and Zero Net Bias (Addition and Subtraction)” on page 30-100. | `RTW.TflCOperationEntry-Generator` | `setTflCOperationEntryParameters` function:<br>• `SlopesMustBeTheSame`: Specify the value `true`.<br>• `MustHaveZeroNetBias`: Specify the value `true`.<br><br>`createAndAddConceptualArg` function:<br>• `CheckSlope`: Specify the value `false`.<br>• `CheckBias`: Specify the value `false`. |

### Example: Creating Fixed-Point Operator Entries for Binary-Point-Only Scaling

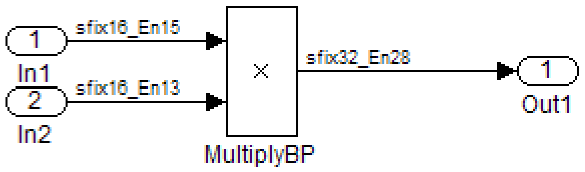
TFL table entries for operations on fixed-point data types can be defined as matching a specific binary-point-only scaling combination on the operator inputs and output. These binary-point-only scaling entries can map the specified binary-point-scaling combination to a replacement function for addition, subtraction, multiplication, or division.

The following example uses the method described in “General Method for Creating Function and Operator Entries” on page 30-20 to create a TFL table entry for multiplication of fixed-point data types where arguments are specified with binary-point-only scaling. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntry` class.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (multiplication), the saturation mode (saturate on overflow), the rounding mode (unspecified), and the name of the replacement function (`s32_mul_s16_s16_binarypoint`).
- The function `createAndAddConceptualArg` is called to create and add conceptual output and input arguments to the operator entry. Each argument specifies that the data type is fixed-point, the mode is binary-point-only scaling, and its derived slope and bias values must exactly match the call-site slope and bias values. The output argument is 32 bits, signed, with a fraction length of 28, while the input arguments are 16 bits, signed, with fraction lengths of 15 and 13.
- The functions `createAndSetCImplementationReturn` and `createAndAddImplementationArg` are called to create and add implementation output and input arguments to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types). In this case, the output argument is 32 bits and signed (`int32`) and the input arguments are 16 bits and signed (`int16`).

```
hTable = RTW.TflTable;

op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
                    'Key',                      'RTW_OP_MUL', ...
                    'Priority',                 90, ...
                    'SaturationMode',           'RTW_SATURATE_ON_OVERFLOW', ...
                    'RoundingMode',             'RTW_ROUND_UNSPECIFIED', ...
                    'ImplementationName',       's32_mul_s16_s16_binarypoint', ...
                    'ImplementationHeaderFile', 's32_mul_s16_s16_binarypoint.h', ...
                    'ImplementationSourceFile', 's32_mul_s16_s16_binarypoint.c');

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric',...
                          'Name',           'y1', ...
                          'IOType',         'RTW_IO_OUTPUT', ...
                          'CheckSlope',     true, ...
                          'CheckBias',      true, ...
                          'DataTypeMode',   'Fixed-point: binary point scaling', ...
                          'IsSigned',       true, ...
                          'WordLength',     32, ...
                          'FractionLength', 28);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u1', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'CheckSlope',     true, ...
                          'CheckBias',      true, ...
                          'DataTypeMode',   'Fixed-point: binary point scaling', ...
                          'IsSigned',       true, ...
                          'WordLength',     16, ...
                          'FractionLength', 15);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u2', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'CheckSlope',     true, ...
                          'CheckBias',      true, ...
                          'DataTypeMode',   'Fixed-point: binary point scaling', ...
                          'IsSigned',       true, ...
                          'WordLength',     16, ...
                          'FractionLength', 13);

createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                              'Name',           'y1', ...
                              'IOType',         'RTW_IO_OUTPUT', ...
                              'IsSigned',       true, ...
                              'WordLength',     32, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',           'u1', ...
                              'IOType',         'RTW_IO_INPUT', ...
                              'IsSigned',       true, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',          'u2', ...
                              'IOType',        'RTW_IO_INPUT', ...
                              'IsSigned',      true, ...
                              'WordLength',    16, ...
                              'FractionLength', 0);

addEntry(hTable, op_entry);
```

To generate code using this table entry, you can follow the general procedure in "Example: Mapping Scalar Operators to Target-Specific Implementations" on page 30-42, substituting in the code above and an ERT-based model such as the following:



For this model,

- Set the Inport 1 **Data type** to `fixdt(1,16,15)`
- Set the Inport 2 **Data type** to `fixdt(1,16,13)`
- In the Product block:
  - Set **Output data type** to `fixdt(1,32,28)`
  - Select the option **Saturate on integer overflow**

## Example: Creating Fixed-Point Operator Entries for [Slope Bias] Scaling

TFL table entries for operations on fixed-point data types can be defined as matching a specific [slope bias] scaling combination on the operator inputs and output. These [slope bias] scaling entries can map the specified [slope bias] combination to a replacement function for addition, subtraction, multiplication, or division.

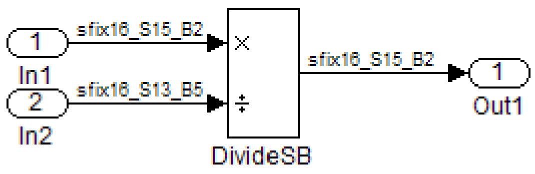
The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry for division of fixed-point data types where arguments are specified using [slope bias] scaling. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntry` class.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (division), the saturation mode (saturate on overflow), the rounding mode (round to ceiling), and the name of the replacement function (`s16_div_s16_s16_slopebias`).
- The function `createAndAddConceptualArg` is called to create and add conceptual output and input arguments to the operator entry. Each argument specifies that the data type is fixed-point, the mode is [slope bias] scaling, and its specified slope and bias values must exactly match the call-site slope and bias values. The output argument and input arguments are 16 bits, signed, each with specific [slope bias] specifications.
- The functions `createAndSetCImplementationReturn` and `createAndAddImplementationArg` are called to create and add implementation output and input arguments to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types). In this case, the output and input arguments are 16 bits and signed (`int16`).

```
hTable = RTW.TflTable;

op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
                    'Key',                      'RTW_OP_DIV', ...
                    'Priority',                 90, ...
                    'SaturationMode',           'RTW_SATURATE_ON_OVERFLOW', ...
                    'RoundingMode',             'RTW_ROUND_CEILING', ...
                    'ImplementationName',       's16_div_s16_s16_slopebias', ...
                    'ImplementationHeaderFile', 's16_div_s16_s16_slopebias.h', ...
                    'ImplementationSourceFile', 's16_div_s16_s16_slopebias.c');

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'y1', ...
                          'IOType',         'RTW_IO_OUTPUT', ...
                          'CheckSlope',     true, ...
                          'CheckBias',      true, ...
                          'DataTypeMode',   'Fixed-point: slope and bias scaling', ...
                          'IsSigned',       true, ...
                          'WordLength',     16, ...
                          'Slope',          15, ...
                          'Bias',           2);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u1', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'CheckSlope',     true, ...
                          'CheckBias',      true, ...
                          'DataTypeMode',   'Fixed-point: slope and bias scaling', ...
                          'IsSigned',       true, ...
                          'WordLength',     16, ...
                          'Slope',          15, ...
                          'Bias',           2);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u2', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'CheckSlope',     true, ...
                          'CheckBias',      true, ...
                          'DataTypeMode',   'Fixed-point: slope and bias scaling', ...
                          'IsSigned',       true, ...
                          'WordLength',     16, ...
                          'Slope',          13, ...
                          'Bias',           5);

createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                              'Name',           'y1', ...
                              'IOType',         'RTW_IO_OUTPUT', ...
                              'IsSigned',       true, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',           'u1', ...
                              'IOType',         'RTW_IO_INPUT', ...
```

```
                                        'IsSigned',       true, ...
                                        'WordLength',     16, ...
                                        'FractionLength', 0);

    createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                                        'Name',           'u2', ...
                                        'IOType',         'RTW_IO_INPUT', ...
                                        'IsSigned',       true, ...
                                        'WordLength',     16, ...
                                        'FractionLength', 0);

    addEntry(hTable, op_entry);
```

To generate code using this table entry, you can follow the general procedure in "Example: Mapping Scalar Operators to Target-Specific Implementations" on page 30-42, substituting in the code above and an ERT-based model such as the following:



For this model,

- Set the Inport 1 **Data type** to `fixdt(1,16,15,2)`
- Set the Inport 2 **Data type** to `fixdt(1,16,13,5)`
- In the Divide block:
  - Set **Output data type** to `Inherit:  Inherit via back propagation`
  - Set **Integer rounding mode** to `Ceiling`
  - Select the option **Saturate on integer overflow**

## Example: Creating Fixed-Point Operator Entries for Relative Scaling (Multiplication and Division)

TFL table entries for multiplication or division of fixed-point data types can be defined as matching relative scaling between operator inputs and output. These relative scaling entries can map a range of slope and bias values to a replacement function for multiplication or division.

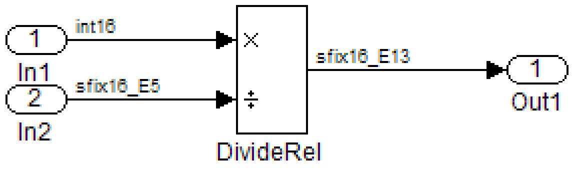
The following example uses the method described in “General Method for Creating Function and Operator Entries” on page 30-20 to create a TFL table entry for division of fixed-point data types using a relative scaling factor. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntryGenerator` class, which provides access to the fixed-point parameters `RelativeScalingFactorF` and `RelativeScalingFactorE`.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (division), the saturation mode (saturation off), the rounding mode (round to ceiling), and the name of the replacement function (`s16_div_s16_s16_rsf0p125`). Additionally, `RelativeScalingFactorF` and `RelativeScalingFactorE` are used to specify the `F` and `E` parts of the relative scaling factor $F2^{E}$.
- The function `createAndAddConceptualArg` is called to create and add conceptual output and input arguments to the operator entry. Each argument is specified as fixed-point, 16 bits, and signed. Also, each argument specifies that TFL replacement request processing should *not* check for an exact match to the call-site slope and bias values.
- The functions `createAndSetCImplementationReturn` and `createAndAddImplementationArg` are called to create and add implementation output and input arguments to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types). In this case, the output and input arguments are 16 bits and signed (`int16`).

```
hTable = RTW.TflTable;

op_entry = RTW.TflCOperationEntryGenerator;
```

```
setTflCOperationEntryParameters(op_entry, ...
                    'Key',                        'RTW_OP_DIV', ...
                    'Priority',                   90, ...
                    'SaturationMode',             'RTW_WRAP_ON_OVERFLOW', ...
                    'RoundingMode',               'RTW_ROUND_CEILING', ...
                    'RelativeScalingFactorF',     1.0, ...
                    'RelativeScalingFactorE',     -3.0, ...
                    'ImplementationName',         's16_div_s16_s16_rsf0p125', ...
                    'ImplementationHeaderFile',   's16_div_s16_s16_rsf0p125.h', ...
                    'ImplementationSourceFile',   's16_div_s16_s16_rsf0p125.c');

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',          'y1', ...
                          'IOType',        'RTW_IO_OUTPUT', ...
                          'CheckSlope',    false, ...
                          'CheckBias',     false, ...
                          'DataType',      'Fixed', ...
                          'IsSigned',      true, ...
                          'WordLength',    16);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',          'u1', ...
                          'IOType',        'RTW_IO_INPUT', ...
                          'CheckSlope',    false, ...
                          'CheckBias',     false, ...
                          'DataType',      'Fixed', ...
                          'IsSigned',      true, ...
                          'WordLength',    16);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',          'u2', ...
                          'IOType',        'RTW_IO_INPUT', ...
                          'CheckSlope',    false, ...
                          'CheckBias',     false, ...
                          'DataType',      'Fixed', ...
                          'IsSigned',      true, ...
                          'WordLength',    16);

createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                              'Name',          'y1', ...
                              'IOType',         'RTW_IO_OUTPUT', ...
                              'IsSigned',       true, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',           'u1', ...
                              'IOType',         'RTW_IO_INPUT', ...
                              'IsSigned',       true, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',           'u2', ...
                              'IOType',         'RTW_IO_INPUT', ...
                              'IsSigned',       true, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

addEntry(hTable, op_entry);
```

To generate code using this table entry, you can follow the general procedure in "Example: Mapping Scalar Operators to Target-Specific Implementations" on page 30-42, substituting in the code above and an ERT-based model such as the following:



For this model,

- Set the Inport 1 **Data type** to `int16`
- Set the Inport 2 **Data type** to `fixdt(1,16,-5)`
- In the Divide block:

- Set **Output data type** to `fixdt(1,16,-13)`
- Set **Integer rounding mode** to `Ceiling`

### Example: Creating Fixed-Point Operator Entries for Net Slope (Multiplication and Division)

TFL table entries for multiplication or division of fixed-point data types can be defined as matching net slope between operator inputs and output. These net slope entries can map a range of slope and bias values to a replacement function for multiplication or division.

The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry for division of fixed-point data types using a net slope. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntryGenerator_NetSlope` class, which provides access to the fixed-point parameters `NetSlopeAdjustmentFactor` and `NetFixedExponent`.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (division), the saturation mode (wrap on overflow), the rounding mode (unspecified), and the name of the replacement function (`user_div_*`). Additionally, `NetSlopeAdjustmentFactor` and `NetFixedExponent` are used to specify the `F` and `E` parts of the net slope $F2^E$.
- The function `createAndAddConceptualArg` is called to create and add conceptual output and input arguments to the operator entry. Each argument is specified as fixed-point and signed. Also, each argument specifies that TFL replacement request processing should *not* check for an exact match to the call-site slope and bias values.
- The function `getTflArgFromString` is called to create implementation output and input arguments that are added to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types).

```
hTable = RTW.TflTable;

wv = [16,32];
```

```
for iy = 1:2
  for inum = 1:2
    for iden = 1:2
      hTable = getDivOpEntry(hTable, ...
                             fixdt(1,wv(iy)),fixdt(1,wv(inum)),fixdt(1,wv(iden)));
    end
  end
end


%------------------------------------------------------
function hTable = getDivOpEntry(hTable,dty,dtnum,dtden)
%------------------------------------------------------
% Create an entry for division of fixed-point data types where
% arguments are specified using Slope and Bias scaling
% Saturation on, Rounding unspecified

funcStr = sprintf('user_div_%s_%s_%s',...
        typeStrFunc(dty),...
        typeStrFunc(dtnum),...
        typeStrFunc(dtden));

op_entry = RTW.TflCOperationEntryGenerator_NetSlope;
setTflCOperationEntryParameters(op_entry, ...
                                'Key',                        'RTW_OP_DIV', ...
                                'Priority',                   90, ...
                                'SaturationMode',             'RTW_WRAP_ON_OVERFLOW',...
                                'RoundingMode',               'RTW_ROUND_UNSPECIFIED',...
                                'NetSlopeAdjustmentFactor', 1.0, ...
                                'NetFixedExponent',           0.0, ...
                                'ImplementationName',         funcStr, ...
                                'ImplementationHeaderFile', [funcStr,'.h'], ...
                                'ImplementationSourceFile', [funcStr,'.c'] );

createAndAddConceptualArg(op_entry, ...
                          'RTW.TflArgNumeric', ...
                          'Name',           'y1',...
                          'IOType',         'RTW_IO_OUTPUT',...
                          'CheckSlope',     false,...
                          'CheckBias',      false,...
                          'DataTypeMode',   'Fixed-point: slope and bias scaling',...
                          'IsSigned',       dty.Signed,...
                          'WordLength',     dty.WordLength,...
                          'Bias',           0);

createAndAddConceptualArg(op_entry, ...
                          'RTW.TflArgNumeric',...
                          'Name',           'u1', ...
                          'IOType',         'RTW_IO_INPUT',...
                          'CheckSlope',     false,...
                          'CheckBias',      false,...
                          'DataTypeMode',   'Fixed-point: slope and bias scaling',...
                          'IsSigned',       dtnum.Signed,...
                          'WordLength',     dtnum.WordLength,...
                          'Bias',           0);

createAndAddConceptualArg(op_entry, ...
                          'RTW.TflArgNumeric', ...
                          'Name',           'u2', ...
                          'IOType',         'RTW_IO_INPUT',...
                          'CheckSlope',     false,...
                          'CheckBias',      false,...
                          'DataTypeMode',   'Fixed-point: slope and bias scaling',...
                          'IsSigned',       dtden.Signed,...
                          'WordLength',     dtden.WordLength,...
                          'Bias',           0);

arg = getTflArgFromString(hTable, 'y1', typeStrBase(dty));
op_entry.Implementation.setReturn(arg);

arg = getTflArgFromString(hTable, 'u1', typeStrBase(dtnum));
op_entry.Implementation.addArgument(arg);

arg = getTflArgFromString(hTable, 'u2',typeStrBase(dtden));
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);

%--------------------------------------------------------------
function str = typeStrFunc(dt)
```

```
%-------------------------------------------------------------

if dt.Signed
    sstr = 's';
else
    sstr = 'u';
end
str = sprintf('%s%d',sstr,dt.WordLength);

%-------------------------------------------------------------
function str = typeStrBase(dt)
%-------------------------------------------------------------

if dt.Signed
    sstr = ;
else
    sstr = 'u';
end
str = sprintf('%sint%d',sstr,dt.WordLength);
```

### Example: Creating Fixed-Point Operator Entries for Equal Slope and Zero Net Bias (Addition and Subtraction)

TFL table entries for addition or subtraction of fixed-point data types can be defined as matching relative slope and bias values (equal slope and zero net bias) across operator inputs and output. These entries allow you to disregard specific slope and bias values and map relative slope and bias values to a replacement function for addition or subtraction.

The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry for addition of fixed-point data types where slopes must be equal and net bias must be zero across the operator inputs and output. In this example:

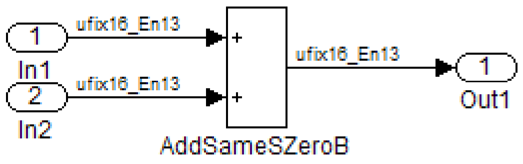
- The TFL operator entry is instantiated using the `RTW.TflCOperationEntryGenerator` class, which provides access to the fixed-point parameters `SlopesMustBeTheSame` and `MustHaveZeroNetBias`.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (addition), the saturation mode (saturation off), the

rounding mode (unspecified), and the name of the replacement function (`u16_add_SameSlopeZeroBias`). Additionally, `SlopesMustBeTheSame` and `MustHaveZeroNetBias` are set to `true` to indicate that slopes must be equal and net bias must be zero across the addition inputs and output.

- The function `createAndAddConceptualArg` is called to create and add conceptual output and input arguments to the operator entry. Each argument is specified as 16 bits and unsigned. Also, each argument specifies that TFL replacement request processing should *not* check for an exact match to the call-site slope and bias values.
- The functions `createAndSetCImplementationReturn` and `createAndAddImplementationArg` are called to create and add implementation output and input arguments to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types). In this case, the output and input arguments are 16 bits and unsigned (`uint16`).

```
hTable = RTW.TflTable;

op_entry = RTW.TflCOperationEntryGenerator;
setTflCOperationEntryParameters(op_entry, ...
                    'Key',                      'RTW_OP_ADD', ...
                    'Priority',                  90, ...
                    'SaturationMode',            'RTW_WRAP_ON_OVERFLOW', ...
                    'RoundingMode',              'RTW_ROUND_UNSPECIFIED', ...
                    'SlopesMustBeTheSame',       true, ...
                    'MustHaveZeroNetBias',       true, ...
                    'ImplementationName',        'u16_add_SameSlopeZeroBias', ...
                    'ImplementationHeaderFile', 'u16_add_SameSlopeZeroBias.h', ...
                    'ImplementationSourceFile', 'u16_add_SameSlopeZeroBias.c');

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'y1', ...
                          'IOType',         'RTW_IO_OUTPUT', ...
                          'CheckSlope',     false, ...
                          'CheckBias',      false, ...
                          'IsSigned',       false, ...
                          'WordLength',     16);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u1', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'CheckSlope',     false, ...
                          'CheckBias',      false, ...
                          'IsSigned',       false, ...
                          'WordLength',     16);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u2', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'CheckSlope',     false, ...
                          'CheckBias',      false, ...
                          'IsSigned',       false, ...
                          'WordLength',     16);

createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                              'Name',           'y1', ...
                              'IOType',         'RTW_IO_OUTPUT', ...
                              'IsSigned',       false, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',           'u1', ...
                              'IOType',         'RTW_IO_INPUT', ...
                              'IsSigned',       false, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                              'Name',           'u2', ...
                              'IOType',         'RTW_IO_INPUT', ...
                              'IsSigned',       false, ...
                              'WordLength',     16, ...
                              'FractionLength', 0);

addEntry(hTable, op_entry);
```

To generate code using this table entry, you can follow the general procedure in “Example: Mapping Scalar Operators to Target-Specific Implementations” on page 30-42, substituting in the code above and an ERT-based model such as the following:



For this model,

- Set the Inport 1 **Data type** to `fixdt(0,16,13)`
- Set the Inport 2 **Data type** to `fixdt(0,16,13)`
- In the Add block:
  - Verify that **Output data type** is set to its default, `Inherit via internal rule`
  - Set **Integer rounding mode** to `Zero`

## Mapping Data Type Conversion (Cast) Operations to Target-Specific Implementations

- "Example: Creating a TFL Entry to Replace Casts From `int32` To `int16`" on page 30-104
- "Example: Creating a TFL Entry to Replace Fixed-Point Casts Using Net Slope" on page 30-105

You can use TFL table entries to replace the default generated code for data type conversion (cast) operations with calls to optimized functions.

For details of the arithmetic supported for replacement of data type conversion, see the data type conversion (cast) subsection of "Fixed-Point Numbers and Arithmetic" on page 30-78.

**Example: Creating a TFL Entry to Replace Casts From `int32` To `int16`.** The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry to replace `int32` to `int16` data type conversion (cast) operations. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntry` class.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (cast), the saturation mode (saturate on overflow), the rounding mode (toward negative infinity), and the name of the replacement function (`my_sat_cast`).
- The function `getTflArgFromString` is called to create an `int16` output argument, which is then added to the operator entry both as the first conceptual argument and the implementation return argument.
- The function `getTflArgFromString` is called to create an `int32` input argument, which is then added to the operator entry both as the second conceptual argument and the sole implementation input argument.

```
hTable = RTW.TflTable;

% Create an int16 to int32 cast replacement
op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
    'Key',                       'RTW_OP_CAST', ...
    'Priority',                  50, ...
    'ImplementationName',        'my_sat_cast', ...
    'SaturationMode',            'RTW_SATURATE_ON_OVERFLOW', ...
    'RoundingMode',              'RTW_ROUND_FLOOR', ...
    'ImplementationHeaderFile', 'some_hdr.h', ...
    'ImplementationSourceFile', 'some_hdr.c');

% Create int16 arg as conceptual arg 1 and implementation return
arg = getTflArgFromString(hTable, 'y1', 'int16');
arg.IOType = 'RTW_IO_OUTPUT';
addConceptualArg(op_entry, arg);
op_entry.Implementation.setReturn(arg);
```

```
% Create int32 arg as conceptual arg 2 and implementation input arg 1
arg = getTflArgFromString(hTable, 'u1', 'int32');
addConceptualArg(op_entry, arg);
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);
```

**Example: Creating a TFL Entry to Replace Fixed-Point Casts Using Net Slope.** The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry to replace data type conversions (casts) of fixed-point data types using a net slope. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntryGenerator_NetSlope` class, which provides access to the fixed-point parameters `NetSlopeAdjustmentFactor` and `NetFixedExponent`.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (cast), the saturation mode (saturate on overflow), the rounding mode (toward negative infinity), and the name of the replacement function (`my_fxp_cast`). Additionally, `NetSlopeAdjustmentFactor` and `NetFixedExponent` are used to specify the `F` and `E` parts of the net slope $F2^E$.
- The function `createAndAddConceptualArg` is called to create conceptual output and input arguments that are added to the operator entry. Each argument is specified as fixed-point and signed. Also, each argument specifies that TFL replacement request processing should *not* check for an exact match to the call-site slope and bias values.
- The functions `createAndSetCImplementationReturn` and `createAndAddImplementationArg` are called to create implementation return and input arguments that are added to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types).

```
hTable = RTW.TflTable;

% Create a fixed-point cast replacement using a NetSlope entry
op_entry = RTW.TflCOperationEntryGenerator_NetSlope;
InFL = 2;
```

```
InWL = 16;
InSgn = true;
OutFL = 4;
OutWL = 32;
OutSgn = true;
setTflCOperationEntryParameters(op_entry, ...
   'Key',                       'RTW_OP_CAST', ...
   'Priority',                  50, ...
   'SaturationMode',            'RTW_SATURATE_ON_OVERFLOW', ...
   'RoundingMode',              'RTW_ROUND_FLOOR', ...
   'NetSlopeAdjustmentFactor',  1.0, ...
   'NetFixedExponent',          (OutFL - InFL), ...
   'SaturationMode',            'RTW_SATURATE_ON_OVERFLOW', ...
   'RoundingMode',              'RTW_ROUND_FLOOR', ...
   'ImplementationName',        'my_fxp_cast', ...
   'ImplementationHeaderFile',  'some_hdr.h', ...
   'ImplementationSourceFile',  'some_hdr.c');

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'CheckSlope',   false, ...
                          'CheckBias',    false, ...
                          'DataTypeMode', 'Fixed-point: binary point scaling', ...
                          'IsSigned',     OutSgn, ...
                          'WordLength',   OutWL, ...
                          'FractionLength',OutFL);

createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',         'u1', ...
                          'IOType',       'RTW_IO_INPUT', ...
                          'CheckSlope',   false, ...
                          'CheckBias',    false, ...
                          'DataTypeMode', 'Fixed-point: binary point scaling', ...
                          'IsSigned',     InSgn, ...
                          'WordLength',   InWL, ...
                          'FractionLength',InFL);

createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'y1', ...
```

```
                                'IOType',         'RTW_IO_OUTPUT', ...
                                'IsSigned',       OutSgn, ...
                                'WordLength',     OutWL, ...
                                'FractionLength', 0);

createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric',...
                                'Name',           'u1', ...
                                'IOType',         'RTW_IO_INPUT', ...
                                'IsSigned',       InSgn, ...
                                'WordLength',     InWL, ...
                                'FractionLength', 0);

addEntry(hTable, op_entry);
```

### Mapping Fixed-Point Shift Left Operations to Target-Specific Implementations

- "Example: Creating a TFL Entry to Replace Shift Lefts for `int16` Data" on page 30-107
- "Example: Creating a TFL Entry to Replace Fixed-Point Shift Lefts Using Net Slope" on page 30-109

You can use TFL table entries to replace the default generated code for `<<` (shift left) operations with calls to optimized functions.

For details of the arithmetic supported for replacement of shift-left operations, see the shift left subsection of "Fixed-Point Numbers and Arithmetic" on page 30-78.

**Example: Creating a TFL Entry to Replace Shift Lefts for `int16` Data.** The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry to replace `<<` (shift left) operations for `int16` data. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntry` class.

- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (shift left) and the name of the replacement function (`my_shift_left`).
- The function `getTflArgFromString` is called to create an `int16` output argument, which is then added to the operator entry both as the first conceptual argument and the implementation return argument.
- The function `getTflArgFromString` is called to create an `int16` input argument, which is then added to the operator entry both as the second conceptual argument and the first implementation input argument.
- The function `getTflArgFromString` is called to create an `int8` input argument, which is then added to the operator entry both as the third conceptual argument and the second implementation input argument. This argument specifies the number of bits to shift the previous input argument. Since the argument type is not relevant, type checking is disabled by setting the `CheckType` property to `false`.

```
hTable = RTW.TflTable;

% Create a shift left replacement for int16 data
op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
    'Key',                      'RTW_OP_SL', ...
    'Priority',                 50, ...
    'ImplementationName',       'my_shift_left', ...
    'ImplementationHeaderFile', 'some_hdr.h', ...
    'ImplementationSourceFile', 'some_hdr.c');

% Create int16 arg as conceptual arg 1 and implementation return
arg = getTflArgFromString(hTable, 'y1', 'int16');
arg.IOType = 'RTW_IO_OUTPUT';
addConceptualArg(op_entry, arg);
op_entry.Implementation.setReturn(arg);

% Create int16 arg as conceptual arg 2 and implementation input arg 1
arg = getTflArgFromString(hTable, 'u1', 'int16');
addConceptualArg(op_entry, arg);
op_entry.Implementation.addArgument(arg);
```

```
% Create int8 arg as conceptual arg 3 and implementation input arg 2
% Turn off type checking for number of bits to shift argument
arg = getTflArgFromString(hTable, 'u2', 'int8');
arg.CheckType = false;
addConceptualArg(op_entry, arg);
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);
```

**Example: Creating a TFL Entry to Replace Fixed-Point Shift Lefts Using Net Slope.** The following example uses the method described in "General Method for Creating Function and Operator Entries" on page 30-20 to create a TFL table entry to replace `<<` (shift left) operations for fixed-point data using a net slope. In this example:

- The TFL operator entry is instantiated using the `RTW.TflCOperationEntryGenerator_NetSlope` class, which provides access to the fixed-point parameters `NetSlopeAdjustmentFactor` and `NetFixedExponent`.
- The function `setTflCOperationEntryParameters` is called to set operator entry parameters. These parameters include the type of operation (shift left), the saturation mode (saturate on overflow), the rounding mode (toward negative infinity), and the name of the replacement function (`my_fxp_shift_left`). Additionally, `NetSlopeAdjustmentFactor` and `NetFixedExponent` are used to specify the `F` and `E` parts of the net slope $F2^{E}$.
- The function `createAndAddConceptualArg` is called to create conceptual output and input arguments that are added to the operator entry. Each argument is specified as fixed-point and signed. Also, each argument specifies that TFL replacement request processing should *not* check for an exact match to the call-site slope and bias values.
- The functions `createAndSetCImplementationReturn` and `createAndAddImplementationArg` are called to create implementation return and input arguments that are added to the operator entry. Implementation arguments must describe fundamental numeric data types (not fixed-point data types).
- The function `getTflArgFromString` is called to create a `uint8` input argument, which is then added to the operator entry both as the third conceptual argument and the second implementation input argument. This

argument specifies the number of bits to shift the previous input argument. Since the argument type is not relevant, type checking is disabled by setting the `CheckType` property to `false`.

```
hTable = RTW.TflTable;

% Create a fixed-point shift left replacement using a NetSlope entry
op_entry = RTW.TflCOperationEntryGenerator_NetSlope;
InFL = 2;
InWL = 16;
InSgn = true;
OutFL = 4;
OutWL = 32;
OutSgn = true;
setTflCOperationEntryParameters(op_entry, ...
   'Key',                         'RTW_OP_SL', ...
   'Priority',                    50, ...
   'SaturationMode',              'RTW_SATURATE_ON_OVERFLOW', ...
   'RoundingMode',                'RTW_ROUND_FLOOR', ...
   'NetSlopeAdjustmentFactor',    1.0, ...
   'NetFixedExponent',            (OutFL - InFL),...
   'SaturationMode',              'RTW_SATURATE_ON_OVERFLOW', ...
   'RoundingMode',                'RTW_ROUND_FLOOR', ...
   'ImplementationName',          'my_fxp_shift_left', ...
   'ImplementationHeaderFile',    'some_hdr.h', ...
   'ImplementationSourceFile',    'some_hdr.c');

% Create fixed-point arg as conceptual arg 1
createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',         'y1', ...
                          'IOType',       'RTW_IO_OUTPUT', ...
                          'CheckSlope',   false, ...
                          'CheckBias',    false, ...
                          'DataTypeMode', 'Fixed-point: binary point scaling', ...
                          'IsSigned',     OutSgn, ...
                          'WordLength',   OutWL, ...
                          'FractionLength',OutFL);

% Create fixed-point arg as conceptual arg 2
createAndAddConceptualArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',         'u1', ...
                          'IOType',       'RTW_IO_INPUT', ...
                          'CheckSlope',   false, ...
                          'CheckBias',    false, ...
                          'DataTypeMode', 'Fixed-point: binary point scaling', ...
                          'IsSigned',     InSgn, ...
                          'WordLength',   InWL, ...
                          'FractionLength',InFL);

% Create implementation return arg
createAndSetCImplementationReturn(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'y1', ...
                          'IOType',         'RTW_IO_OUTPUT', ...
                          'IsSigned',       OutSgn, ...
                          'WordLength',     OutWL, ...
                          'FractionLength', 0);

% Create implementation input arg 1
createAndAddImplementationArg(op_entry, 'RTW.TflArgNumeric', ...
                          'Name',           'u1', ...
                          'IOType',         'RTW_IO_INPUT', ...
                          'IsSigned',       InSgn, ...
                          'WordLength',     InWL, ...
                          'FractionLength', 0);

% Create uint8 arg as conceptual arg 3 and implementation input arg 2
% Turn off type checking for number of bits to shift argument
arg = getTflArgFromString(hTable, 'u2', 'uint8');
arg.CheckType = false;
addConceptualArg(op_entry, arg);
op_entry.Implementation.addArgument(arg);

addEntry(hTable, op_entry);
```

## Remapping Operator Outputs to Implementation Function Input Positions

If you need your generated code to meet a specific coding pattern or you want more flexibility, for example, to further improve performance, you have the option of remapping operator outputs to input positions in an implementation function argument list.

---

**Note** Remapping outputs to implementation function inputs is supported only for operator replacement.

---

For example, for a sum operation, the build process might generate code similar to the following:

```
rtY.Out1 = u8_add_u8_u8(rtU.In1, rtU.In2);
```

If you remap the output to the first input, the build process generates code similar to the following:

```
uint8_T rtb_Add8;

u8_add_u8_u8(&rtb_Add8, rtU.In1, rtU.In2);
rtY.Out1 = rtb_Add8;
```

To remap an operator output to an implementation function input for an existing TFL operator replacement entry, you modify the TFL table definition file as follows:

1. In the `setTflCOperationEntryParameters` function call for the operator replacement, specify the `SideEffects` parameter as `true`.
2. When defining the implementation function return, create a new `void` output argument, for example, `y2`.
3. When defining the implementation function arguments, set the operator output argument (for example, `y1`) as an additional input argument, marking its `IOType` as output, and make its type a pointer type.

For example, the following TFL table definition file for a sum operation has been modified to remap operator output `y1` as the first function input argument. The modified lines of code are shown in **bold** type. (This definition file generated the example remap code shown above.)

```
function hTable = tfl_table_add_uint8
```

```
%TFL_TABLE_ADD_UINT8 - Describe operator entry for a Target Function Library table.

hTable = RTW.TflTable;

% Create entry for addition of built-in uint8 data type
op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
                    'Key',                        'RTW_OP_ADD', ...
                    'Priority',                   90, ...
                    'ImplementationName',         'u8_add_u8_u8', ...
                    'ImplementationHeaderFile', 'u8_add_u8_u8.h', ...
                    'ImplementationSourceFile', 'u8_add_u8_u8.c', ...
                    'SideEffects',                true );

arg = getTflArgFromString(hTable, 'y1', 'uint8');
arg.IOType = 'RTW_IO_OUTPUT';
addConceptualArg(op_entry, arg);

arg = getTflArgFromString(hTable, 'u1', 'uint8');
addConceptualArg(op_entry, arg );

arg = getTflArgFromString(hTable, 'u2', 'uint8');
addConceptualArg(op_entry, arg );

% Create new void output y2
arg = getTflArgFromString(hTable, 'y2', 'void');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.setReturn(arg);

% Set y1 as first input arg, mark IOType as output, and use pointer type
arg=getTflArgFromString(hTable, 'y1', 'uint8*');
arg.IOType = 'RTW_IO_OUTPUT';
op_entry.Implementation.addArgument(arg);

arg=getTflArgFromString(hTable, 'u1', 'uint8');
op_entry.Implementation.addArgument(arg);

arg=getTflArgFromString(hTable, 'u2', 'uint8');
op_entry.Implementation.addArgument(arg);
```

```
addEntry(hTable, op_entry);
```

## Specifying Build Information for Function Replacements

- "Functions for Specifying Table Entry Build Information" on page 30-114
- "Using RTW.copyFileToBuildDir to Copy Files to the Build Directory" on page 30-115
- "RTW.copyFileToBuildDir Examples" on page 30-116

### Functions for Specifying Table Entry Build Information

As you create TFL table entries for function or operator replacement, you specify the header and source file information for each function implementation using one of the following:

- The arguments `ImplementationHeaderFile`, `ImplementationHeaderPath`, `ImplementationSourceFile`, and `ImplementationSourcePath` to `setTflCFunctionEntryParameters` or `setTflCOperationEntryParameters`
- The `headerFile` argument to `registerCFunctionEntry` or `registerCPromotableMacroEntry`

Also, each table entry can specify additional header files, source files, and object files to be included in model builds whenever the TFL table entry is matched and used to replace a function or operator in generated code. To add an additional header file, source file, or object file, use the following TFL table creation functions.

| Function | Description |
|---|---|
| `addAdditionalHeaderFile` | Add additional header file to array of additional header files for TFL table entry |
| `addAdditionalIncludePath` | Add additional include path to array of additional include paths for TFL table entry |
| `addAdditionalLinkObj` | Add additional link object to array of additional link objects for TFL table entry |

| Function | Description |
|---|---|
| `addAdditionalLinkObjPath` | Add additional link object path to array of additional link object paths for TFL table entry |
| `addAdditionalSourceFile` | Add additional source file to array of additional source files for TFL table entry |
| `addAdditionalSourcePath` | Add additional source path to array of additional source paths for TFL table entry |

For function descriptions and examples, see the function reference pages in the Real-Time Workshop Embedded Coder reference documentation.

## Using RTW.copyFileToBuildDir to Copy Files to the Build Directory

If a TFL table entry uses header, source, or object files that reside in external directories, and if the table entry is matched and used to replace a function or operator in generated code, the external files will need to be copied to the build directory before the generated code is built. The `RTW.copyFileToBuildDir` function can be invoked after code generation to copy the table entry's specified header file, source file, additional header files, additional source files, and additional link objects to the build directory. The copied files are then available for use in the build process.

To direct that a table entry's external files should be copied to the build directory after code generation, specify the argument `'RTW.copyFileToBuildDir'` to the `genCallback` parameter of the TFL function that you use to set the table entry parameters, among the following:

- `registerCFunctionEntry`
- `registerCPromotableMacroEntry`
- `setTflCFunctionEntryParameters`
- `setTflCOperationEntryParameters`

### RTW.copyFileToBuildDir Examples

The following example defines a table entry for an optimized multiplication function that takes signed 32-bit integers and returns a signed 32-bit integer, taking saturation into account. Multiplications in the generated code will be replaced with calls to your optimized function. Your optimized function resides in an external directory and must be copied into the build directory to be compiled and linked into the application.

The multiplication table entry specifies the source and header file names as well as their full paths. To request the copy to be performed, the table entry specifies the argument `'RTW.copyFileToBuildDir'` to the `genCallback` parameter of the `setTflCOperationEntryParameters` function. In this example, the header file `s32_mul.h` contains an inlined function that invokes assembly functions contained in `s32_mul.s`. If the table entry is matched and used to generate code, the `RTW.copyFileToBuildDir` function will copy the specified source and header files into the build directory.

```
function hTable = make_my_tfl_table

hTable = RTW.TflTable;

op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
                'Key',                      'RTW_OP_MUL', ...
                'Priority',                 100, ...
                'SaturationMode',           'RTW_SATURATE_ON_OVERFLOW', ...
                'RoundingMode',             'RTW_ROUND_UNSPECIFIED', ...
                'ImplementationName',       's32_mul_s32_s32_sat', ...
                'ImplementationHeaderFile', 's32_mul.h', ...
                'ImplementationSourceFile', 's32_mul.s', ...
                'ImplementationHeaderPath', {fullfile('$(MATLAB_ROOT)','tfl')}, ...
                'ImplementationSourcePath', {fullfile('$(MATLAB_ROOT)','tfl')}, ...
                'GenCallback',              'RTW.copyFileToBuildDir');
.
.
.
addEntry(hTable, op_entry);
```

The following example shows the use of the `addAdditional*` functions along with `RTW.copyFileToBuildDir`.

```
hTable = RTW.TflTable;

% Path to external source, header, and object files
libdir = fullfile('$(MATLAB_ROOT)','..', '..', 'lib');

op_entry = RTW.TflCOperationEntry;
setTflCOperationEntryParameters(op_entry, ...
                'Key',                        'RTW_OP_ADD', ...
                'Priority',                   90, ...
                'SaturationMode',             'RTW_SATURATE_UNSPECIFIED', ...
                'RoundingMode',               'RTW_ROUND_UNSPECIFIED', ...
                'ImplementationName',         's32_add_s32_s32', ...
                'ImplementationHeaderFile', 's32_add_s32_s32.h', ...
                'ImplementationSourceFile', 's32_add_s32_s32.c'...
                'GenCallback',                'RTW.copyFileToBuildDir');

addAdditionalHeaderFile(op_entry, 'all_additions.h');
addAdditionalIncludePath(op_entry, fullfile(libdir, 'include'));
addAdditionalSourceFile(op_entry, 'all_additions.c');
addAdditionalSourcePath(op_entry, fullfile(libdir, 'src'));
addAdditionalLinkObj(op_entry, 'addition.o');
addAdditionalLinkObjPath(op_entry, fullfile(libdir, 'bin'));
.
.
.
addEntry(hTable, op_entry);
```

## Adding Target Function Library Reserved Identifiers

The Real-Time Workshop software reserves certain words for its own use as keywords of the generated code language. Real-Time Workshop keywords are reserved for use internal to the Real-Time Workshop software or C programming and should not be used in Simulink models as identifiers or function names. Real-Time Workshop reserved keywords include many TFL identifiers, the majority of which are function names, such as `acos`. To view the base list of TFL reserved identifiers, see “Reserved Keywords” in the Real-Time Workshop documentation.

In a TFL table, each function implementation name defined by a table entry is registered as a reserved identifier. You can register additional reserved identifiers for the table on a per-header-file basis. Providing additional reserved identifiers can help prevent duplicate symbols and other identifier-related compile and link issues.

To register additional TFL reserved identifiers, use the following function.

| Function | Description |
|---|---|
| `setReservedIdentifiers` | Register specified reserved identifiers to be associated with TFL table |

You can register up to four reserved identifier structures in a TFL table. One set of reserved identifiers can be associated with an arbitrary TFL, while the other three (if present) must be associated with ANSI, ISO[12], or GNU[13] libraries. The following example shows a reserved identifier structure that specifies two identifiers and the associated header file.

```
d{1}.LibraryName = 'ANSI';
d{1}.HeaderInfos{1}.HeaderName = 'math.h';
d{1}.HeaderInfos{1}.ReservedIds = {'y0', 'y1'};
```

The specified identifiers are added to the reserved identifiers collection and honored during the Real-Time Workshop build procedure. For more information and examples, see `setReservedIdentifiers` in the Real-Time Workshop Embedded Coder reference documentation.

12. ISO® is a registered trademark of the International Organization for Standardization.

13. GNU® is a registered trademark of the Free Software Foundation.

## Examining and Validating Function Replacement Tables

**In this section...**

### Overview of Function Replacement Table Validation

After you create a target function library (TFL) table containing your function replacement entries, but before you deploy production TFLs containing your table for general use in building models, you can use various techniques to examine and validate the TFL table entries. These include:

- Invoking the table definition M-file
- Using the TFL Viewer at various stages of TFL development to examine TFLs, tables, and entries
- Tracing code generated from models for which your TFL is selected
- Examining TFL cache hits and misses logged during code generation

### Invoking the Table Definition M-File

Immediately after creating or modifying a table definition M-file (as described in "Creating Function Replacement Tables" on page 30-15), you should invoke it at the MATLAB command line. This invocation serves as a check of the validity of your table entries. For example,

```
>> tbl = tfl_table_sinfcn

tbl =
RTW.TflTable
            Version: '1.0'
         AllEntries: [2x1 RTW.TflCFunctionEntry]
    ReservedSymbols: []

>>
```

Any errors found during the invocation are displayed. In the following example, a typo in a data type name is detected and displayed.

```
>> tbl = tfl_table_sinfcn
??? RTW_CORE:tfl:TflTable: Unsupported data type, 'dooble'.

Error in ==> tfl_table_sinfcn at 7
hTable.registerCFunctionEntry(100, 1, 'sin', 'dooble', 'sin_dbl', ...

>>
```

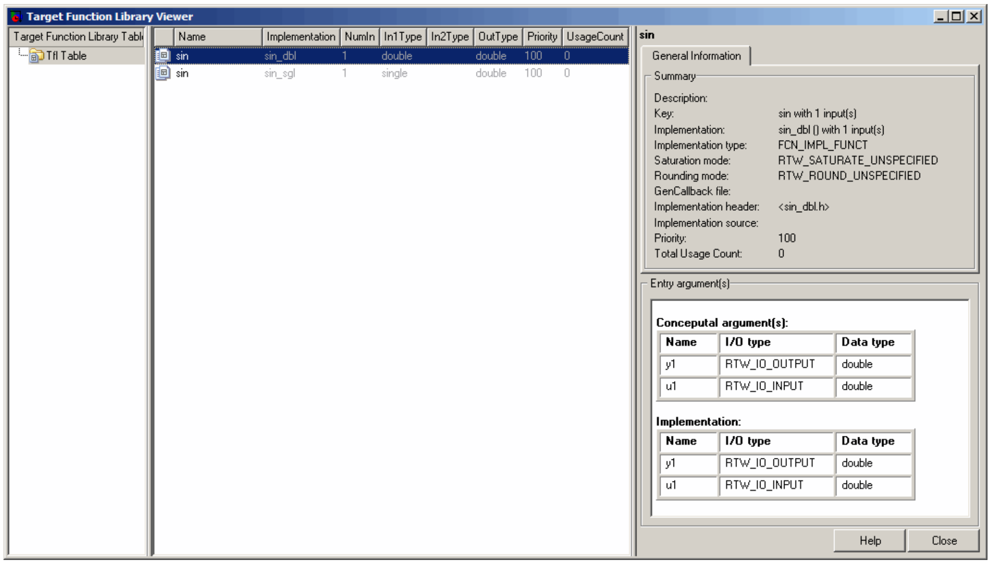
## Using the Target Function Library Viewer to Examine Your Table

After creating or modifying a table definition M-file, as a further check of your table entries, you should use the TFL Viewer to display and examine your table. Invoke the TFL Viewer using the following form of the MATLAB command `RTW.viewTfl`:

```
RTW.viewTfl(table-name)
```

For example,

```
>> RTW.viewTfl(tfl_table_sinfcn)
```



| Name | Implementation | NumIn | In1Type | In2Type | OutType | Priority | UsageCount |
|---|---|---|---|---|---|---|---|
| sin | sin_dbl | 1 | double | | double | 100 | 0 |
| sin | sin_sgl | 1 | single | | double | 100 | 0 |

Summary

| | |
|---|---|
| Description: | |
| Key: | sin with 1 input(s) |
| Implementation: | sin_dbl () with 1 input(s) |
| Implementation type: | FCN_IMPL_FUNCT |
| Saturation mode: | RTW_SATURATE_UNSPECIFIED |
| Rounding mode: | RTW_ROUND_UNSPECIFIED |
| GenCallback file: | |
| Implementation header: | <sin_dbl.h> |
| Implementation source: | |
| Priority: | 100 |
| Total Usage Count: | 0 |

Entry argument(s)

**Conceptual argument(s):**

| Name | I/O type | Data type |
|---|---|---|
| y1 | RTW_IO_OUTPUT | double |
| u1 | RTW_IO_INPUT | double |

**Implementation:**

| Name | I/O type | Data type |
|---|---|---|
| y1 | RTW_IO_OUTPUT | double |
| u1 | RTW_IO_INPUT | double |

Select entries in your table and verify that the graphical display of the contents of your table meets your expectations. Common problems that can be detected at this stage include:

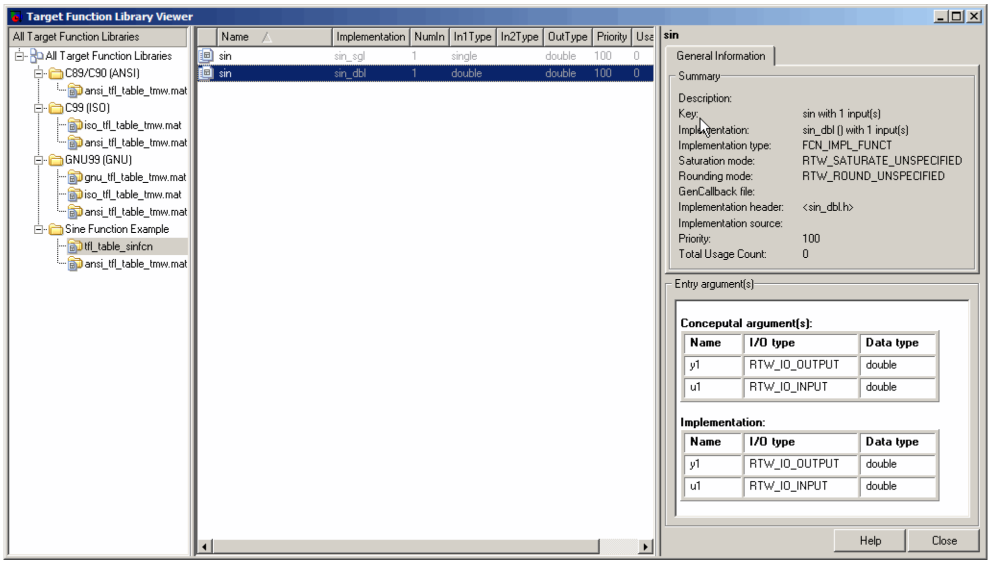
- Incorrect argument order
- Conceptual argument naming that does not match the naming convention used by the code generation process
- Incorrect relative priority of entries within the table (highest priority is 0, and lowest priority is 100).

For more information about the TFL Viewer, see "Using the Target Function Library Viewer" in the Real-Time Workshop documentation.

## Using the Target Function Library Viewer to Examine Registered TFLs

After you register a TFL that includes your function replacement table (as described in "Registering Target Function Libraries" on page 30-128), you should use the TFL Viewer to verify that your TFL was properly registered and to examine the TFL and the tables it contains. Invoke the TFL Viewer using the MATLAB command `RTW.viewTfl` with no arguments. This command displays all TFLs registered in the current Simulink session. For example:

```
>> RTW.viewTfl
```



All Target Function Libraries
- C89/C90 (ANSI)
  - ansi_tfl_table_tmw.mat
- C99 (ISO)
  - iso_tfl_table_tmw.mat
  - ansi_tfl_table_tmw.mat
- GNU99 (GNU)
  - gnu_tfl_table_tmw.mat
  - iso_tfl_table_tmw.mat
  - ansi_tfl_table_tmw.mat
- Sine Function Example
  - tfl_table_sinfcn
  - ansi_tfl_table_tmw.mat

| Name | Implementation | NumIn | In1Type | In2Type | OutType | Priority | Usa |
|---|---|---|---|---|---|---|---|
| sin | sin_sgl | 1 | single | | double | 100 | 0 |
| sin | sin_dbl | 1 | double | | double | 100 | 0 |

sin

General Information

Summary

| | |
|---|---|
| Description: | |
| Key: | sin with 1 input(s) |
| Implementation: | sin_dbl () with 1 input(s) |
| Implementation type: | FCN_IMPL_FUNCT |
| Saturation mode: | RTW_SATURATE_UNSPECIFIED |
| Rounding mode: | RTW_ROUND_UNSPECIFIED |
| GenCallback file: | |
| Implementation header: | <sin_dbl.h> |
| Implementation source: | |
| Priority: | 100 |
| Total Usage Count: | 0 |

Entry argument(s)

**Conceptual argument(s):**

| Name | I/O type | Data type |
|---|---|---|
| y1 | RTW_IO_OUTPUT | double |
| u1 | RTW_IO_INPUT | double |

**Implementation:**

| Name | I/O type | Data type |
|---|---|---|
| y1 | RTW_IO_OUTPUT | double |
| u1 | RTW_IO_INPUT | double |

If your TFL is not displayed,

- There may be an error in your TFL registration file.
- You may need to refresh the TFL registration information by issuing the MATLAB command `sl_refresh_customizations` or, for an Embedded MATLAB Coder TFL registration, using the command `RTW.TargetRegistry.getInstance('reset')`.

If your TFL is displayed, select the TFL and examine and compare its tables, including their relative order. Common problems that can be detected at this stage include

- Incorrect relative order of tables in the library (tables are displayed in search order)
- Table entry problems as listed in the previous section

For more information about the TFL Viewer, see "Using the Target Function Library Viewer" in the Real-Time Workshop documentation.

## Tracing Code Generated Using Your Target Function Library

After you register a TFL that includes your function replacement tables, you should use the TFL to generate code and verify that you are obtaining the function or operator replacement that you expect. For example, the following approach uses model-to-code highlighting to trace a specific expected replacement.

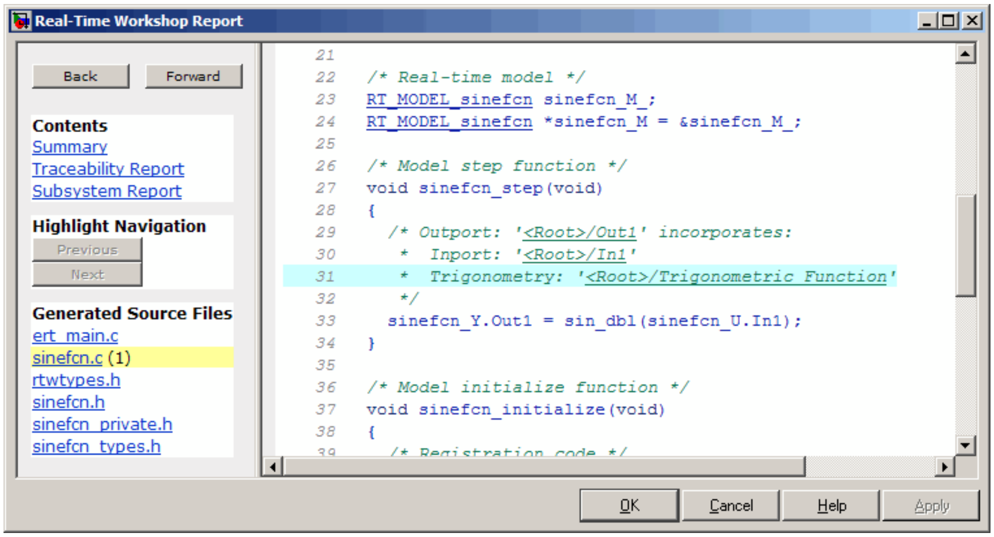
1. Open a ERT-based model for which you anticipate that a function or operator replacement should occur.

2. Select your TFL in the **Target function library** drop-down list on the **Interface** pane of the Configuration Parameters dialog box.

3. Go to the **Real-Time Workshop > Report** pane of the Configuration Parameters dialog box and select the options **Create code generation report** and **Model-to-code**.

4. Go to the **Real-Time Workshop** pane, select the **Generate code only** option, and generate code for the model.

5. Go to the model window and use model-to-code highlighting to trace the code generated using your TFL. For example, right-click a block that you expect to have generated a function or operator replacement and select **Real-Time Workshop > Navigate to Code**. This selection highlights the applicable generated function code within the HTML report, as shown in the following example.



```

/* Real-time model */
RT_MODEL_sinefcn sinefcn_M_;
RT_MODEL_sinefcn *sinefcn_M = &sinefcn_M_;

/* Model step function */
void sinefcn_step(void)
{
  /* Outport: '<Root>/Out1' incorporates:
   *  Inport: '<Root>/In1'
   *  Trigonometry: '<Root>/Trigonometric Function'
   */
  sinefcn_Y.Out1 = sin_dbl(sinefcn_U.In1);
}

/* Model initialize function */
void sinefcn_initialize(void)
{
  /* Registration code */
```

Inspect the generated code and see if the function or operator replacement occurred as you expected.

---

**Note** If a function or operator was not replaced as you expected, it means that a call site request was not matched as you intended by your table entry attributes. Either a higher-priority (lower priority value) match was used or no match was found. You can analyze the TFL table entry matching behavior by using the following resources together:

- TFL Viewer, as described in "Using the Target Function Library Viewer to Examine Your Table" on page 30-120 and "Using the Target Function Library Viewer to Examine Registered TFLs" on page 30-121
- HTML code generation reports, with bidirectional tracing including model-to-code highlighting
- Statistics for TFL cache hits and misses logged during code generation, as described in "Examining TFL Cache Hits and Misses" on page 30-125

---

## Examining TFL Cache Hits and Misses

Target function library (TFL) replacement may behave differently than you expect in some cases. To verify that you are obtaining the function or operator replacement that you expect, you first inspect the generated code, as described in "Tracing Code Generated Using Your Target Function Library" on page 30-123.

To analyze replacement behavior, in addition to referencing the generated code and examining your TFL tables in the TFL Viewer, you can view the TFL cache hits and misses logged during the most recent code generation session. This approach provides information on what data types and attributes should be registered in order to achieve the desired replacement.

To display the TFL cache hits and misses logged during the most recent code generation session, you specify the model parameter `TargetFcnLibHandle` in a `get_param` call, as follows:

```
>> tfl=get_param('model', 'TargetFcnLibHandle')
```

The resulting display includes the following fields:

| Field | Description |
|---|---|
| `HitCache` | Table containing function entries that were successfully matched during a code generation session. These entries represent function implementations that should appear in the generated code. |
| `MissCache` | Table containing function entries that failed to match during a code generation session. These entries are created by the code generation process for the purpose of querying the TFL to locate a registered implementation. If there is a registered implementation that you feel should have been used in the generated code and was not, examining the `MissCache` for entries that are similar but did not match can help you locate discrepancies in a conceptual argument list or in table entry attributes. |

**Note** You also can view cache hits and misses in the TFL Viewer, using the TFL handle returned by the `get_param` call. For example:

```
>> tfl=get_param('model', 'TargetFcnLibHandle')
>> RTW.viewTfl(tfl)
```

This opens the TFL viewer. You can then examine the cache hits and misses by clicking on the entries under those caches.

In the following example, the most recent code generation session logged one cache hit and zero cache misses. You can examine the logged `HitCache` entry using its table index.

```
>> a=get_param('sinefcn','TargetFcnLibHandle')

a =

RTW.TflControl
        Version: '1.0'
       HitCache: [1x1 RTW.TflCFunctionEntry]
      MissCache: [0x1 handle]
    TLCCallList: [0x1 handle]
      TflTables: [2x1 RTW.TflTable]

>> a.HitCache(1)

ans =

RTW.TflCFunctionEntry
                        Key: 'sin'
                   Priority: 100
             ConceptualArgs: [2x1 RTW.TflArgNumeric]
             Implementation: [1x1 RTW.CImplementation]
          RTWmakecfgLibName: ''
                GenCallback: ''
                GenFileName: ''
             SaturationMode: 'RTW_SATURATE_UNSPECIFIED'
               RoundingMode: 'RTW_ROUND_UNSPECIFIED'
            AcceptExprInput: 1
```

```
                 SideEffects: 0
                  UsageCount: 2
            SharedUsageCount: 0
                 Description: ''
                    ImplType: 'FCN_IMPL_FUNCT'
       AdditionalHeaderFiles: {0x1 cell}
      AdditionalIncludePaths: {0x1 cell}
       AdditionalSourceFiles: {0x1 cell}
       AdditionalSourcePaths: {0x1 cell}
          AdditionalLinkObjs: {0x1 cell}
     AdditionalLinkObjsPaths: {0x1 cell}

>>
```

## Registering Target Function Libraries

**In this section...**

### Overview of TFL Registration

After you define function and operator replacements in a target function library (TFL) table definition file, your table can be included in a TFL that you register either with Simulink software or with Embedded MATLAB Coder software. When a TFL is registered, it appears in the **Target function library** drop-down list on the **Interface** pane of either the Simulink Configuration Parameters dialog box or the Embedded MATLAB Coder Real-Time Workshop dialog box. You can select it from the **Target function library** drop-down list for use in code generation.

To register TFLs with Simulink software, use the Simulink customization file `sl_customization.m`. This file is a mechanism that allows you to use M-code to perform customizations of the standard Simulink user interface. The Simulink software reads the `sl_customization.m` file, if present on the MATLAB path, when it starts and the customizations specified in the file are applied to the Simulink session. For more information on the `sl_customization.m` customization file, see "Customizing the Simulink User Interface" in the Simulink documentation.

To register TFLs with Embedded MATLAB Coder software, use the Embedded MATLAB Coder customization file `rtwTargetInfo.m`. This file is a mechanism that allows you to use M-code to perform customizations of the standard Embedded MATLAB Coder Real-Time Workshop dialog box. The Embedded MATLAB Coder software reads the `rtwTargetInfo.m` file, if present on the MATLAB path, when it starts and the customizations specified in the file are applied to the Embedded MATLAB Coder session.

## Using the sl_customization API to Register a TFL with Simulink Software

To register a TFL, you create an instance of `sl_customization.m` and include it on the MATLAB path of the Simulink installation that you want to customize. The `sl_customization` function accepts one argument: a handle to a customization manager object. The function is declared as follows:

```
function sl_customization(cm)
```

The body of the `sl_customization` function invokes the `registerTargetInfo(tfl)` method to register one or more TFLs with the Simulink software. Typically, the `registerTargetInfo` function call references a local function that defines the TFLs to be registered. For example:

```
  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION
```

Below the `sl_customization` function, the referenced local function describes one or more TFLs to be registered. For example, you can declare the local function as follows:

```
% Local function to define a TFL
function thisTfl = locTflRegFcn
```

In the local function body, for each TFL to be registered, you instantiate a TFL registry entry using `tfl = RTW.TflRegistry`. For example,

```
  thisTfl = RTW.TflRegistry;
```

Then, you define the TFL properties shown in the following table within the registry entry.

| TFL Property | Description |
|---|---|
| `Name` | String specifying the name of the TFL, as it should be displayed in the **Target function library** drop-down list on the **Interface** pane of the Configuration Parameters dialog box. |
| `Description` | String specifying a text description of the TFL, as it should be displayed in the tool tip for the TFL in the Configuration Parameters dialog box. |
| `TableList` | Cell array of strings specifying the tables that make up the TFL, in descending priority order. |
| `BaseTfl` | String specifying the name of the TFL on which this TFL is based. **Note** To ensure that functions, macros, and constants used by built-in blocks are available in your TFL, and to help ensure compatibility between releases, you must specify one of the default MathWorks libraries as the base TFL: `'C89/C90 (ANSI)'`, `'C99 (ISO)'`, `'GNU99 (GNU)'`, or an equivalent alias. |
| `TargetHWDeviceType` | Always specify `{'*'}`. |

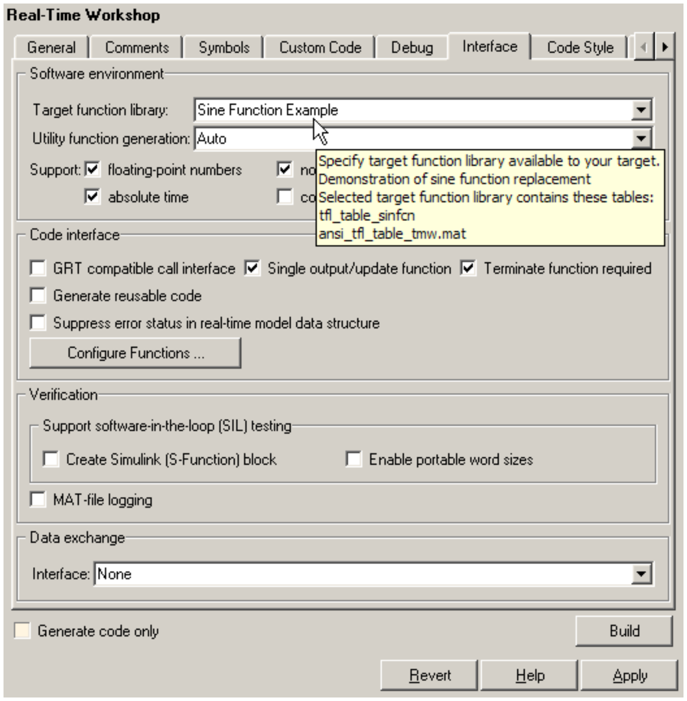
For example:

```
    thisTfl.Name = 'Sine Function Example';
    thisTfl.Description = 'Demonstration of sine function replacement';
    thisTfl.TableList = {'tfl_table_sinfcn'};
    thisTfl.BaseTfl = 'C89/C90 (ANSI)';
    thisTfl.TargetHWDeviceType = {'*'};

  end % End of LOCTFLREGFCN
```

Combining the elements described in this section, the complete `sl_customization` function for the `'Sine Function Example'` TFL would appear as follows:

```
function sl_customization(cm)
% sl_customization function to register a target function library (TFL)
% for use with Simulink

  % Register the TFL defined in local function locTflRegFcn
  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION


% Local function to define a TFL containing tfl_table_sinfcn
function thisTfl = locTflRegFcn

  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Sine Function Example';
  thisTfl.Description = 'Demonstration of sine function replacement';
  thisTfl.TableList = {'tfl_table_sinfcn'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

If you place the `sl_customization.m` file containing this function in the MATLAB search path or in the current working directory, the TFL is registered at each Simulink startup. The Simulink software will display the TFL in the **Target function library** drop-down list on the **Interface** pane of the Configuration Parameters dialog box. For example, the following figure shows the Configuration Parameters dialog box display, including tool tip, for the `'Sine Function Example'` TFL.



Software environment

Target function library: Sine Function Example

Utility function generation: Auto

Support: [✓] floating-point numbers [✓] no… [✓] absolute time [ ] co…

Specify target function library available to your target.
Demonstration of sine function replacement
Selected target function library contains these tables:
tfl_table_sinfcn
ansi_tfl_table_tmw.mat

Code interface

[ ] GRT compatible call interface [✓] Single output/update function [✓] Terminate function required

[ ] Generate reusable code

[ ] Suppress error status in real-time model data structure

Verification

Support software-in-the-loop (SIL) testing

[ ] Create Simulink (S-Function) block [ ] Enable portable word sizes

[ ] MAT-file logging

Data exchange

Interface: None

[ ] Generate code only

**Tip**

- To refresh Simulink customizations within the current MATLAB session, use the command `sl_refresh_customizations`.
- To list all `sl_customization` files in the current search path, use the command `which sl_customization -all`.
- If you disable a TFL registration (for example, by renaming the registration file `sl_customization.m` and then issuing `sl_refresh_customizations`), you may want to reset and save the **Target function library** option setting in any saved models that selected the disabled TFL.

## Using the rtwTargetInfo API to Register a TFL with Embedded MATLAB Coder Software

To register a TFL for use with Embedded MATLAB Coder software, you create an instance of `rtwTargetInfo.m` and include it on the MATLAB path of the Embedded MATLAB Coder installation that you want to customize. The `rtwTargetInfo` function accepts one argument: a handle to a target registration object. The function is declared as follows:

```
function rtwTargetInfo(tr)
```

The body of the `rtwTargetInfo` function invokes the `registerTargetInfo(tfl)` method provided by the target registry object to register one or more TFLs with the Embedded MATLAB Coder software. Typically, the `registerTargetInfo` function call references a local function that defines the TFLs to be registered. For example:

```
  % Register the TFL defined in local function locTflRegFcn
  tr.registerTargetInfo(@locTflRegFcn);

end % End of RTWTARGETINFO
```

Below the `rtwTargetInfo` function, the referenced local function describes one or more TFLs to be registered. The format exactly matches the TFL description format previously described for Simulink use. For example, here is the Embedded MATLAB Coder equivalent of the complete TFL registration file displayed in "Using the sl_customization API to Register a TFL with Simulink Software" on page 30-129.

```
function rtwTargetInfo(tr)
% rtwTargetInfo function to register a target function library (TFL)
% for use with emlc

  % Register the TFL defined in local function locTflRegFcn
  tr.registerTargetInfo(@locTflRegFcn);

end % End of RTWTARGETINFO


% Local function to define a TFL containing tfl_table_sinfcn
function thisTfl = locTflRegFcn
```

```
  % Instantiate a TFL registry entry
  thisTfl = RTW.TflRegistry;

  % Define the TFL properties
  thisTfl.Name = 'Sine Function Example';
  thisTfl.Description = 'Demonstration of sine function replacement';
  thisTfl.TableList = {'tfl_table_sinfcn'};
  thisTfl.BaseTfl = 'C89/C90 (ANSI)';
  thisTfl.TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

If you place the `rtwTargetInfo.m` file containing this function in the MATLAB search path or in the current working directory, the TFL is registered at each Embedded MATLAB Coder startup. The Embedded MATLAB Coder software will display the TFL in the **Target function library** drop-down list on the **Interface** pane of the Real-Time Workshop dialog box.

**Tip** To refresh Embedded MATLAB Coder TFL registration information within the current MATLAB session, use the command `RTW.TargetRegistry.getInstance('reset');`.

## Registering Multiple TFLs

For an example of a TFL registration file that registers multiple TFLs, see the `sl_customization.m` file used in the TFL demo, `rtwdemo_tfl_script`. The following excerpt illustrates the general approach, which applies equally to Simulink and Embedded MATLAB Coder TFL registration files.

```
function sl_customization(cm)

  cm.registerTargetInfo(@locTflRegFcn);

end % End of SL_CUSTOMIZATION

% Local function(s)
function thisTfl = locTflRegFcn
  % Register a Target Function Library for use with model: rtwdemo_tfladdsub.mdl
  thisTfl(1) = RTW.TflRegistry;
  thisTfl(1).Name = 'Addition & Subtraction Examples';
  thisTfl(1).Description = 'Demonstration of addition/subtraction operator replacement';
  thisTfl(1).TableList = {'tfl_table_addsub'};
  thisTfl(1).BaseTfl = 'C89/C90 (ANSI)';
  thisTfl(1).TargetHWDeviceType = {'*'};
  .
  .
  .
  % Register a Target Function Library for use with model: rtwdemo_tflmath.mdl
  thisTfl(4) = RTW.TflRegistry;
  thisTfl(4).Name = 'Math Function Examples';
  thisTfl(4).Description = 'Demonstration of math function replacement';
  thisTfl(4).TableList = {'tfl_table_math'};
  thisTfl(4).BaseTfl = 'C89/C90 (ANSI)';
  thisTfl(4).TargetHWDeviceType = {'*'};

end % End of LOCTFLREGFCN
```

## Target Function Library Limitations

- Target function library (TFL) replacement may behave differently than you expect in some cases. For example, data types that you observe in a model do not necessarily match what the code generator determines to use as intermediate data types in an operation. To verify whether you are obtaining the function or operator replacement that you expect, inspect the generated code.
- To analyze replacement behavior, in addition to referencing the generated code and examining your TFL tables in the TFL Viewer, view the TFL cache hits and misses logged during the most recent code generation session. This approach provides information on what data types should be registered in order to achieve the desired replacement. For more information on analyzing TFL table entries, see "Examining and Validating Function Replacement Tables" on page 30-119.
- You must register TFL in the `sl_customization.m` or `rtwTargetInfo` file, but not in both files.

# Setting Up Generated Code To Interface With Components in the Run-Time Environment

# Configuring the Target Hardware Environment

## Configuring Support for Numeric Data

By default, ERT targets support code generation for integer, floating-point, nonfinite, and complex numbers.

| To Generate Code that Supports... | Do... |
|---|---|
| Integer data only | Deselect **Support floating-point numbers**. If any noninteger data or expressions are encountered during code generation, an error message reports the offending blocks and parameters. |
| Floating-point data | Select **Support floating-point numbers**. |
| Nonfinite values (for example, `NaN`, `Inf`) | Select **Support floating-point numbers** and **Support non-finite numbers** . |
| Complex data | Select **Support complex numbers** . |

For more information, see "Real-Time Workshop Pane: Interface" in the Real-Time Workshop reference documentation.

## Configuring Support for Time Values

Certain blocks require the value of absolute time (that is, the time from the start of program execution to the present time) , elapsed time (for example, the time elapsed between two trigger events), or continuous time. Depending on the blocks used, you might need to adjust the configuration settings for supported time values.

| To... | Select... |
|---|---|
| Generate code that creates and maintains integer counters for blocks that use absolute or elapsed time values (default) | **Support absolute time**. For further information on the allocation and operation of absolute and elapsed timers, see the "Using Timers" chapter of the Real-Time Workshop documentation. If you do not select this parameter and the model includes block that use absolute or elapsed time values, the build process generates an error. |
| Generate code for blocks that rely on continuous time | **Support continuous time**. If you do not select this parameter and the model includes continuous-time blocks, the build process generates an error. |

For more information, see "Real-Time Workshop Pane: Interface" in the Real-Time Workshop reference documentation.

## Setting Up Support for Non-Inlined S-Functions

To generate code for noninlined S-Functions in a model, select **Support noninlined S-functions**. The generation of noninlined S-functions requires floating-point and nonfinite numbers. Thus, when you select **Support non-inlined S-functions**, the ERT target automatically selects **Support floating-point numbers** and **Support non-finite numbers**.

When you select **Support non-finite numbers**, the build process generates an error if the model includes a C MEX S-function that does not have a corresponding TLC implementation (for inlining code generation).

Note that inlining S-functions is highly advantageous in production code generation, for example in implementing device drivers. To enforce the use of inlined S-functions for code generation, deselect **Support non-inlined S-functions**.

For more information, see “Real-Time Workshop Pane: Interface” in the Real-Time Workshop reference documentation.

## Configuring Model Function Generation and Argument Passing

For ERT targets, you can configure how a model's functions are generated and how arguments are passed to the functions.

| To... | Do... |
|---|---|
| Generate model function calls that are compatible with the main program module of the GRT target (`grt_main.c` or `.cpp`) | Select **GRT compatible call interface** and **MAT-file logging** . In addition, deselect **Suppress error status in real-time model data structure**. **GRT compatible call interface** provides a quick way to use ERT target features with a GRT-based custom target by generating wrapper function calls that interface to the ERT target's `Embedded-C` formatted code. |
| Reduce overhead and use more local variables by combining the output and update functions in a single *`model`*`_step` function | Select **Single output/update function** Errors or unexpected behavior can occur if a Model block is part of a cycle and "Single output/update function" is enabled (the default). See "Model Blocks and Direct Feedthrough" for details. |
| Generate a *`model`*`_terminate` function for a model not designed to run indefinitely | Select **Terminate function required**. For more information, see the description of `model_terminate`. |
| Generate reusable, reentrant code from a model or subsystem | Select **Generate reusable code**. See "Setting Up Support for Code Reuse" on page 31-7 for details. |
| Statically allocate model data structures and access them directly in the model code | Deselect **Generate reusable code**. The generated code is not reusable or reentrant. See "Model Entry Points" on page 32-14 for information on the calling interface generated for model functions in this case. |

| To... | Do... |
|---|---|
| Suppress the generation of an error status field in the real-time model data structure, `rtModel`, for example, if you do not need to log or monitor error messages | Select **Suppress error status in real-time model data structure**. Selecting this parameter can also cause the `rtModel` structure to be omitted completely from the generated code.<br><br>When generating code for multiple integrated models, set this parameter the same for all of the models. Otherwise, the integrated application might exhibit unexpected behavior. For example, if you select the option in one model but not in another, the error status might not be registered by the integrated application.<br><br>Do not select this parameter if you select the **MAT-file logging** option. The two options are incompatible. |
| Launch the Model Step Functions dialog box (see "Configuring Model Function Prototypes" on page 28-4) preview and modify the model's *`model`*`_step` function prototype | Click **Configure Step Function**. Based on the **Function specification** value you select for your *`model`*`_step` function (supported values include `Default model-step function` and `Model specific C prototype`), you can preview and modify the function prototype. Once you validate and apply your changes, you can generate code based on your function prototype modifications. For more information about using the **Configure Step Function** button and the Model Step Functions dialog box, see Chapter 28, "Controlling Generation of Function Prototypes". |

For more information, see "Real-Time Workshop Pane: Interface" in the Real-Time Workshop reference documentation.

## Setting Up Support for Code Reuse

For ERT targets, you can configure how a model reuses code using the **Generate reusable code** parameter.

**Pass root-level I/O as** provides options that control how model inputs and outputs at the root level of the model are passed to the *`model`*`_step` function.

| To... | Select... |
|---|---|
| Pass each root-level model input and output argument to the*`model`*`_step` function individually (the default) | **Generate reusable code** and **Pass root-level I/O as** > `Individual arguments`. |
| Pack root-level input arguments and root-level output arguments into separate structures that are then passed to the *`model`*`_step` function | **Generate reusable code** and **Pass root-level I/O as** > `Structure reference` |

In some cases, selecting **Generate reusable code** can generate code that compiles but is not reentrant. For example, if any signal, `DWork` structure, or parameter data has a storage class other than `Auto`, global data structures are generated. To handle such cases, use the **Reusable code error diagnostic** parameter to choose the severity levels for diagnostics

In some cases, the Real-Time Workshop Embedded Coder software is unable to generate valid and compilable code. For example, if the model contains any of the following, the code generated would be invalid.

- An S-function that is not code-reuse compliant
- A subsystem triggered by a wide function call trigger

In these cases, the build terminates after reporting the problem.

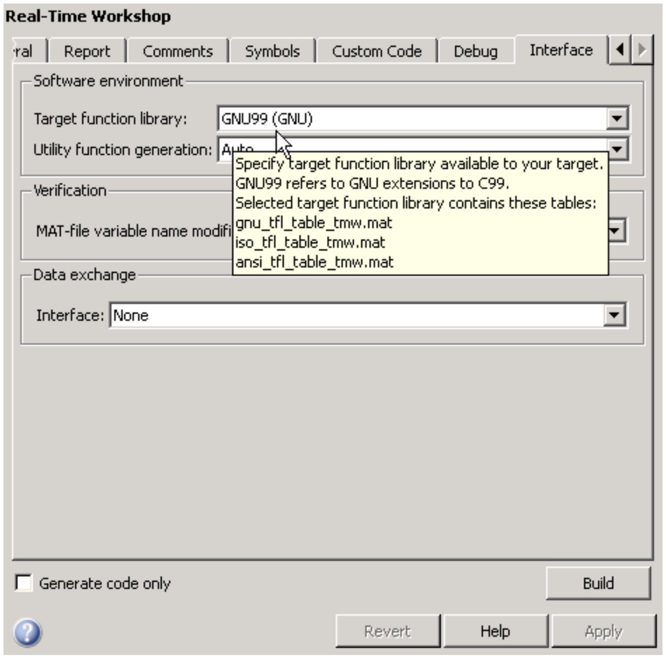
For more information, see “Real-Time Workshop Pane: Interface” in the Real-Time Workshop reference documentation.

## Configuring Target Function Libraries

A *target function library* (TFL) is a set of one or more function replacement tables that define the target-specific implementations of math functions and operators to be used in generating code for your Simulink model. The Real-Time Workshop product provides three default TFLs, which you can select from the **Target function library** drop-down list on the **Interface** pane of the Configuration Parameters dialog box.

| TFL | Description | Contains tables... |
|---|---|---|
| `C89/C90 (ANSI)` | Generates calls to the ISO/IEC 9899:1990 C standard math library for floating-point functions. | `ansi_tfl_table_tmw.mat` |
| `C99 (ISO)` | Generates calls to the ISO/IEC 9899:1999 C standard math library. | `iso_tfl_table_tmw.mat`<br>`ansi_tfl_table_tmw.mat` |
| `GNU99 (GNU)` | Generates calls to the Free Software Foundation's GNU gcc math library, which provides C99 extensions as defined by compiler option `-std=gnu99`. | `gnu_tfl_table_tmw.mat`<br>`iso_tfl_table_tmw.mat`<br>`ansi_tfl_table_tmw.mat` |

TFL tables provide the basis for replacing default math functions and operators in your model code with target-specific code. If you select a library and then hover over the selected library with the cursor, a tool tip is displayed that describes the TFL and lists the function replacement tables it contains. Tables are listed in the order in which they are searched for a function or operator match.


Real-Time Workshop

Software environment

Target function library: GNU99 (GNU)

Utility function generation: Auto

Specify target function library available to your target.
GNU99 refers to GNU extensions to C99.
Selected target function library contains these tables:
gnu_tfl_table_tmw.mat
iso_tfl_table_tmw.mat
ansi_tfl_table_tmw.mat

Verification

MAT-file variable name modifi

Data exchange

Interface: None

Generate code only

The Real-Time Workshop product allows you to view the content of TFL function replacement tables using the Target Function Library Viewer, as described in "Selecting and Viewing Target Function Libraries". The Real-Time Workshop Embedded Coder product allows you to additionally create and register the function replacement tables that make up a TFL, as described in Chapter 30, "Replacing Math Functions and Operators Using Target Function Libraries".

# Interfacing With Hardware That is Not Running an Operating System (Bare Board)

## About Standalone Program Execution

By default, the Real-Time Workshop Embedded Coder software generates *standalone* programs that do not require an external real-time executive or operating system. A standalone program requires minimal modification to be adapted to the target hardware. The standalone program architecture supports execution of models with either single or multiple sample rates.

## Generating a Standalone Program

To generate a standalone program:

1. In the **Custom templates** subpane of the **Real-Time Workshop/Templates** pane of the Configuration Parameters dialog box, select the **Generate an example main program** option ( is on by default). This enables the **Target operating system** menu.

2. From the **Target operating system** menu, select `BareBoardExample` (the default selection).

3. Generate the code.

The Real-Time Workshop Embedded Coder software generates significantly different code for multirate models depending on the following factors:

- Whether the model executes in single-tasking or multitasking mode.
- Whether or not reusable code is being generated.

These factors affect the scheduling algorithms used in generated code, and in some cases affect the API for the model entry point functions. The following sections discuss these variants.

## Standalone Program Components

The core of a standalone program is the main loop. On each iteration, the main loop executes a background or null task and checks for a termination condition.

The main loop is periodically interrupted by a timer. The Real-Time Workshop function `rt_OneStep` is either installed as a timer interrupt service routine (ISR), or called from a timer ISR at each clock step.

The execution driver, `rt_OneStep`, sequences calls to the *`model`*`_step` functions. The operation of `rt_OneStep` differs depending on whether the generating model is single-rate or multirate. In a single-rate model, `rt_OneStep` simply calls the *`model`*`_step` function. In a multirate model, `rt_OneStep` prioritizes and schedules execution of blocks according to the rates at which they run.

## Main Program

| In this section... |
|---|
| "Overview of Operation" on page 32-5 |
| "Guidelines for Modifying the Main Program" on page 32-5 |

### Overview of Operation

The following pseudocode shows the execution of a Real-Time Workshop Embedded Coder main program.

```
main()
{
  Initialization (including installation of rt_OneStep as an
    interrupt service routine for a real-time clock)
  Initialize and start timer hardware
  Enable interupts
  While(not Error) and (time < final time)
    Background task
  EndWhile
  Disable interrupts (Disable rt_OneStep from executing)
  Complete any background tasks
  Shutdown
}
```

The pseudocode is a design for a harness program to drive your model. The `ert_main.c` or `.cpp` program only partially implements this design. You must modify it according to your specifications.

### Guidelines for Modifying the Main Program

This section describes the minimal modifications you should make in your production version of `ert_main.c` or `.cpp` to implement your harness program.

1. Call `*model*_initialize`.

2. Initialize target-specific data structures and hardware, such as ADCs or DACs.

3. Install `rt_OneStep` as a timer ISR.

4. Initialize timer hardware.

5. Enable timer interrupts and start the timer.

---

**Note** `rtModel` is not in a valid state until *`model`*`_initialize` has been called. Servicing of timer interrupts should not begin until *`model`*`_initialize` has been called.

---

6. Optionally, insert background task calls in the main loop.

7. On termination of the main loop (if applicable):

   - Disable timer interrupts.
   - Perform target-specific cleanup such as zeroing DACs.
   - Detect and handle errors. Note that even if your program is designed to run indefinitely, you may need to handle severe error conditions, such as timer interrupt overruns.

     You can use the macros `rtmGetErrorStatus` and `rtmSetErrorStatus` to detect and signal errors.

## rt_OneStep and Scheduling Considerations

**In this section...**

### Overview of Operation

The operation of `rt_OneStep` depends upon

- Whether your model is single-rate or multirate. In a single-rate model, the sample times of all blocks in the model, and the model's fixed step size, are the same. Any model in which the sample times and step size do not meet these conditions is termed multirate.
- Your model's solver mode (`SingleTasking` versus `MultiTasking`)

Permitted Solver Modes for Real-Time Workshop® Embedded Coder™ Targeted Models on page 32-7 summarizes the permitted solver modes for single-rate and multirate models. Note that for a single-rate model, only `SingleTasking` solver mode is allowed.

**Permitted Solver Modes for Real-Time Workshop Embedded Coder Targeted Models**

| Mode | Single-Rate | Multirate |
|---|---|---|
| `SingleTasking` | Allowed | Allowed |
| `MultiTasking` | Disallowed | Allowed |
| `Auto` | Allowed<br>(defaults to `SingleTasking`) | Allowed<br>(defaults to `MultiTasking`) |

The generated code for `rt_OneStep` (and associated timing data structures and support functions) is tailored to the number of rates in the model and to the solver mode. The following sections discuss each possible case.

## Single-Rate Single-tasking Operation

The only valid solver mode for a single-rate model is `SingleTasking`. Such models run in "single-rate" operation.

The following pseudocode shows the design of `rt_OneStep` in a single-rate program.

```
rt_OneStep()
{
  Check for interrupt overflow or other error
  Enable "rt_OneStep" (timer) interrupt
  Model_Step()  -- Time step combines output,logging,update
}
```

For the single-rate case, the generated *`model`*`_step` function is

```
void model_step(void)
```

Single-rate `rt_OneStep` is designed to execute *`model`*`_step` within a single clock period. To enforce this timing constraint, `rt_OneStep` maintains and checks a timer overrun flag. On entry, timer interrupts are disabled until the overrun flag and other error conditions have been checked. If the overrun flag is clear, `rt_OneStep` sets the flag, and proceeds with timer interrupts enabled.

The overrun flag is cleared only upon successful return from *`model`*`_step`. Therefore, if `rt_OneStep` is reinterrupted before completing *`model`*`_step`, the reinterruption is detected through the overrun flag.

Reinterruption of `rt_OneStep` by the timer is an error condition. If this condition is detected `rt_OneStep` signals an error and returns immediately. (Note that you can change this behavior if you want to handle the condition differently.)

Note that the design of `rt_OneStep` assumes that interrupts are disabled before `rt_OneStep` is called. `rt_OneStep` should be noninterruptible until the interrupt overflow flag has been checked.

## Multirate Multitasking Operation

In a multirate multitasking system, the Real-Time Workshop Embedded Coder software uses a prioritized, preemptive multitasking scheme to execute the different sample rates in your model.

The following pseudocode shows the design of `rt_OneStep` in a multirate multitasking program.

```
rt_OneStep()
{
  Check for base-rate interrupt overrun
  Enable "rt_OneStep" interrupt
  Determine which rates need to run this time step

  Model_Step0()        -- run base-rate time step code

  For N=1:NumTasks-1   -- iterate over sub-rate tasks
    If (sub-rate task N is scheduled)
    Check for sub-rate interrupt overrun
      Model_StepN()    -- run sub-rate time step code
    EndIf
  EndFor
}
```

### Task Identifiers

The execution of blocks having different sample rates is broken into tasks. Each block that executes at a given sample rate is assigned a *task identifier* (`tid`), which associates it with a task that executes at that rate. Where there are `NumTasks` tasks in the system, the range of task identifiers is 0..`NumTasks`-1.

### Prioritization of Base-Rate and Subrate Tasks

Tasks are prioritized, in descending order, by rate. The *base-rate* task is the task that runs at the fastest rate in the system (the hardware clock rate). The base-rate task has highest priority (`tid` 0). The next fastest task (`tid` 1) has the next highest priority, and so on down to the slowest, lowest priority task (`tid` `NumTasks`-1).

The slower tasks, running at submultiples of the base rate, are called *subrate* tasks.

## Rate Grouping and Rate-Specific model_step Functions

In a single-rate model, all block output computations are performed within a single function, `model_step`. For multirate, multitasking models, the Real-Time Workshop Embedded Coder software uses a different strategy (whenever possible). This strategy is called *rate grouping*. Rate grouping generates separate `model_step` functions for the base rate task and each subrate task in the model. The function naming convention for these functions is

```
model_stepN
```

where `N` is a task identifier. For example, for a model named `my_model` that has three rates, the following functions are generated:

```
void my_model_step0 (void);
void my_model_step1 (void);
void my_model_step2 (void);
```

Each `model_stepN` function executes all blocks sharing `tid N`; in other words, all block code that executes within task `N` is grouped into the associated `model_stepN` function.

## Scheduling model_stepN Execution

On each clock tick, `rt_OneStep` and `model_step0` maintain scheduling counters and *event flags* for each subrate task. The counters are implemented in the `Timing.TaskCounters.TIDn` fields of `rtModel`. The event flags are implemented as arrays, indexed on `tid`.

The scheduling counters are maintained by the `rate_monotonic_scheduler` function, which is called by `model_step0` (that is, in the base-rate task). The function updates flags—an active task flag for each subrate and rate transition flags for tasks that exchange data—and assumes the use of a rate monotonic scheduler. The scheduling counters are, in effect, clock rate dividers that count up the sample period associated with each subrate task.

The event flags indicate whether or not a given task is scheduled for execution. `rt_OneStep` maintains the event flags based on a task counter that is maintained by code in the model's example main program (`ert_main.c`). When a counter indicates that a task's sample period has elapsed, the example main code sets the event flag for that task.

On each invocation, `rt_OneStep` updates its scheduling data structures and steps the base-rate task (`rt_OneStep` always calls *`model`*`_step0` because the base-rate task must execute on every clock step). Then, `rt_OneStep` iterates over the scheduling flags in `tid` order, unconditionally calling *`model`*`_step`*`N`* for any task whose flag is set. This ensures that tasks are executed in order of priority.

### Preemption

Note that the design of `rt_OneStep` assumes that interrupts are disabled before `rt_OneStep` is called. `rt_OneStep` should be noninterruptible until the base-rate interrupt overflow flag has been checked (see pseudocode above).

The event flag array and loop variables used by `rt_OneStep` are stored as local (stack) variables. This ensures that `rt_OneStep` is reentrant. If `rt_OneStep` is reinterrupted, higher priority tasks preempt lower priority tasks. Upon return from interrupt, lower priority tasks resume in the previously scheduled order.

### Overrun Detection

Multirate `rt_OneStep` also maintains an array of timer overrun flags. `rt_OneStep` detects timer overrun, per task, by the same logic as single-rate `rt_OneStep`.

---

**Note** If you have developed multirate S-functions, or if you use a customized static main program module, see "Rate Grouping Compliance and Compatibility Issues" on page 32-21 for information about how to adapt your code for rate grouping compatibility. This adaptation lets your multirate, multitasking models generate more efficient code.

---

## Multirate Single-Tasking Operation

In a multirate single-tasking program, by definition, all sample times in the model must be an integer multiple of the model's fixed-step size.

In a multirate single-tasking program, blocks execute at different rates, but under the same task identifier. The operation of `rt_OneStep`, in this case, is a simplified version of multirate multitasking operation. Rate grouping is not used. The only task is the base-rate task. Therefore, only one *`model`*`_step` function is generated:

```
void model_step(int_T tid)
```

On each clock tick, `rt_OneStep` checks the overrun flag and calls *`model`*`_step`, passing in `tid 0`. The scheduling function for a multirate single-tasking program is `rate_scheduler` (rather than `rate_monotonic_scheduler`). The scheduler maintains scheduling counters on each clock tick. There is one counter for each sample rate in the model. The counters are implemented in an array (indexed on tid) within the `Timing` structure within `rtModel`.

The counters are, in effect, clock rate dividers that count up the sample period associated with each subrate task. When a counter indicates that a sample period for a given rate has elapsed, `rate_scheduler` clears the counter. This condition indicates that all blocks running at that rate should execute on the next call to *`model`*`_step`, which is responsible for checking the counters.

## Guidelines for Modifying rt_OneStep

`rt_OneStep` does not require extensive modification. The only required modification is to reenable interrupts after the overrun flags and error conditions have been checked. If applicable, you should also

- Save and restore your FPU context on entry and exit to `rt_OneStep`.
- Set model inputs associated with the base rate before calling *`model`*`_step0`.
- Get model outputs associated with the base rate after calling *`model`*`_step0`.

---

**Note** If you modify `rt_OneStep` to read a value from a continuous output port after each base-rate model step, see the relevant cautionary guideline below.

---

- In a multirate, multitasking model, set model inputs associated with subrates before calling *`model`*`_step`*`N`* in the subrate loop.
- In a multirate, multitasking model, get model outputs associated with subrates after calling *`model`*`_step`*`N`* in the subrate loop.

Comments in `rt_OneStep` indicate the appropriate place to add your code.

In multirate `rt_OneStep`, you can improve performance by unrolling `for` and `while` loops.

In addition, you may choose to modify the overrun behavior to continue execution after error recovery is complete.

Also observe the following cautionary guidelines:

- You should not modify the way in which the counters, event flags, or other timing data structures are set in `rt_OneStep`, or in functions called from `rt_OneStep`. The `rt_OneStep` timing data structures (including `rtModel`) and logic are critical to correct operation of any Real-Time Workshop Embedded Coder program.
- If you have customized `ert_main.c` or `.cpp` to read model outputs after each base-rate model step, be aware that selecting model options **Support: continuous time** and **Single output/update function** together may cause output values read from `ert_main` for a continuous output port to differ slightly from the corresponding output values in the model's logged data. This is because, while logged data is a snapshot of output at major time steps, output read from `ert_main` after the base-rate model step potentially reflects intervening minor time steps. To eliminate the discrepancy, either separate the generated output and update functions (clear the **Single output/update function** option) or place a Zero-Order Hold block before the continuous output port.

## Model Entry Points

The following functions represent entry points in the generated code for a Simulink model.

| Function | Description |
|---|---|
| `model_initialize` | Initialization entry point in generated code for Simulink model |
| `model_SetEventsForThisBaseStep` | Set event flags for multirate, multitasking operation before calling *`model`*`_step` for Simulink model — not generated as of Version 5.1 (R2008a) |
| `model_step` | Step routine entry point in generated code for Simulink model |
| `model_terminate` | Termination entry point in generated code for Simulink model |

Note that the calling interface generated for each of these functions differs significantly depending on how you set the **Generate reusable code** option (see Chapter 31, "Configuring the Target Hardware Environment").

By default, **Generate reusable code** is off, and the model entry point functions access model data with statically allocated global data structures.

When **Generate reusable code** is on, model data structures are passed in (by reference) as arguments to the model entry point functions. For efficiency, only those data structures that are actually used in the model are passed in. Therefore when **Generate reusable code** is on, the argument lists generated for the entry point functions vary according to the requirements of the model.

The entry points are exported with *`model`*`.h`. To call the entry-point functions from your hand-written code, add an `#include` *`model`*`.h` directive to your code. If **Generate reusable code** is on, you must examine the generated code to determine the calling interface required for these functions.

For more information, see the reference pages for the listed functions.

---

**Note** The function reference pages document the default (**Generate reusable code** off) calling interface generated for these functions.

---

## Static Main Program Module

**In this section...**

### Overview

In most cases, the easiest strategy for deploying generated code is to use the **Generate an example main program option** to generate the `ert_main.c` or `.cpp` module (see "Generating a Standalone Program" on page 32-3).

However, if you turn the **Generate an example main program** option off, you can use the module `*matlabroot*/rtw/c/ert/ert_main.c` as a template example for developing your embedded applications. The module is not part of the generated code; it is provided as a basis for your custom modifications, and for use in simulation. If your existing applications, developed prior to this release, depend upon a static `ert_main.c`, you may need to continue using this module.

When developing applications using a static `ert_main.c`, you should copy this module to your working directory and rename it to `*model*_ert_main.c` before making modifications. Also, you must modify the template makefile such that the build process creates `*model*_ert_main.obj` (on UNIX, `*model*_ert_main.o`) in the build directory.

The static `ert_main.c` contains

- `rt_OneStep`, a timer interrupt service routine (ISR). `rt_OneStep` calls `*model*_step` to execute processing for one clock period of the model.
- A skeletal `main` function. As provided, `main` is useful in simulation only. You must modify `main` for real-time interrupt-driven execution.

For single-rate models, the operation of `rt_OneStep` and the main function are essentially the same in the static version of `ert_main.c` as they are in the autogenerated version described in "About Standalone Program Execution" on page 32-2. For multirate, multitasking models, however, the static and generated code is slightly different. The next section describes this case.

## Rate Grouping and the Static Main Program

Targets based on the ERT target sometimes use a static `ert_main` module and disallow use of the **Generate an example main program** option. This may be necessary because target-specific modifications have been added to the static `ert_main.c`, and these modifications would not be preserved if the main program were regenerated.

Your `ert_main` module may or may not use rate grouping compatible *`model`*`_step`*`N`* functions. If your `ert_main` module is based on the static `ert_main.c` module, it does not use rate-specific *`model`*`_step`*`N`* function calls. The static `ert_main.c` module uses the old-style *`model`*`_step` function, passing in a task identifier:

```
void model_step(int_T tid);
```

By default, when the **Generate an example main program** option is off, the ERT target generates a *`model`*`_step` "wrapper" for multirate, multitasking models. The purpose of the wrapper is to interface the rate-specific *`model`*`_step`*`N`* functions to the old-style call. The wrapper code dispatches to the appropriate *`model`*`_step`*`N`* call with a `switch` statement, as in the following example:

```
void mymodel_step(int_T tid) /* Sample time:  */
{

  switch(tid) {
   case 0 :
    mymodel_step0();
    break;
   case 1 :
    mymodel_step1();
    break;
   case 2 :
    mymodel_step2();
    break;
   default :
    break;
    }
  }
```

The following pseudocode shows how `rt_OneStep` calls *`model`*`_step` from the static main program in a multirate, multitasking model.

```
  rt_OneStep()
  {
    Check for base-rate interrupt overflow
    Enable "rt_OneStep" interrupt
    Determine which rates need to run this time step

    ModelStep(tid=0)     --base-rate time step

    For N=1:NumTasks-1  -- iterate over sub-rate tasks
      Check for sub-rate interrupt overflow
      If (sub-rate task N is scheduled)
        ModelStep(tid=N)    --sub-rate time step
      EndIf
    EndFor
  }
```

You can use the TLC variable `RateBasedStepFcn` to specify that only the rate-based step functions are generated, without the wrapper function. If your target calls the rate grouping compatible *`model`*`_step`*`N`* function directly, set `RateBasedStepFcn` to `1`. In this case, the wrapper function is not generated.

You should set `RateBasedStepFcn` prior to the `%include "codegenentry.tlc"` statement in your system target file. Alternatively, you can set `RateBasedStepFcn` in your `target_settings.tlc` file.

## Modifying the Static Main Program

As in the generated `ert_main.c`, a few modifications to the main loop and `rt_OneStep` are necessary. See "Guidelines for Modifying the Main Program" on page 32-5 and "Guidelines for Modifying rt_OneStep" on page 32-12.

Also, you should replace the `rt_OneStep` call in the main loop with a background task call or null statement.

Other modifications you may need to make are

- If your model has multiple rates, the generated code does not operate correctly unless:
  - The multirate scheduling code is removed. The relevant code is tagged with the keyword `REMOVE` in comments (see also the Version 3.0 comments in `ert_main.c`).
  - Use the `MODEL_SETEVENTS` macro (defined in `ert_main.c`) to set the event flags instead of accessing the flags directly. The relevant code is tagged with the keyword `REPLACE` in comments.
- Remove old `#include ertformat.h` directives. `ertformat.h` will be obsoleted in a future release. The following macros, formerly defined in `ertformat.h`, are now defined within `ert_main.c`:

  ```
  EXPAND_CONCAT
  CONCAT
  MODEL_INITIALIZE
  MODEL_STEP
  MODEL_TERMINATE
  MODEL_SETEVENTS
  RT_OBJ
  ```

  See also the comments in `ertformat.h`.
- If applicable, follow comments in the code regarding where to add code for reading/writing model I/O and saving/restoring FPU context.

**Note** If you modify `ert_main.c` to read a value from a continuous output port after each base-rate model step, see the relevant cautionary guideline in "Guidelines for Modifying rt_OneStep" on page 32-12.

- When the **Generate an example main program** option is off, the Real-Time Workshop Embedded Coder software generates the file `autobuild.h` to provide an interface between the main module and generated model code. If you create your own static main program module, you would normally include `autobuild.h`.

Alternatively, you can suppress generation of `autobuild.h`, and include *`model`*`.h` directly in your main module. To suppress generation of `autobuild.h`, use the following statement in your system target file:

```
%assign AutoBuildProcedure = 0
```

- If you have cleared the **Terminate function required** option, remove or comment out the following in your production version of `ert_main.c`:
  - The `#if TERMFCN...` compile-time error check
  - The call to `MODEL_TERMINATE`
- If you do *not* want to combine output and update functions, clear the **Single output/update function** option and make the following changes in your production version of `ert_main.c`:
  - Replace calls to `MODEL_STEP` with calls to `MODEL_OUTPUT` and `MODEL_UPDATE`.
  - Remove the `#if ONESTEPFCN...` error check.
- The static `ert_main.c` module does not support the **Generate Reusable Code** option. Use this option only if you are generating a main program. The following error check raises a compile-time error if **Generate Reusable Code** is used illegally.

  ```
  #if MULTI_INSTANCE_CODE==1
  ```

- The static `ert_main.c` module does not support the **External mode** option. Use this option only if you are generating a main program. The following error check raises a compile-time error if **External mode** is used illegally.

  ```
  #ifdef EXT_MODE
  ```

## Rate Grouping Compliance and Compatibility Issues

**In this section...**

### Main Program Compatibility

When the **Generate an example main program** option is off, the Real-Time Workshop Embedded Coder software generates slightly different rate grouping code, for compatibility with the older static `ert_main.c` module. See "Rate Grouping and the Static Main Program" on page 32-17 for details.

### Making Your S-Functions Rate Grouping Compliant

All built-in Simulink blocks, as well as all Signal Processing Blockset blocks, are compliant with the requirements for generating rate grouping code. However, user-written multirate inlined S-functions may not be rate grouping compliant. Noncompliant blocks generate less efficient code, but are otherwise compatible with rate grouping. To take full advantage of the efficiency of rate grouping, your multirate inlined S-functions must be upgraded to be fully rate grouping compliant. You should upgrade your TLC S-function implementations, as described in this section.

Use of noncompliant multirate blocks to generate rate-grouping code generates dead code. This can cause two problems:

- Reduced code efficiency.
- Warning messages issued at compile time. Such warnings are caused when dead code references temporary variables before initialization. Since the dead code never runs, this problem does not affect the run-time behavior of the generated code.

To make your S-functions rate grouping compliant, you can use the following TLC functions to generate `ModelOutputs` and `ModelUpdate` code, respectively:

```
OutputsForTID(block, system, tid)
UpdateForTID(block, system, tid)
```

The code listings below illustrate generation of output computations without rate grouping (Listing 1) and with rate grouping (Listing 2). Note the following:

- The `tid` argument is a task identifier (`0..NumTasks-1`).
- Only code guarded by the `tid` passed in to `OutputsForTID` is generated. The `if (%<LibIsSFcnSampleHit(portName)>)` test is not used in `OutputsForTID`.
- When generating rate grouping code, `OutputsForTID` and/or `UpdateForTID` is called during code generation. When generating non-rate-grouping code, `Outputs` and/or `Update` is called.
- In rate grouping compliant code, the top-level `Outputs` and/or `Update` functions call `OutputsForTID` and/or `UpdateForTID` functions for each rate (`tid`) involved in the block. The code returned by `OutputsForTID` and/or `UpdateForTID` must be guarded by the corresponding `tid` guard:

  ```
  if (%<LibIsSFcnSampleHit(portName)>)
  ```

  as in Listing 2.

## Listing 1: Outputs Code Generation Without Rate Grouping

```
%% multirate_blk.tlc

%implements "multirate_blk" "C"


%% Function: mdlOutputs =====================================================
%% Abstract:
%%
%%  Compute the two outputs (input signal decimated by the
%%  specified parameter). The decimation is handled by sample times.
%%  The decimation is only performed if the block is enabled.
%%  Each ports has a different rate.
%%
%%  Note, the usage of the enable should really be protected such that
%%  Neach task has its own enable state. In this example, the enable
%% occurs immediately which may or may not be the expected behavior.
```

```
%%
  %function Outputs(block, system) Output
  /* %<Type> Block: %<Name> */
  %assign enable = LibBlockInputSignal(0, "", "", 0)
  {
    int_T *enabled = &%<LibBlockIWork(0, "", "", 0)>;

    %if LibGetSFcnTIDType("InputPortIdx0") == "continuous"
      %% Only check the enable signal on a major time step.
      if (%<LibIsMajorTimeStep()> && ...
                        %<LibIsSFcnSampleHit("InputPortIdx0")>) {
        *enabled = (%<enable> > 0.0);
      }
    %else
      if (%<LibIsSFcnSampleHit("InputPortIdx0")>) {
        *enabled = (%<enable> > 0.0);
      }
    %endif

    if (*enabled) {
      %assign signal = LibBlockInputSignal(1, "", "", 0)
      if (%<LibIsSFcnSampleHit("OutputPortIdx0")>) {
        %assign y = LibBlockOutputSignal(0, "", "", 0)
        %<y> = %<signal>;
      }
      if (%<LibIsSFcnSampleHit("OutputPortIdx1")>) {
        %assign y = LibBlockOutputSignal(1, "", "", 0)
        %<y> = %<signal>;
      }
    }
  }

  %endfunction
%% [EOF] sfun_multirate.tlc
```

### Listing 2: Outputs Code Generation With Rate Grouping

```
%% example_multirateblk.tlc

%implements "example_multirateblk" "C"
```

```
%% Function: mdlOutputs =====================================================
%% Abstract:
%%
%% Compute the two outputs (the input signal decimated by the
%% specified parameter). The decimation is handled by sample times.
%% The decimation is only performed if the block is enabled.
%% All ports have different sample rate.
%%
%% Note: the usage of the enable should really be protected such that
%% each task has its own enable state. In this example, the enable
%% occurs immediately which may or may not be the expected behavior.
%%
%function Outputs(block, system) Output



%assign portIdxName = ["InputPortIdx0","OutputPortIdx0","OutputPortIdx1"]
%assign portTID     = [%<LibGetGlobalTIDFromLocalSFcnTID("InputPortIdx0")>, ...
                       %<LibGetGlobalTIDFromLocalSFcnTID("OutputPortIdx0")>, ...
                       %<LibGetGlobalTIDFromLocalSFcnTID("OutputPortIdx1")>]
%foreach i = 3
  %assign portName = portIdxName[i]
  %assign tid      = portTID[i]
  if (%<LibIsSFcnSampleHit(portName)>) {
                     %<OutputsForTID(block,system,tid)>
  }
%endforeach

%endfunction

%function OutputsForTID(block, system, tid) Output
/* %<Type> Block: %<Name> */
%assign enable = LibBlockInputSignal(0, "", "", 0)
%assign enabled = LibBlockIWork(0, "", "", 0)
%assign signal = LibBlockInputSignal(1, "", "", 0)

%switch(tid)
  %case LibGetGlobalTIDFromLocalSFcnTID("InputPortIdx0")
```

```
                         %if LibGetSFcnTIDType("InputPortIdx0") == "continuous"
                           %% Only check the enable signal on a major time step.
                           if (%<LibIsMajorTimeStep()>) {
                             %<enabled> = (%<enable> > 0.0);
                           }
                         %else
                           %<enabled> = (%<enable> > 0.0);
                         %endif
                         %break
    %case LibGetGlobalTIDFromLocalSFcnTID("OutputPortIdx0")
                         if (%<enabled>) {
                           %assign y = LibBlockOutputSignal(0, "", "", 0)
                           %<y> = %<signal>;
                         }
                         %break
    %case LibGetGlobalTIDFromLocalSFcnTID("OutputPortIdx1")
                         if (%<enabled>) {
                           %assign y = LibBlockOutputSignal(1, "", "", 0)
                           %<y> = %<signal>;
                         }
                         %break
    %default
                         %% error it out
  %endswitch

  %endfunction

%% [EOF] sfun_multirate.tlc
```

# Wind River Systems VxWorks Example Main Program

## Introduction to the VxWorks Example Main Program

The Real-Time Workshop Embedded Coder product provides a Wind River Systems VxWorks example main program as a template for the deployment of generated code in a real-time operating system (RTOS) environment. You should read the preceding sections of this chapter as a prerequisite to working with the VxWorks example main program. An understanding of the Real-Time Workshop Embedded Coder scheduling and tasking concepts and algorithms, described in "About Standalone Program Execution" on page 32-2, is essential to understanding how generated code is adapted to an RTOS.

In addition, an understanding of how tasks are managed under the VxWorks RTOS is required. See your VxWorks documentation.

To generate a VxWorks example program:

1. In the **Custom templates** subpane of the **Real-Time Workshop/Templates** pane of the Configuration Parameters dialog box, select the **Generate an example main program** option (this option is on by default).

2. When **Generate an example main program** is selected, the **Target operating system** menu is enabled. Select `VxWorksExample` from this menu.

Some modifications to the generated code are required; comments in the generated code identify the required modifications.

## Task Management

**In this section...**

### Overview of Operation

In a VxWorks example program, the main program and the base rate and subrate tasks (if any) run as prioritized tasks. The logic of a VxWorks example program parallels that of a stand-alone program; the main difference lies in the fact that base rate and subrate tasks are activated by clock semaphores managed by the operating system, rather than directly by timer interrupts.

Your application code must spawn `model_main()` as an independent VxWorks task. The task priority you specify is passed in to `model_main()`.

As with a stand-alone program, the VxWorks example program architecture is tailored to the number of rates in the model and to the solver mode (see Permitted Solver Modes for Real-Time Workshop® Embedded Coder™ Targeted Models on page 32-7). The following sections discuss each possible case.

### Single-Rate Single-tasking Operation

In a single-rate, single-tasking model, `model_main()` spawns a base rate task, `tBaseRate`. In this case `tBaseRate` is the functional equivalent to `rtOneStep`. The base rate task is activated by a clock semaphore provided by the VxWorks RTOS, rather than by a timer interrupt. On each activation, `tBaseRate` calls `model_step`.

Note that the clock rate granted by the VxWorks RTOS may not be the same as the rate requested by `model_main`.

## Multirate Multitasking Operation

In a multirate, multitasking model, *`model`*`_main()` spawns a base rate task and subrate tasks. Task priorities are assigned by rate.

As in a stand-alone program, rate grouping code is used (where possible) for multirate, multitasking models. The base rate task calls *`model`*`_step0`, while the subrate tasks call *`model`*`_step`*`N`*. The base rate task calls a function that updates flags—an active task flag for each subrate and rate transition flags for tasks that exchange data. This function assumes the use of a rate-monotonic scheduler.

## Multirate Single-tasking Operation

In a multirate, single-tasking model, *`model`*`_main()` spawns only a base rate task, `tBaseRate`. All rates run under this task. The base rate task is activated by a clock semaphore provided by the VxWorks RTOS, rather than by a timer interrupt. On each activation, `tBaseRate` calls *`model`*`_step`.

*`model`*`_step` in turn calls the `rate_scheduler` utility, which maintains the scheduling counters that determine which rates should execute. *`model`*`_step` is responsible for checking the counters.

# Verifying Generated Code Applications

# Tracing Generated Code to Requirements

## About Generated Code and Requirements Traceability

Assuming that you have captured application requirements in a document, spreadsheet, data base, or requirements management tool, using a tool such as Simulink Report Generator, Microsoft® Word, Microsoft Excel, raw HTML, Telelogic®, or DOORS®, you can use interactive traceability and traceability reports to validate whether generated code meets the documented requirements. These mechanisms provide a way to trace generated code back to documented requirements and generate traceability reports.

## Goals of Generated Code and Requirements Traceability

For example, you can

- Associate requirements documents with objects in a concept model and generate a report on requirements associated with that model. For more information, see:
  - `slvnvdemo_fuelsys_docreq`
  - “Managing Model Requirements” in the Simulink Verification and Validation documentation
  - Bidirectional tracing in Microsoft Word, Microsoft Excel, HTML, and Telelogic DOORS
- Include requirements tags in generated code. For more information, see:
  - rtwdemo_requirements
  - “Including Requirements Information with Generated Code” in the Simulink Verification and Validation documentation
- Trace model blocks and subsystems to generated code and vice versa. For more information, see:
  - rtwdemo_hyperlinks
  - “About Traceability Extensions” on page 35-2

# Verifying Generated Code

## Code Generation Traceability Extensions

**In this section...**

### About Traceability Extensions

The Real-Time Workshop product introduces traceability capabilities.

- "About Code Traceability"
- "Format of Traceability Tags"
- "Examples of Tagged Code"
- "Tracing Code To Blocks Using hilite_system"
- "Traceability Limitations"

The Real-Time Workshop Embedded Coder product extends the preceding capabilities to support:

- "Tracing Code To Model Objects Using Hyperlinks" on page 35-2
- "Tracing Blocks to Generated Code" on page 35-4
- "Reloading Existing Trace Information" on page 35-6
- "Customizing Traceability Reports" on page 35-7

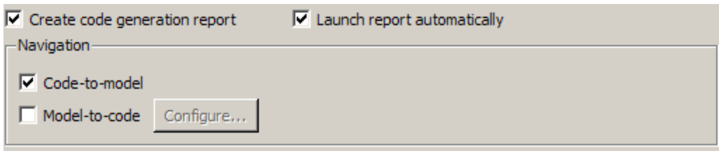
### Tracing Code To Model Objects Using Hyperlinks

When using the Real-Time Workshop product, you can trace code to model objects using the `hilite_system` command. The Real-Time Workshop Embedded Coder product simplifies traceability with the use of hyperlinks in HTML code generation reports. The reports display hyperlinks in "Regarding," "Outport," and other comment lines in generated code. You can highlight the corresponding block or subsystem in the model diagram by clicking the hyperlinks.

To use hyperlinks for tracing code to model objects:

1 Open the model and make sure it is configured for an ERT target.

2 In the Configuration Parameters dialog box, select **Real-Time Workshop > Report Create code generation report**. The parameter is selected by default. When selected, the parameter enables and selects **Launch report automatically** and **Code-to-model**.



☑ Create code generation report ☑ Launch report automatically

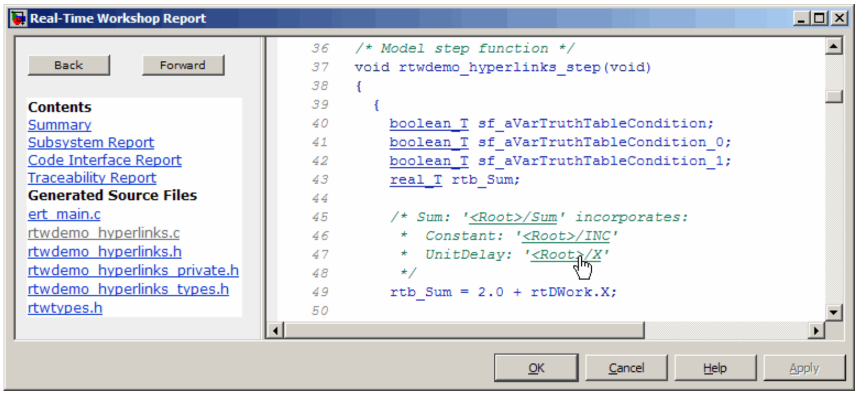
Navigation

☑ Code-to-model

☐ Model-to-code

3 Build or generate code for the model. An HTML code generation report is displayed.

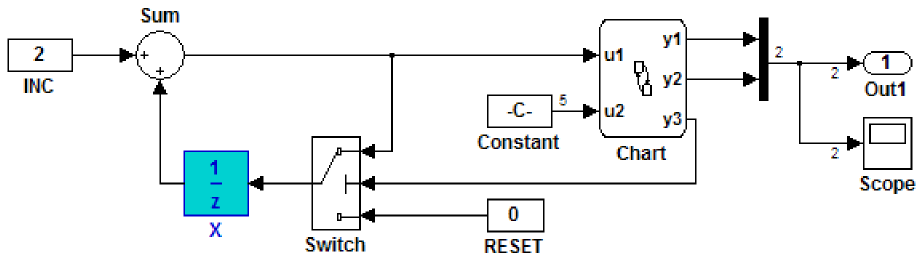
4 In the HTML report window, click hyperlinks to highlight source blocks. For example, generate an HTML report for model rtwdemo_hyperlinks. In the generated code for the model step function, click the first UnitDelay block hyperlink .



Contents
Summary
Subsystem Report
Code Interface Report
Traceability Report
Generated Source Files
ert_main.c
rtwdemo_hyperlinks.c
rtwdemo_hyperlinks.h
rtwdemo_hyperlinks_private.h
rtwdemo_hyperlinks_types.h
rtwtypes.h

```
/* Model step function */
void rtwdemo_hyperlinks_step(void)
{
  {
    boolean_T sf_aVarTruthTableCondition;
    boolean_T sf_aVarTruthTableCondition_0;
    boolean_T sf_aVarTruthTableCondition_1;
    real_T rtb_Sum;

    /* Sum: '<Root>/Sum' incorporates:
     *  Constant: '<Root>/INC'
     *  UnitDelay: '<Root>/X'
     */
    rtb_Sum = 2.0 + rtDWork.X;

```

In the model window, the corresponding UnitDelay block is highlighted.



For more information on generating HTML code generation reports or using the `hilite_system` command to trace code to blocks, see the following topics in the Real-Time Workshop documentation:

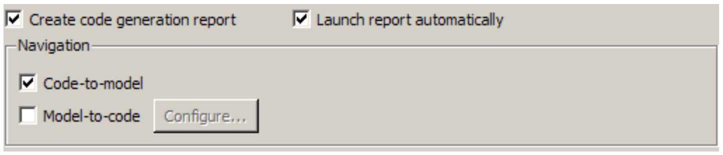
- "Generating Reports for Code Reviews and Traceability Analysis"
- "Tracing Generated Code"

## Tracing Blocks to Generated Code

To trace blocks to generated code:

1. Open the model and make sure it is configured for an ERT target.

2. In the Configuration Parameters dialog box, select **Real-Time Workshop > Report > Create code generation report**. The parameter is selected by default. When selected, the parameter enables and selects the **Launch report automatically** and **Code-to-model** parameters.



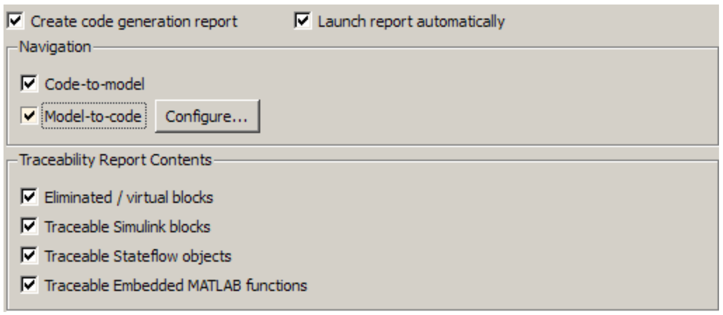
☑ Create code generation report ☑ Launch report automatically

Navigation

☑ Code-to-model

☐ Model-to-code

3. Select **Model-to-code**.


☑ Create code generation report ☑ Launch report automatically

Navigation

☑ Code-to-model

☑ Model-to-code Configure...

Traceability Report Contents

☑ Eliminated / virtual blocks

☑ Traceable Simulink blocks

☑ Traceable Stateflow objects

☑ Traceable Embedded MATLAB functions

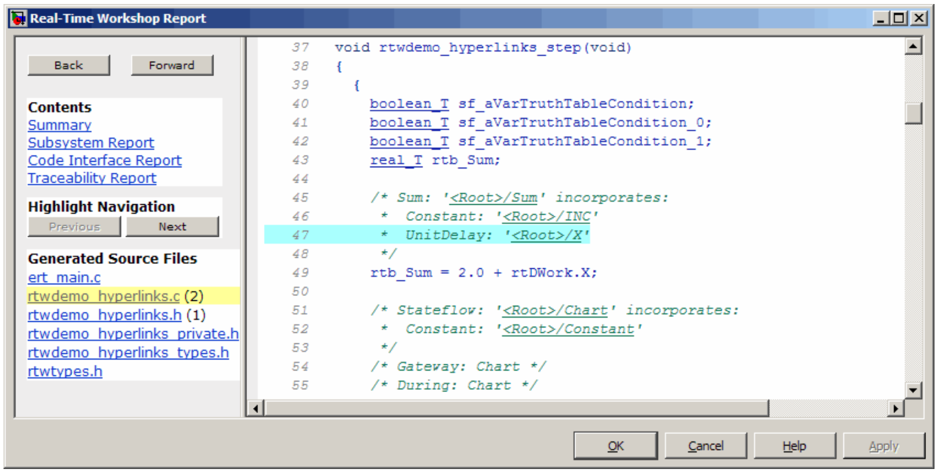
This parameter:

- Enables the **Configure** button, which opens a dialog box for loading existing trace information.
- Enables and selects parameters for customizing the content of a traceability report.

**4** Build or generate code for the model. An HTML code generation report is displayed.

**5** In the model window, right-click a block.

**6** In the context menu, select **Real-Time Workshop > Navigate to Code**. In the HTML code generation report, you see the first instance of highlighted code generated for the block. In the left pane of the report, numbers that appear to the right of generated file names indicate the total number of highlighted lines in each file. The following figure shows the result of tracing the Unit Delay block in model `rtwdemo_hyperlinks`.



**Contents**
Summary
Subsystem Report
Code Interface Report
Traceability Report

**Generated Source Files**
ert_main.c
rtwdemo_hyperlinks.c (2)
rtwdemo_hyperlinks.h (1)
rtwdemo_hyperlinks_private.h
rtwdemo_hyperlinks_types.h
rtwtypes.h

```
void rtwdemo_hyperlinks_step(void)
{
  {
    boolean_T sf_aVarTruthTableCondition;
    boolean_T sf_aVarTruthTableCondition_0;
    boolean_T sf_aVarTruthTableCondition_1;
    real_T rtb_Sum;

    /* Sum: '<Root>/Sum' incorporates:
     *  Constant: '<Root>/INC'
     *  UnitDelay: '<Root>/X'
     */
    rtb_Sum = 2.0 + rtDWork.X;

    /* Stateflow: '<Root>/Chart' incorporates:
     *  Constant: '<Root>/Constant'
     */
    /* Gateway: Chart */
    /* During: Chart */
```

To navigate through multiple instances of highlighted lines, click **Previous** and **Next**.

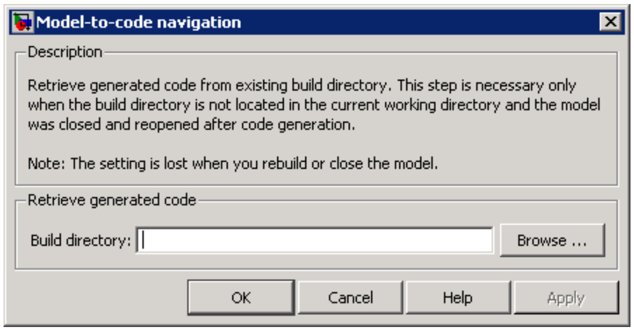
If you close and reopen a model, the **Navigate to Code** context menu option might not be available. This occurs because Real-Time Workshop Embedded Coder cannot find a build directory for your model in the current working directory. To address this, do one of the following:

- Reset the current working directory to the parent directory of the existing build directory.
- Select **Model-to-code** and rebuild the model. This regenerates the build directory into the current working directory.
- Click **Configure** and in the Model-to-code navigation dialog box, reload the existing trace information.

## Reloading Existing Trace Information

To reload existing trace information for a model:

1 In the Configuration Parameters dialog box, click **Real-Time Workshop > Report > Configure**. The Model-to-code navigation dialog box opens.


Model-to-code navigation

Description

Retrieve generated code from existing build directory. This step is necessary only when the build directory is not located in the current working directory and the model was closed and reopened after code generation.

Note: The setting is lost when you rebuild or close the model.

Retrieve generated code

Build directory:

2 In the **Build directory** field, type or browse to the build directory that contains the existing trace information.

If you close and reopen a model, the **Navigate to Code** context menu option might not be available. This occurs because Real-Time Workshop Embedded Coder cannot find a build directory for your model in the current working directory. To fix this without having to reset the current working directory or rebuild the model, do the following:

1 Click **Configure** to open the Model-to-code navigation dialog box.

2 In the Model-to-code navigation dialog box, click **Browse**.

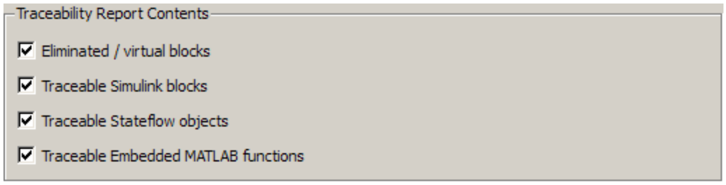
3 Browse to the build directory for your model, and select the directory. The build directory path is displayed in the **Build directory** field, as shown in the preceding figure.

4 Click **Apply** or **OK**. This loads trace information from the earlier build into your Simulink session, provided that you selected **Model-to-code** for the build.

5 Right-click **Real-Time Workshop > Navigate to Code** to open the context menu and trace a block to corresponding code.

## Customizing Traceability Reports

In the Configuration Parameters dialog box, the **Real-Time Workshop > Report > Traceability Report Contents** section lists parameters you can select and clear to customize the content of your traceability reports. By default, all parameters are selected, as shown in the following figure.


Traceability Report Contents

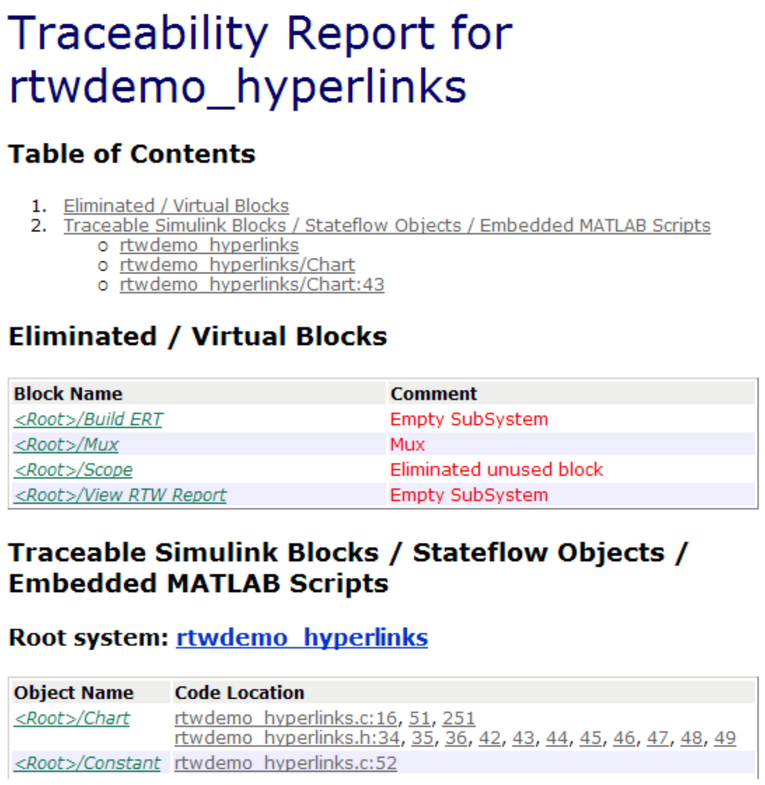
- [✓] Eliminated / virtual blocks
- [✓] Traceable Simulink blocks
- [✓] Traceable Stateflow objects
- [✓] Traceable Embedded MATLAB functions

Select or clear any combination of the following:

- **Eliminated / virtual blocks** (account for blocks that are untraceable)
- **Traceable Simulink blocks**
- **Traceable Stateflow objects**
- **Traceable Embedded MATLAB functions**

If you select all parameters, you get a complete mapping between model elements and the generated code.

The following figure shows the top section of the traceability report generated by selecting all traceability content parameters for model `rtwdemo_hyperlinks`.



# Traceability Report for rtwdemo_hyperlinks

**Table of Contents**

1. Eliminated / Virtual Blocks
2. Traceable Simulink Blocks / Stateflow Objects / Embedded MATLAB Scripts
   - rtwdemo_hyperlinks
   - rtwdemo_hyperlinks/Chart
   - rtwdemo_hyperlinks/Chart:43

**Eliminated / Virtual Blocks**

| Block Name | Comment |
|---|---|
| <Root>/Build ERT | Empty SubSystem |
| <Root>/Mux | Mux |
| <Root>/Scope | Eliminated unused block |
| <Root>/View RTW Report | Empty SubSystem |

**Traceable Simulink Blocks / Stateflow Objects / Embedded MATLAB Scripts**

**Root system: rtwdemo_hyperlinks**

| Object Name | Code Location |
|---|---|
| <Root>/Chart | rtwdemo_hyperlinks.c:16, 51, 251<br>rtwdemo_hyperlinks.h:34, 35, 36, 42, 43, 44, 45, 46, 47, 48, 49 |
| <Root>/Constant | rtwdemo_hyperlinks.c:52 |

## Traceability Limitations

In addition to the Real-Time Workshop traceability limitations, the following limitations apply to reports generated by Real-Time Workshop Embedded Coder software.

- Under the following conditions, model-to-code traceability is disabled for a block if the block name contains:
  - A single quote (').
  - An asterisk (*), that causes a name-mangling ambiguity relative to other names in the model. This name-mangling ambiguity occurs if in a block name or at the end of a block name, an asterisk precedes or follows a slash (/).

  - The character  (`char(255)`).
- You cannot trace blocks representing the following types of subsystems to generated code:
  - Virtual subsystems
  - Masked subsystems
  - Nonvirtual subsystems for which code has been optimized away

  If you cannot trace a subsystem at subsystem level, you might be able to trace individual blocks within the subsystem.

## Checking Code Correctness

**In this section...**

### About Checking Code Correctness

Checking code correctness involves verifying that no compile-time, link-time, or run-time errors (for example, an overflow, divide by zero, or out-of-bounds array access) are in the source code.

### How To Check Code Correctness

You can rely on integrated development environment (IDE) tools to detect and facilitate correction of compile-time and link-time errors. However, it is more difficult to detect and correct run-time errors, such as overflows and division by zero. Some methods of detecting run-time errors include

- Running the executable and analyzing the results
- Inserting code instrumentation, such as print statements
- Writing and running tests

When checking the correctness of code generated by Real-Time Workshop technology, you also have the option of using PolySpace® products. PolySpace products are based on verification technology that uses formal methods to detect and mathematically prove whether classes of run-time errors, such as overflows, exist.

In addition, the PolySpace Model Link™ SL product lets you trace the results reported by PolySpace® Client™ for C/C++ software back to your Simulink model.

For more information about using PolySpace products, see the PolySpace documentation.

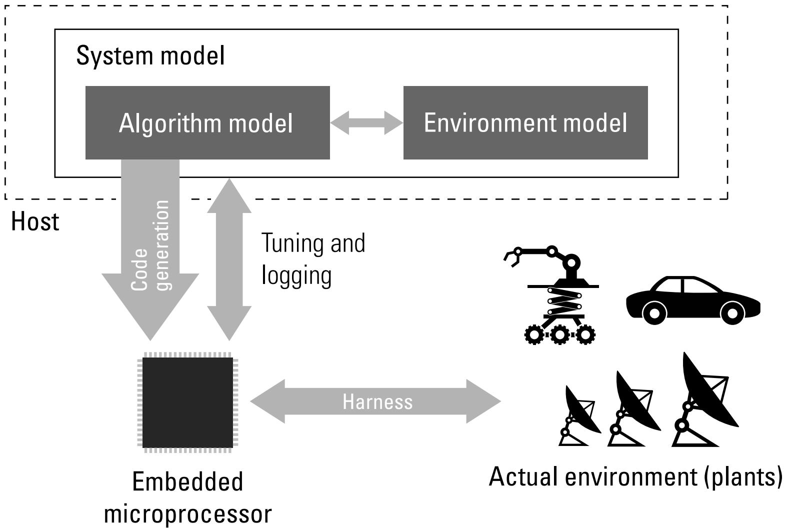
# Rapid Prototyping On a Target System

## About On-Target Rapid Prototyping

After you refine a detailed software design, you are ready to generate code to run on an embedded microprocessor and optimize the code with on-target rapid prototyping. During on-target rapid prototyping, you run generated code in real time, tune parameters, and monitor real-time data on the same processor that you plan to use in mass production, or a close equivalent to it.

Real-Time Workshop technology provides a framework for on-target rapid prototyping. You can generate code from your model and then assess, interact with, and optimize the code using real embedded compilers and hardware. This effort can help determine whether your algorithm can fit on or run fast enough for production devices, which typically have limited processor resources.

The following figure shows an example of an on-target rapid prototyping environment.



## Goals of On-Target Rapid Prototyping

Assuming that you have a detailed software design and an embedded microprocessor target, you can use on-target rapid prototyping to:

- Refine the concept model of your component or system
- Test and validate model functionality in real time
- Test hardware
- Obtain real-time profiles and code metrics for analysis and sizing based on an embedded processor
- Assess the feasibility of an algorithm based on integration with environment or plant hardware

## Optimizing Generated Code for an Embedded Processor With On-Target Rapid Prototyping

To do on-target rapid prototyping:

1. Generate the source code for your models, integrate the code into your production build environment, and run it on existing hardware. For more information see:
   - "Testing and Refining a Model With Rapid Prototyping" in the Real-Time Workshop documentation
   - "Selecting and Configuring a Target "
   - "Interfacing With a Real-Time Operating System "
2. Integrate existing, externally written C or C++ code with your model for simulation and code generation. For more information, see "Integrating Existing C Functions into Simulink Models with the Legacy Code Tool" in the Simulink documentation.
3. Use a third-party integrated development environment (IDE) or makefile with a MathWorks link product, third-party product, or custom integration to build an executable for the embedded microprocessor.
4. To monitor signals, tune parameters, and log data as the embedded microprocessor controls the actual environment or plant, use the following MathWorks products:
   - Embedded IDE Link product for integration with selected IDEs
   - Target Support Package product for deployment on selected embedded processors
5. If using custom integration, use a Real-Time Workshop Embedded Coder runtime interface option, such as external mode, C API, or ASAP2 file generation, to monitor and tune signals. Also consider using the Vehicle Network Toolbox™ product if you are developing a solution based on a controller-area network (CAN).

# Verifying Generated Source Code With Software-In-the-Loop Simulation

## About Software-In-the-Loop Simulation Extensions

The Real-Time Workshop product introduces software-in-the-loop (SIL) simulation capabilities. See:

- “About Software-In-the-Loop Simulation”
- “Maintaining Bit-True Agreement Between Host Simulations and Code for Target Deployment”
- “Setting Up and Running SIL Simulations Using a Hand-Written S-Function Wrapper”

The Real-Time Workshop Embedded Coder product extends the preceding capabilities to support:

- “Setting Up a Model to Generate Code for Host Simulations and Target Deployment” on page 37-3
- “Generating an S-Function Wrapper for SIL Testing” on page 37-6

Other SIL simulation options are available through the PIL infrastructure (see Chapter 40, “Verifying Compiled Object Code with Processor-in-the-Loop Simulation”). By setting the simulation mode for a model or Model block to PIL you can effectively run SIL simulations. For more information, see `rtwdemo_sil_pil`.

## Setting Up a Model to Generate Code for Host Simulations and Target Deployment

**In this section...**

When configuring a model for SIL simulation with the Real-Time Workshop product and when processor word sizes differ between host and target platforms, you can configure the model to use an emulation hardware option. That option guarantees bit-true agreement for integer and fixed-point operations between host system simulation results and target deployment.

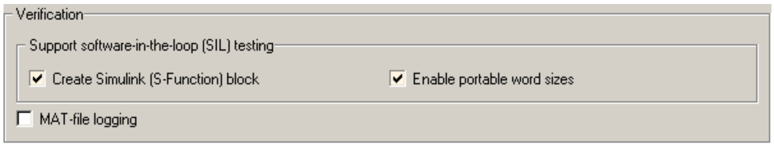
In addition to the emulation hardware option, the Real-Time Workshop Embedded Coder product provides an option for configuring a model to use portable word sizes. Using this second option, you can configure a model to generate code that you can compile without changing it for a platform. You can then use the code for SIL simulation on a host system and for deployment on a target system.

**Note**

- When you use either of the above methods for SIL simulation, differences between your host and target processor characteristics can cause differences in the simulation results of the generated ERT S-function wrapper block when compared to the original model or subsystem.
- If processor word sizes differ between host and target platforms, and you use neither of the above methods for SIL simulation, there are likely to be differences between host simulation results and target execution results. When using portable word sizes for SIL simulation, subtle differences in host and target processor behavior can still cause host simulation results to differ from target execution results, but this is not as common. For more information, see "Portable Word Sizes Limitation" on page 37-5.

To configure a model to use portable word sizes, set model configuration parameters.

| Set... | To... |
|---|---|
| **Hardware Implementation > Emulation hardware > None** | Selected |
| **Real-Time Workshop > Interface > Create Simulink (S-Function) block** | Selected |
| **Real-Time Workshop > Interface > Enable portable word sizes** | Selected |


Verification
Support software-in-the-loop (SIL) testing
[✓] Create Simulink (S-Function) block
[✓] Enable portable word sizes
[ ] MAT-file logging

When you generate code for a model with the preceding parameter settings, the code generator conditionalizes data type definitions:

- `tmwtypes.h` supports SIL simulation on the host system
- Real-Time Workshop types support deployment on the target system

For example, in the following generated code, the first two lines define types for SIL simulation on a host system. The **bold** lines define types for target deployment.

```
#ifdef PORTABLE_WORDSIZES    /* PORTABLE_WORDSIZES defined */
# include "tmwtypes.h"
#else                        /* PORTABLE_WORDSIZES not defined */
#define __TMWTYPES__
#include <limits.h>
...
typedef signed char int8_T;
typedef unsigned char uint8_T;
typedef int int16_T;
typedef unsigned int uint16_T;
typedef long int32_T;
typedef unsigned long uint32_T;
typedef float real32_T;
typedef double real64_T;
...
#endif                         /* PORTABLE_WORDSIZES */
```

For an example of how to configure a model to maintain bit-true agreement between host simulation and target deployment, and generate code that is portable between the host and target systems, see `rtwdemo_sil_pil`.

## Compiling Generated Code That Supports Portable Word Sizes

When compiling generated code that supports portable word sizes for SIL testing, you need to pass the definition `PORTABLE_WORDSIZES` to the compiler.

For example:

```
-DPORTABLE_WORDSIZES
```

To build the same code for target deployment, compile the code without the `PORTABLE_WORDSIZES` definition.

## Portable Word Sizes Limitation

When performing SIL testing, using the **Enable portable word sizes** model configuration parameter, numerical results of the S-function simulation on the MATLAB host might differ from results on the actual target. This difference is due to differences in target characteristics, such as:

- C integral promotion in expressions may be different on the target processor
- Signed integer division rounding behavior may be different on the target processor
- Signed integer arithmetic shift right may behave differently on the target processor
- Floating-point precision may be different on the target processor

## Generating an S-Function Wrapper for SIL Testing

When using the Real-Time Workshop product to set up SIL tests, you write an S-function wrapper and use the `mex` command to create a block to represent the S-function. If you have a Real-Time Workshop Embedded Coder license, the setup procedure for SIL tests is simpler.

1. In the Configuration Parameters dialog box, select **Real-Time Workshop > Interface > Create Simulink (S-Function) block**.
2. Right-click the subsystem that you want to simulate on the MATLAB host system.
3. Select **Real-Time Workshop > Build Subsystem**. This initiates a subsystem build that generates an S-function wrapper and block for the generated subsystem code.
4. Add the generated S-function block to an environment or test harness model that supplies test vectors or stimulus input.
5. Run SIL tests on the host system by simulating the environment model.
6. Verify that the generated code captured in the S-function block provides the same result as the original subsystem.

For an example of SIL testing, see `rtwdemo_sil_pil`. For more information about using the **Create Simulink (S-Function) block** parameter to generate an S-function wrapper, including limitations, see Chapter 25, “Generating S-Function Wrappers”.

# Verifying a Component in the Target Environment

## About Component Verification in the Target Environment

After you generate production code for a component design, you need to integrate, compile, link, and deploy the code as a complete application on the embedded system. One approach is to manually integrate the code into an existing software framework that consists of an operating system, device drivers, and support utilities. The algorithm can include externally written legacy or custom code.

An easier and more recommended approach to verifying a component in a target environment, is to use processor-in-the-loop (PIL) simulation. For details on applying PIL simulations, see Chapter 40, "Verifying Compiled Object Code with Processor-in-the-Loop Simulation".

## Goals of Component Verification in the Target Environment

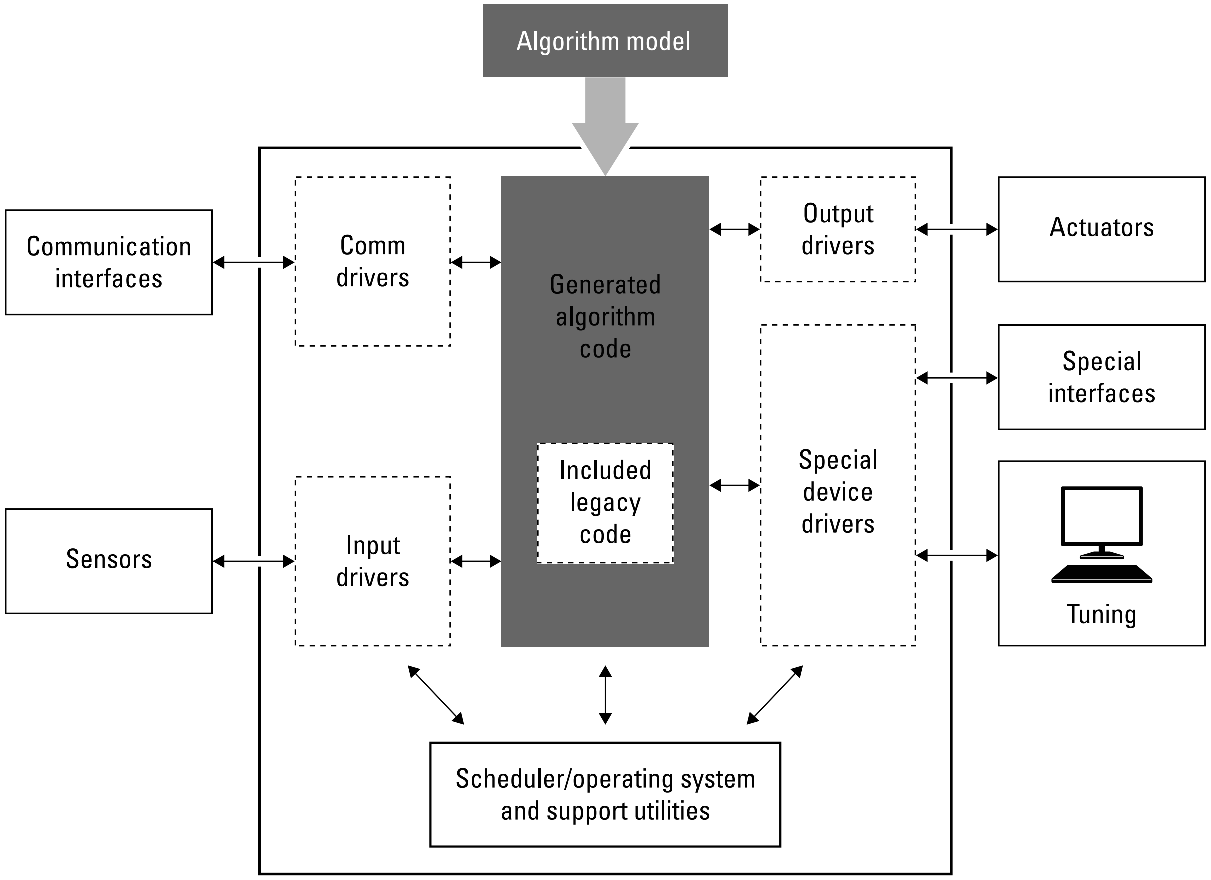
Assuming that you have generated production quality source code and integrated necessary externally written code, such as drivers and a scheduler, you can verify that the integrated software operates correctly by testing it in the target environment. During testing, you can achieve either of the following goals, depending on whether you export code that is strictly ANSI C/C++ or mixes ANSI C/C++ with code optimized for a target environment.

| Goal | Type of Code Export |
|---|---|
| Maximize code portability and configurability | ANSI C/C++ |
| Simplify integration and maximize use of processor resources and code efficiency | Mixed code |

Regardless of your goal, you must integrate any required external driver and scheduling software. To achieve real-time execution, you must integrate the necessary real-time scheduling software.

## Maximizing Code Portability and Configurability

To maximize code portability and configurability, limit the application code to ANSI/ISO C or C++ code only, as the following figure shows.

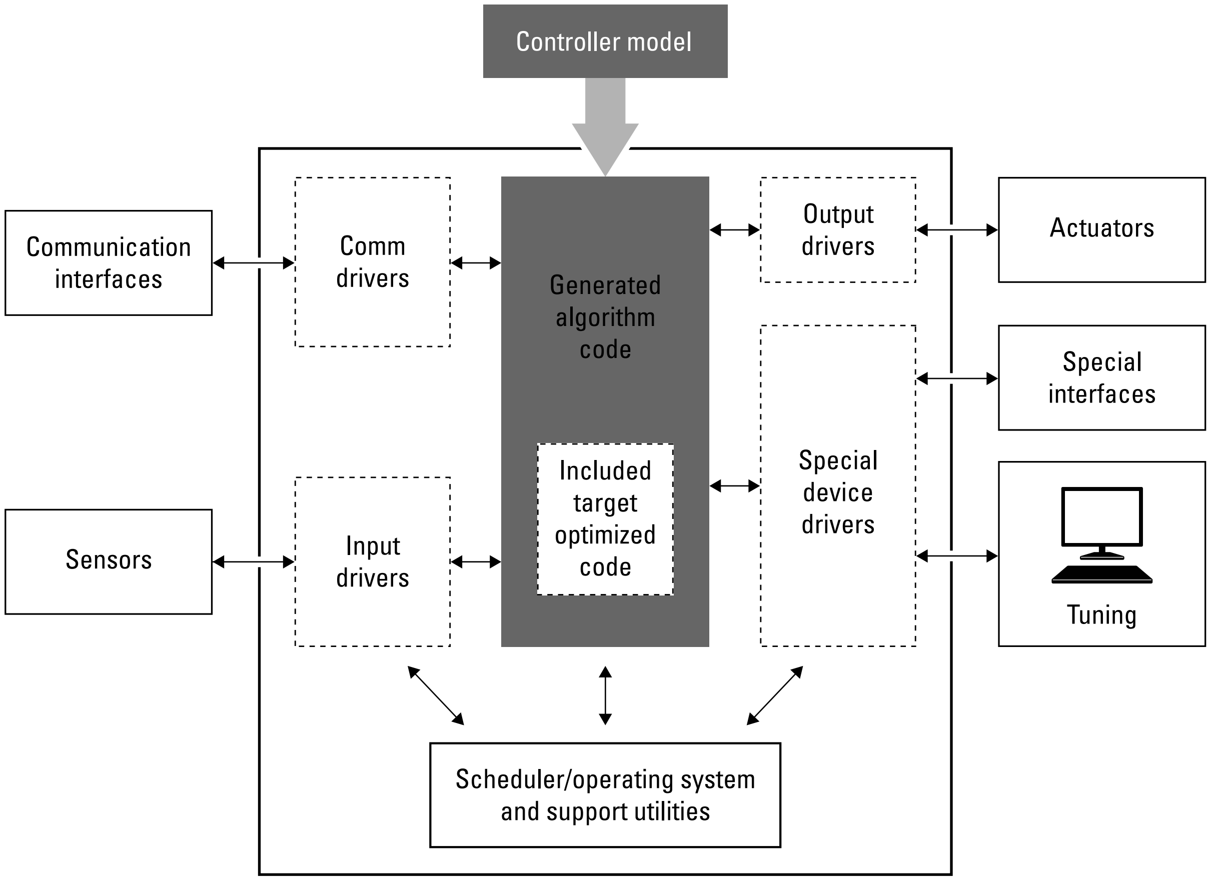


## Simplifying Code Integration and Maximizing Code Efficiency

To simplify code integration and maximize code efficiency for a target environment, use Real-Time Workshop Embedded Coder features for:

- Controlling code interfaces
- Exporting subsystems
- Including target-specific code, including compiler optimizations

The following figure shows a mix of ANSI C/C++ code with code that is optimized for a target environment.


Controller model
Communication interfaces
Comm drivers
Generated algorithm code
Included target optimized code
Output drivers
Actuators
Special interfaces
Special device drivers
Tuning
Sensors
Input drivers
Scheduler/operating system and support utilities

## Running Component Tests in the Target Environment

The workflow for running software component tests in the target environment is:

1. Integrate external code, for example, for device drivers and a scheduler, with the generated C or C++ code for your component model. For more information, see Integrating External Code and Generated C and C++ Code on page 1 and "Integrating External Code With Generated C and C++ Code" in the Real-Time Workshop documentation. For more specific references depending on your verification goals, see the following table.

| **For...** | **See...** |
|---|---|
| ANSI C/C++ code integration | "Integrating Existing C Functions into Simulink Models with the Legacy Code Tool" in the Simulink documentation. Also, open `rtwdemos` and navigate to the **Custom Code** folder. |
| Mixed code integration | • Chapter 26, "Exporting Function-Call Subsystems" and examplertwdemo_export_functions<br>• Chapter 28, "Controlling Generation of Function Prototypes", Chapter 29, "Controlling Generation of Encapsulated C++ Model Interfaces", and example rtwdemo_fcnprotoctrl<br>• Chapter 30, "Replacing Math Functions and Operators Using Target Function Libraries" and example `rtwdemo_tfl_script` |

2. Simulate the integrated component model.

3. Generate code for the integrated component model.

4. Connect to data interfaces for the generated C code data structures. See "Interacting with Target Application Signals and Parameters Using the C API" and "Generating Model Information for Host-Based ASAP2 Data

Measurement and Calibration" in the Real-Time Workshop documentation. Also see examples `rtwdemo_capi` and `rtwdemo_asap2`.

5 Customize and control the build process, as necessary. See "Customizing Code Generation and the Build Process", in the Real-Time Workshop documentation, and example `rtwdemo_buildinfo` .

6 Create a zip file that contains generated code files, static files, and dependent data to build the generated code in an environment other than your host computer. See "Relocating Code to Another Development Environment", in the Real-Time Workshop documentation, and example `rtwdemo_buildinfo`.

# Verifying a Component by Building a Complete Real-Time Target Environment

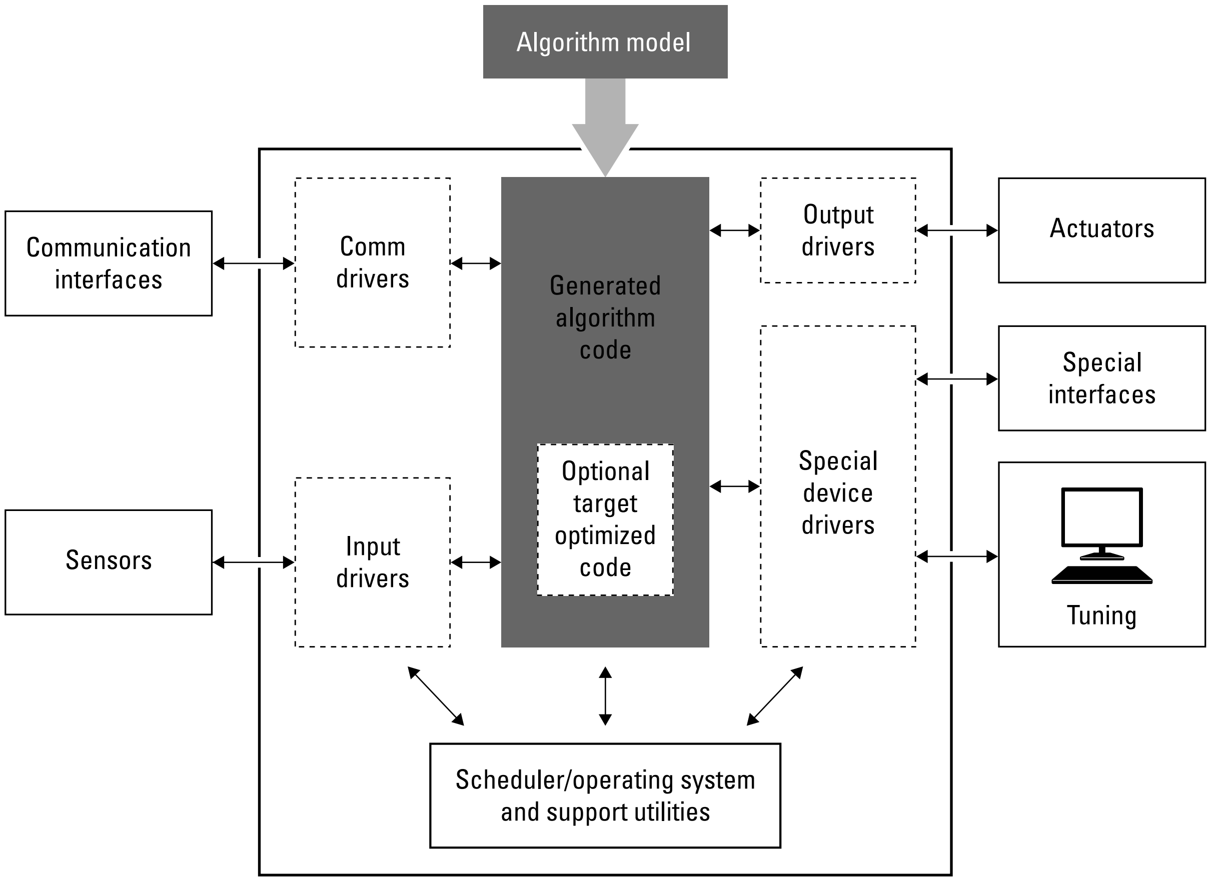
## About Component Verification With a Complete Real-Time Target Environment

One approach to verifying a software component is to build the component into a complete software system that can execute in real time in the target environment. A complete software system includes:

- Algorithm for the software component
- Scheduling algorithms
- Calls to drivers for board-specific devices

This single build approach is more time consuming to set up, but makes it easier to get the complete application running in the target environment.

The following figure shows code generated for an algorithm being built into a complete system executable for the target environment.


Algorithm model
Communication interfaces
Comm drivers
Generated algorithm code
Optional target optimized code
Output drivers
Actuators
Special interfaces
Special device drivers
Tuning
Sensors
Input drivers
Scheduler/operating system and support utilities

## Goals of Component Verification With a Complete Real-Time Target Environment

Assuming that you have generated production quality source code and integrated necessary externally written code, such as drivers and a scheduler, you can verify that component software operates correctly in the context of a complete system for testing in the target environment.

## Testing a Component as Part of a Complete Real-Time Target Environment

The workflow for testing component software as part of a complete real-time target environment is:

1. Develop a component model and generate source code for production.

   For information on building in scheduling and real-time system support, see:

   - "Scheduling Considerations" in the Real-Time Workshop documentation. For an example, open `rtwdemos` and navigate to the **Multirate Support** folder.
   - "Handling Asynchronous Events" in the Real-Time Workshop documentation and example `rtwdemo_async`
   - "Interfacing With a Real-Time Operating System " in the Real-Time Workshop documentation and Chapter 33, "Wind River Systems VxWorks Example Main Program"
   - Chapter 32, "Interfacing With Hardware That is Not Running an Operating System (Bare Board)"
   - Chapter 22, "Generating Code for AUTOSAR Software Components" and examples rtwdemo_autosar_legacy_script, rtwdemo_autosar_mulitrunnables_script, and rtwdemo_autosar_clientserver_script
   - Example `rtwdemo_osek`

2. Optimize generated code for a specific run-time environment, using specialized function libraries. For more information, see Chapter 30, "Replacing Math Functions and Operators Using Target Function Libraries" and example `rtwdemo_tfl_script`.

3. Customize post code generation build processing to accommodate third-party tools and processes, as necessary. See "Customizing Code Generation and the Build Process" in the Real-Time Workshop documentation and example `rtwdemo_buildinfo`.

4 Integrate external code, for example, for device drivers and a scheduler, with the generated C or C++ code for your component model. For more information, see Integrating External Code and Generated C and C++ Code on page 1 and "Integrating External Code With Generated C and C++ Code" in the Real-Time Workshop documentation. For more specific references depending on your verification goals, see the following table.

| **For...** | **See...** |
|---|---|
| ANSI C/C++ code integration | "Integrating Existing C Functions into Simulink Models with the Legacy Code Tool" in the Simulink documentation. Also, open `rtwdemos` and navigate to the **Custom Code** folder. |
| Mixed code integration | • Chapter 26, "Exporting Function-Call Subsystems" and examplertwdemo_export_functions<br>• Chapter 28, "Controlling Generation of Function Prototypes", Chapter 29, "Controlling Generation of Encapsulated C++ Model Interfaces", and example rtwdemo_fcnprotoctrl<br>• Chapter 30, "Replacing Math Functions and Operators Using Target Function Libraries" and example `rtwdemo_tfl_script` |

5 Simulate the integrated model.

6 Generate code for the integrated model.

7 Connect to data interfaces for the generated C code data structures. See "Interacting with Target Application Signals and Parameters Using the C API" and "Generating Model Information for Host-Based ASAP2 Data Measurement and Calibration" in the Real-Time Workshop documentation. Also see examples `rtwdemo_capi` and `rtwdemo_asap2`.

8 Customize and control the build process, as necessary. See “Customizing Code Generation and the Build Process”, in the Real-Time Workshop documentation, and example `rtwdemo_buildinfo` .

9 Create a zip file that contains generated code files, static files, and dependent data to build the generated code in an environment other than your host computer. See “Relocating Code to Another Development Environment”, in the Real-Time Workshop documentation, and example `rtwdemo_buildinfo`.

# Verifying Compiled Object Code with Processor-in-the-Loop Simulation

## About Process-In-the-Loop Simulation

**In this section...**

### What Is Processor-in-the-Loop Simulation?

You can use processor-in-the-loop (PIL) simulation to verify your generated code. PIL is a technique that helps you evaluate the behavior of a candidate algorithm ( for instance, a control or signal processing algorithm) on the target processor (or instruction set simulator) selected for the application. In PIL simulation, the target processor participates fully in the simulation loop — hence the term *processor-in-the-loop simulation*. You can compare the output of regular simulation modes, such as Normal or Accelerator, and PIL simulation mode to verify your generated code.

You can easily switch between simulation and PIL modes. This flexibility allows you to verify the generated code by executing the model as compiled code in the target environment. You can model and test your embedded software component in Simulink and then reuse your regression test suites across simulation and compiled object code. This avoids the time-consuming process of leaving the Simulink software environment to run tests again on object code compiled for the production hardware.

### Comparison of PIL and SIL Simulation

Use SIL or PIL simulation to verify automatically generated code by comparing the results with a normal mode simulation. With SIL, you can easily verify the behavior of production-intent source code on your host computer. However, you generally cannot verify exactly the same code that will subsequently be compiled for your target hardware because the code must be compiled for your host platform (that is, a different compiler and different processor architecture than the target). With PIL simulation, you can verify exactly the same code that you intend to deploy in production, and you can run the code on either real target hardware or an instruction set simulator.

You can use any of the following verification approaches:

- *Software-in-the-loop* (SIL). You simulate target behavior on the host machine. There are two approaches for SIL:
  - Run generated code through an S-function wrapper on the host machine. The SIL S-function links directly against the generated code, so the generated code runs inside the MATLAB process.
  - Run a PIL simulation and select your host machine as the target hardware. This allows you to use the PIL simulation mode to perform SIL verification. A PIL application is built and run as a separate process on the host machine, independently of the MATLAB process. The PIL S-function uses the PIL Connectivity API to communicate over TCP/IP with the PIL application containing the generated code. For information on how to select your host machine as the target hardware, see “Using PIL Mode for Software-in-the-Loop (SIL) Verification” on page 40-29.

    Using PIL mode for SIL provides an alternative to the block-based S-function approach for SIL.

  In both SIL cases, execution is host/host and non-real-time.
- *Processor-in-the-loop* on non-host hardware. Test the generated code as cross-compiled object code on the target processor or equivalent instruction set simulator. PIL exercises the same object code used in production software. PIL execution is host/target and non-real-time.

To decide which verification approach you want to use, see “Choosing a PIL Simulation Approach” on page 40-6.

## Why Use PIL Simulation?

Normal simulation techniques do not account for restrictions and requirements that the hardware imposes, such as limited memory resources or behavior of target-specific optimized code. PIL simulation provides an intermediate stage between simulation and deployment. You can perform code verification and evaluate code performance earlier in the development cycle. When you reach the stage of deploying code on the target hardware, PIL allows you to test the object code using test vectors that you have developed and applied to your Simulink model. You can verify correct code behavior on your target hardware and collect metrics, for example, code coverage and execution time. If you need to return to the original model and change it, you achieve faster iteration between model development and generated code verification.

## Problems That PIL Simulation Can Detect

PIL is useful for detecting problems such as:

- Incorrect target-specific code

  Undetectable with software-in-the-loop (SIL) testing because of the target-specific nature of the optimized code
- Unwanted side effects of compiler settings and optimizations
- Floating-point implementation issues
  - Floating-point applications may produce slightly different results in simulation and on hardware due to different floating-point implementations (unlike standard fixed-point applications, which give identical results in simulation and on hardware).
  - For example, the target may not implement strict IEEE® floating point. PIL detects these differences and allows you to analyze the differences.
  - In a closed-loop model, you can analyze build up of floating-point errors in the whole system.
- Code generator bugs
- Compiler bugs

You can also use PIL simulation with third-party tools, like a debugger with features such as code coverage, report generation, and execution profiling.

## How PIL Simulation Works

In a PIL simulation, Real-Time Workshop Embedded Coder software generates code for either the top model or part of the model. This code is cross-compiled for the target hardware and runs on the target platform.

Simulink sends, via a communication channel, stimulus signals to the code on the target platform for each sample interval of the simulation:

- For a top model, Simulink uses stimulus signals from the base or model workspace.
- If you have designated only part of the model to simulate in PIL mode, then a part of the model remains in Simulink without the use of code generation. Typically, you configure this part of the model to provide test vectors for the software executing on the hardware. This part of the model can represent other parts of the algorithm or the environment model in which the algorithm operates.

When the target platform receives signals from Simulink, it executes the PIL algorithm for one sample step. The PIL algorithm returns output signals computed during this step to Simulink through a communication channel. At this point, one sample cycle of the simulation is complete and Simulink proceeds to the next sample interval. The process repeats and the simulation progresses. PIL simulations do not run in real time. At each sample period, Simulink and the object code exchange *all* I/O data. See also “Verifying Signals with PIL Testing” on page 40-15.

---

**Note** By selecting your host machine as the target hardware, you can use the PIL simulation mode to perform Software-in-the-Loop (SIL) verification.

---

## Choosing a PIL Simulation Approach

**In this section...**

### Comparing Methods for Applying SIL and PIL Simulations

This section describes how to choose the approach for SIL or PIL verification that best fits your needs.

The following table compares the code interfaces and API support for the Model block with PIL and the PIL block (for the Embedded IDE Link product).

| PIL Feature | Standalone Code Interface | Model Reference Code Interface | Target Connectivity API Support |
|---|---|---|---|
| Top-model PIL | Yes | No (but you can include Model blocks inside your top model) | Yes |
| Model block PIL mode | No | Yes | Yes |
| PIL block | Top-model or subsystem build | No (but you can include Model blocks inside your subsystem or model) | No |

See the demo `rtwdemo_sil_pil` to see examples comparing:

- S-Function Block for SIL Simulation
- SIL or PIL Simulation for Model Blocks
- SIL or PIL Simulation for Top Models

## When to Use Top-Model PIL

Use top-model PIL if you want to:

- Verify code generated for a top model (standalone code interface).
- Load test vectors or stimulus inputs from the MATLAB workspace.
- Switch the entire model between normal and SIL or PIL simulation modes.
- Run a SIL simulation using the default connectivity configuration, or provide a target-specific connectivity configuration to run a true PIL simulation using your real target hardware or instruction set simulator.

For an example, see `rtwdemo_sil_pil` .

## When to Use Model Block PIL

Use Model block PIL if you want to:

- Verify code generated for referenced models (model reference code interface).
- Provide a test harness model (or a system model) to generate test vector or stimulus inputs.
- Switch a Model block between normal and SIL or PIL simulation mode.
- Run either a SIL simulation using the default connectivity configuration, or provide a target-specific connectivity configuration to run a true PIL simulation ( using your real target hardware or instruction set simulator).

See “PIL Modeling Scenarios with the Model Block” on page 40-8.

## When to Use the PIL Block

Use the PIL Block if you want to:

- Use a compiler and target environment supported by the Embedded IDE Link product.
- Verify code generated for a top model (standalone code interface) or subsystem (right-click build standalone code interface).
- Change the model and insert a PIL block to represent a component running in SIL or PIL mode, and the test harness model or a system model provides test vector or stimulus inputs.

See "Modeling Scenarios with the PIL Block" on page 40-12.

## PIL Modeling Scenarios with the Model Block

You can use the Model block PIL mode to test single components or a whole hierarchy of model reference components. For example, you can select a single leaf component for PIL verification. Later in the development cycle, as your components become integrated into a larger system, you can select a hierarchy of components for PIL verification.

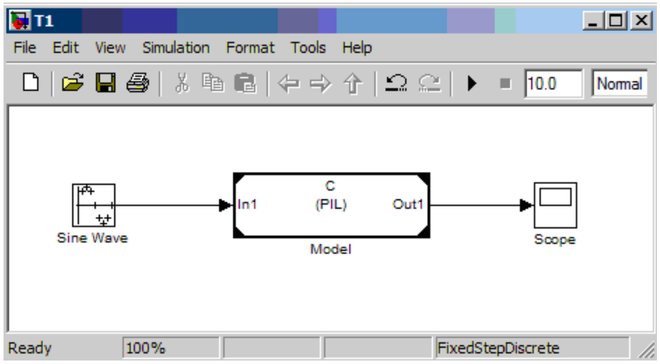
For more information about the standalone and model reference target code interfaces that are referenced in the following section, see "PIL Code Interfaces" on page 40-21.

You must deploy your Model block component code as part of a standalone executable. The following examples show ways of testing your component.

- "Testing a Model Reference Component in PIL Mode" on page 40-8
- "Deploying Through an Atomic Subsystem" on page 40-9
- "Deploying Through a Top Model" on page 40-11

### Testing a Model Reference Component in PIL Mode

You can test a model reference component or hierarchy of components by placing a Model block in a test harness model, as shown in model `T1`.



To test the component:

1. Set the simulation mode of component C to PIL mode.

2. Simulate the model to run component C in PIL mode, and test its Real-Time Workshop model reference target.

---

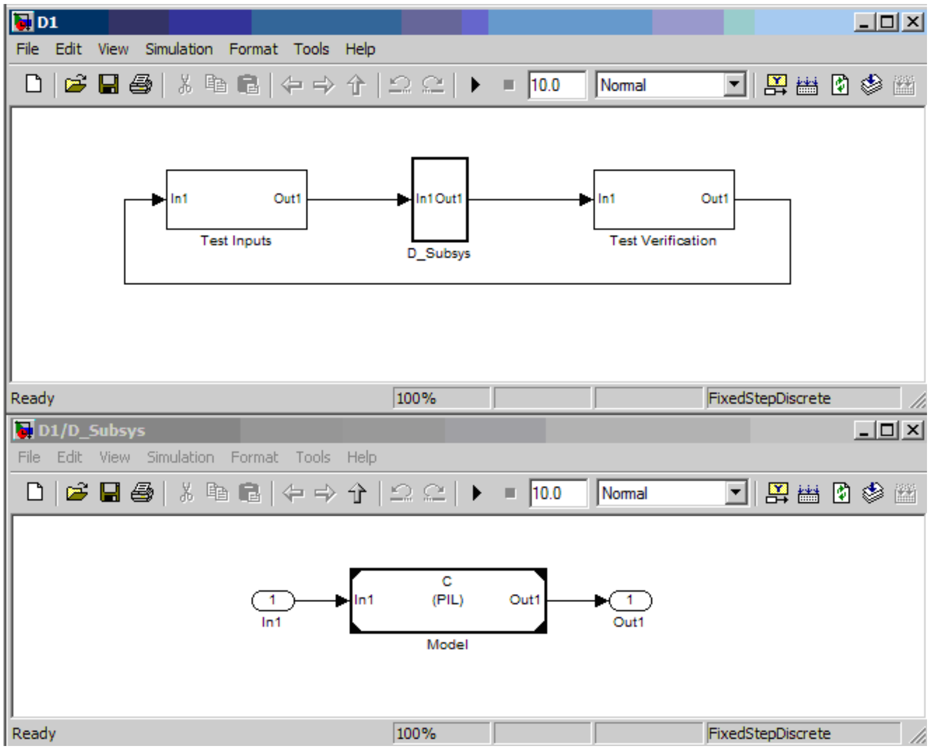
**Note** Simulating the model generates the model reference target code interface for component C, if it does not already exist.

---

The deployment scenarios in the next sections reuse the model reference target of component C. This reuse ensures that you test exactly the same object code that you deploy.

## Deploying Through an Atomic Subsystem

To generate code with the standalone interface for deployment, place a Model block inside an atomic subsystem, as shown by model `D1`.



To create standalone code, perform a subsystem build of `D_Subsys`. The standalone code calls the Real-Time Workshop model reference target of component C.

To test the component:

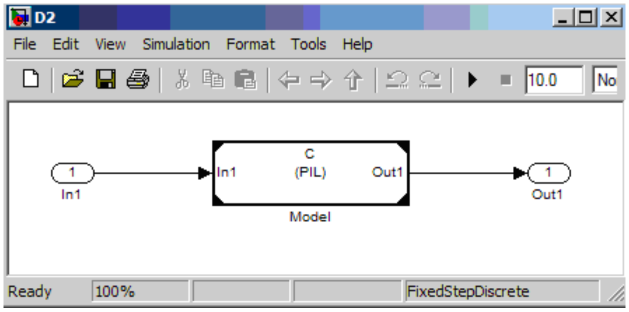
1 Set the simulation mode of component C to PIL mode.

2 Simulate the model to run component C in PIL mode, and test its Real-Time Workshop model reference target.

You can place multiple Model blocks and other blocks into the model to deploy a whole system of components.

## Deploying Through a Top Model

To generate code with the standalone interface for deployment, place the Model block inside a top model as shown by model D2.

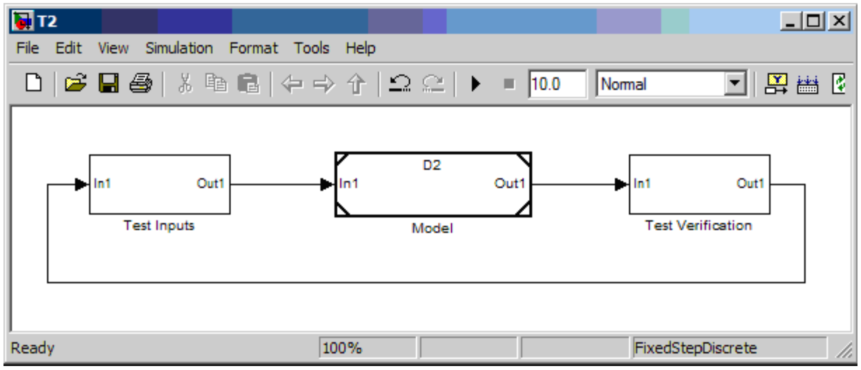


To create standalone code, perform a build of D2. The standalone code calls the Real-Time Workshop model reference target of component C.

You can place multiple Model blocks and other blocks into the model to deploy a whole system of components.

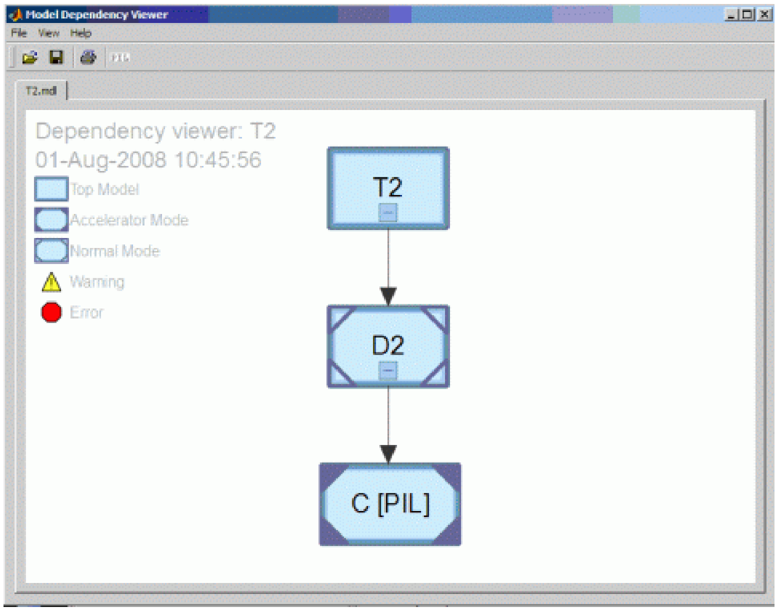
To pass test inputs to component C (running in PIL mode):

1 Create a test harness model that references model D2 in normal mode, as shown by model T2.



2 Simulate the T2 model to run component C in PIL mode and test its Real-Time Workshop model reference target.

The Model Dependency Viewer shows the model reference hierarchy of `T2` and the simulation modes of each Model block component.

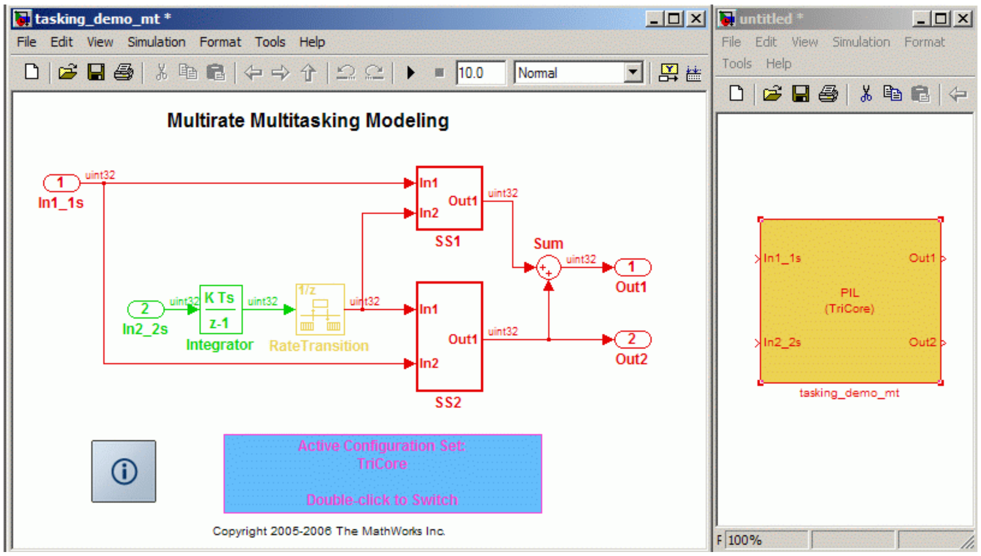


## Modeling Scenarios with the PIL Block

You can create a PIL block for a top-model build or a right-click build for a subsystem.

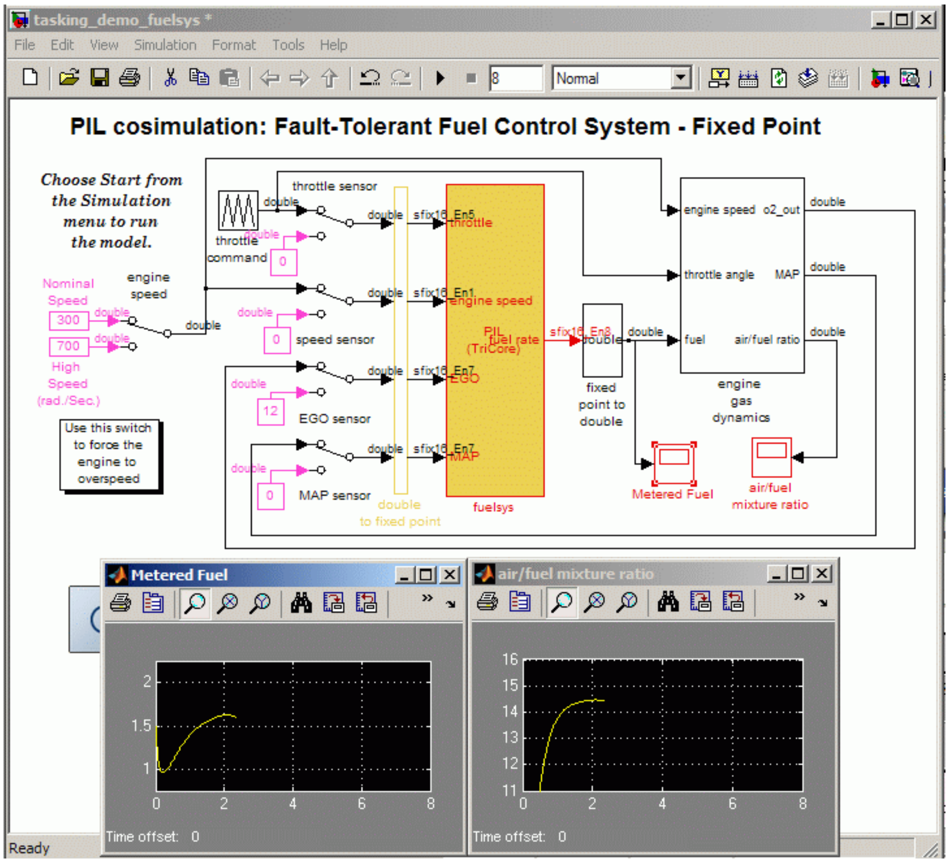
For a top-model build, you get a PIL block that represents the whole model. You can test the deployable standalone object code by calling the PIL block from a test harness model.

The following example shows the PIL block generated for a top-model build of the `tasking_demo_mt` model.



For a right-click subsystem build, you get a PIL block that represents the subsystem. You can test the deployable standalone object code, for example, by copying the PIL block into the original model to replace the original subsystem.

The following example shows the PIL block generated for the `fuelsys` subsystem, and copied into the original model.



## Verifying Signals with PIL Testing

Outputs of the PIL component are available for verification. If you want to examine an internal signal, you can manually route the signal up to the top level, or use GoTo and From blocks to route buried signals up to top-level Inports and Outports inside the PIL component. To view the signal names at the top level in these blocks, set the **Icon Display** parameters to `Tag and signal name` .

For more information on signal support in PIL, see "I/O Support " on page 40-49.

## Running a Complete Model as a PIL Simulation

Real-Time Workshop Embedded Coder provides a top-model Processor-in-the-Loop (PIL) simulation mode. In this mode, you can run a complete model as a PlL simulation on your target processor or instruction set simulator.

With top-model PIL simulation:

- Simulink generates and executes code that uses the same code interface produced by the standalone build process. See "PIL Code Interfaces" on page 40-21.
- You can specify external stimulus signals and log output signals, which allows you to verify object code generated from a complete model without creating a separate test harness model. Running the PIL simulation is a simple single-step operation. See "Configuring a Top-Model PIL Simulation" on page 40-27.

Top-model PIL simulation is an alternative to the block-based approach where you provide a test harness model that wraps either a Model block (in PIL mode) or a PIL block . There are differences between the block-based approach and top-model PIL simulation:

- With Model block PIL simulation, the model reference target that is generated does not have the same interface as standalone code (see "PIL Code Interfaces" on page 40-21).
- With PIL block simulation, you must perform two steps before you can run the simulation. First, you carry out a right-click subsystem build to create the PIL block. Then you replace the subsystem in the original model with the newly created PIL block.
- With Model block PIL and PIL block simulations, you cannot directly specify external stimulus signals or enable signal logging. You must use input and output blocks to feed signals into and out of your model. See "Verifying Signals with PIL Testing" on page 40-15 and "Choosing a PIL Simulation Approach" on page 40-6.

To compare all PIL simulation options, see "Choosing a PIL Simulation Approach" on page 40-6.

For the top-model PIL approach, Simulink creates a hidden *wrapper* model. When you run a top-model PIL simulation, the software generates code for the model and creates a hidden wrapper model to call this code at each time step.

- If something goes wrong during a PIL simulation, you may see messages that refer to the wrapper model. If an error message is generated that refers to the wrapper model, then the wrapper model is made visible to allow you to investigate the error.
- For *signal logging*, the software adds the suffix `_wrapper` to the block path for signals in `logsout`, as shown in the following example:

```
>> logsout.SignalLogging

          Name: 'SignalLogging'
     BlockPath: 'pillogging_wrapper/pillogging'
     PortIndex: 1
    SignalName: 'SignalLogging'
    ParentName: 'SignalLogging'
      TimeInfo: [1x1 Simulink.TimeInfo]
          Time: [11x1 double]
          Data: [11x1 double]
```

- For *output logging*, if the save format is `Structure` or `Structure with time`, then the software adds the suffix `_wrapper` to the block name for signals in `yout`, as shown in the following example:

```
>> yout.signals

ans =
        values: [11x1 double]
    dimensions: 1
         label: 'SignalLogging'
     blockName: 'pillogging_wrapper/OutputLogging'
```

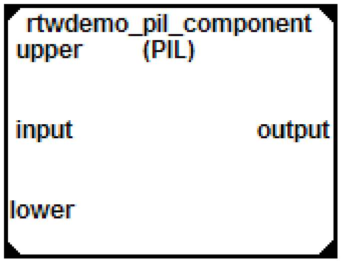
  If the save format is `Array`, then the software does not add a wrapper suffix.

## Running a Referenced Model as a PIL Simulation

If you have a Real-Time Workshop Embedded Coder license, Model blocks have a **Processor-in-the-loop (PIL)** mode.

You can switch the Model block between simulation and PIL modes. This allows you to easily verify the generated code by executing the referenced model as compiled code in the target environment. You can model and test your embedded software component in Simulink and you can reuse your regression test suites across simulation and compiled object code. This capability avoids the time-consuming process of leaving the Simulink software environment to run tests again on object code compiled for the production hardware.

When a Model block is in PIL mode, you see the label `(PIL)` on the block.



To understand how PIL works in the Model block, see the following sections:

- "Model Block PIL Behavior and Model Referencing" on page 40-18
- "PIL Code Interfaces" on page 40-21
- "When to Use Model Block PIL" on page 40-7
- "PIL Modeling Scenarios with the Model Block" on page 40-8

For an introduction to the Model block, see the Model block section in the Simulink reference documentation.

### Model Block PIL Behavior and Model Referencing

You can view your model hierarchy in the Model Dependency Viewer.

In the Referenced Model Instances view, Model blocks appear differently to indicate Normal, Accelerator, and PIL modes. A parent model can override the simulation mode of a Model block, as follows:

- A Model block in Accelerator mode overrides the behavior of any Model blocks beneath it in the model reference hierarchy. The Accelerator mode Model block links against the simulation targets (SIM targets) of the blocks beneath. See “Model Reference Simulation Targets” in the Simulink documentation.
- A Model block in PIL mode overrides the behavior of any Model blocks beneath it in the model reference hierarchy. The PIL mode Model block uses the model reference targets of the blocks beneath. See “Code Interface for Model Block PIL” on page 40-21.

A block behaves as specified by its simulation mode if it has a Normal mode path from the top model.

---

**Note** In a Model reference hierarchy, only one branch can simulate in PIL mode.

---

For an example model hierarchy, see “PIL Modeling Scenarios with the Model Block” on page 40-8.

## Programming PIL Support for Third-Party Tools and Target Hardware

With the top-model and Model block PIL modes, you can use the Processor-in-the-loop (PIL) Connectivity API to apply the power of PIL verification to object code compiled for your target processor. There are many custom or third-party tools for building, downloading, and communicating with an executable on a target environment. Use the API to integrate your tools for:

- Building the PIL application (an executable for the target hardware)
- Downloading and running the executable
- Communicating with the executable

You can use PIL with any target hardware or instruction set simulator, and any combination of tools that provide the required level of automation. For hardware cases that The MathWorks does not support, see "PIL Simulation Support and Limitations" on page 40-40.

For instructions and demos on top-model and Model block PIL modes and the Target Connectivity API, see:

- "Configuring a PIL Simulation" on page 40-27
- "Creating a Connectivity Configuration for a Target" on page 40-34
- "Demos of the Target Connectivity API" on page 40-38

## PIL Code Interfaces

To understand the difference between top-model PIL, Model block PIL, and the PIL block with the Embedded IDE Link product simulations, you must first understand the different code interfaces that the code generation products produce.

You generate “Standalone code” when you perform a top-model or right-click subsystem build for a single deployable component. You can compile and link standalone code into a standalone executable or integrate it with other code. For more information on the standalone code interface, see “Model Entry Points” on page 32-14.

When you generate code for a referenced model hierarchy, the software generates standalone executable code for the top model, and a library module called a *model reference target* for each referenced model. When the code executes, the standalone executable invokes the applicable model reference targets to compute the referenced model outputs. For more information, see “Creating Model Components” in the Real-Time Workshop documentation.

---

**Note** The model reference target does not have the same code interface as standalone code.

If you intend to integrate automatically generated code with legacy code, use standalone code because the standalone code interface (for example, entry points) is fully documented.

---

### Code Interface for Top-Model PIL

Top-model PIL generates the *standalone code interface* for the model.

When you run a top-model PIL simulation, the software calls the standalone code for the model if it already exists, or generates the standalone code if it does not yet exist.

### Code Interface for Model Block PIL

Model block PIL mode generates the *model reference* code interface.

When you run a simulation with a Model block in PIL mode, the software calls the model reference target for the Model block if it already exists, or generates the model reference target if it does not yet exist.

If the model reference target does not yet exist, you can generate it in one of three ways:

- Run the simulation.
- Build the top model containing the Model block by pressing **Ctrl+B**.
- Use the command `slbuild`, specifying the model reference option, for example:

```
    slbuild('model','ModelReferenceRTWTargetOnly')
```

You cannot use standalone code with the Model block. You can generate standalone code for a model referenced by a Model block by opening the model and performing a top-level build. However, this standalone code cannot be used with Model block PIL simulation. If you want to test standalone code, use the PIL block with the Embedded IDE Link product.

See the table under “Choosing a PIL Simulation Approach” on page 40-6.

## Code Interface for the PIL Block

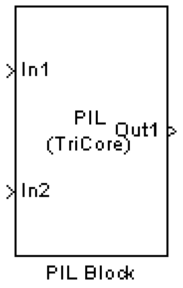
The PIL block generates the *standalone code interface.*

With the Embedded IDE Link product, you can generate standalone code through a top-model or a right-click subsystem build, and automatically create a PIL block to test the code. Code is rebuilt only if necessary.

## Setting Up PIL Simulations With the Embedded IDE Link Product PIL Block

The *PIL block* is available only with the Embedded IDE Link product. You cannot use the Target Connectivity API with the PIL block.

With the Embedded IDE Link product, you can automatically create a PIL block to test the code generated from your model. During the Real-Time Workshop Embedded Coder code generation process, you can create a PIL block from a complete model or from a subsystem.



After you create and build a PIL block, you can either:

- Copy the PIL block into your model to replace the original subsystem. Save the original subsystem in a different model so that you can restore it.
- Add the PIL block to your model to compare it to the original subsystem during simulation.

To understand the differences between Model block PIL and the PIL block, see:

- “PIL Code Interfaces” on page 40-21
- “Choosing a PIL Simulation Approach” on page 40-6
- “Modeling Scenarios with the PIL Block” on page 40-12
- “PIL Simulation Support and Limitations” on page 40-40

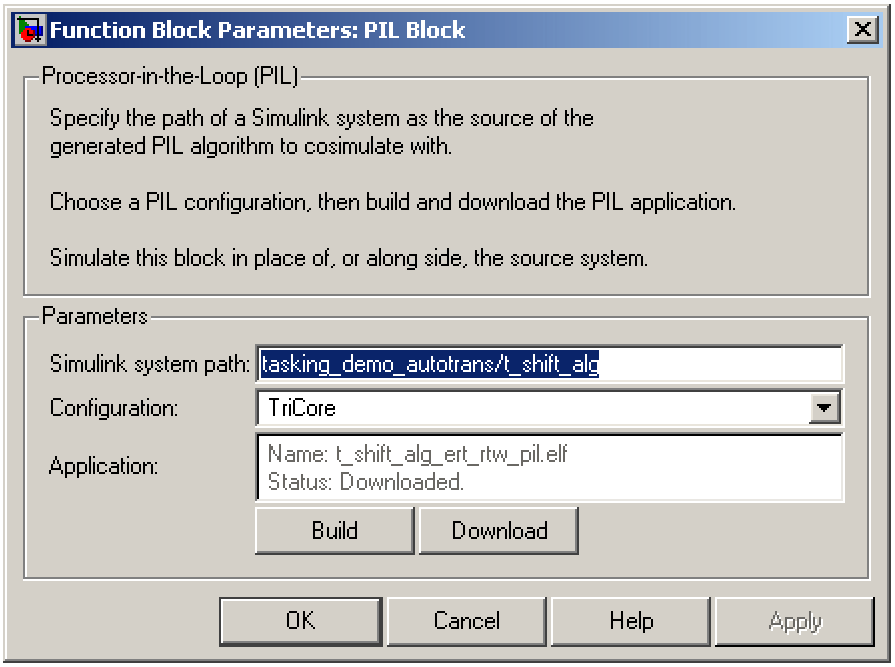
---

**Note** You can use the PIL block with Embedded IDE Link software. However, you can only use top-model PIL and Model block PIL with Embedded IDE Link software that is specific to Altium®TASKING®.

---

The PIL block is a basic building block that you can use to:

- Select a PIL algorithm
- Choose a PIL configuration
- Build and download a PIL application
- Run a PIL simulation


Function Block Parameters: PIL Block

Processor-in-the-Loop (PIL)

Specify the path of a Simulink system as the source of the generated PIL algorithm to cosimulate with.

Choose a PIL configuration, then build and download the PIL application.

Simulate this block in place of, or along side, the source system.

Parameters

Simulink system path: tasking_demo_autotrans/t_shift_alg

Configuration: TriCore

Application: Name: t_shift_alg_ert_rtw_pil.elf
Status: Downloaded.

To build and download the PIL application manually:

1 Double-click the PIL block to open the mask.

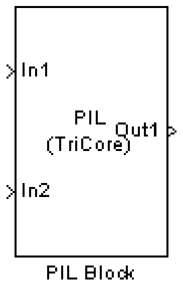
2 Click **Build**. Wait until you see the updated **Application** name in the mask and the "build complete" message.

3 Click **Download**.

4 Wait until you see the "download complete" message in the PIL block. Click **OK** to close the block mask.

The PIL application is now ready. To run a PIL simulation with it, copy the PIL block into your model, either to replace the original subsystem or as an additional block for comparison. Click **Start Simulation**.

The PIL block takes the same shape and signal names as the parent subsystem. This inheritance is convenient for copying the PIL block into the model to replace the original subsystem for the PIL simulation.



The PIL block has the following parameters:

- **Simulink system path** — Allows you to select a PIL algorithm. You specify the path of a Simulink system (model or subsystem) as the source of the generated PIL algorithm to use for simulation.

  The Simulink system path is the full path to the system and "/" must be escaped to "//". For example, a subsystem named "`fuel/sys`" inside a model named "`demo_fuelsys`" has the escaped system path:

  ```
  demo_fuelsys/fuel//sys
  ```

  You obtain the correct system path by clicking the system and then running the `gcb` command. In this example,

```
>> gcb
ans =
demo_fuelsys/fuel//sys
```

- **Configuration** — Allows you to specify a PIL configuration to use for building the PIL application and running the subsequent PIL simulation. For more information, see your Embedded IDE Link documentation.

*PIL Block Definitions*

**PIL Algorithm**

The algorithmic code (for example, the control algorithm) that you want to test during the PIL simulation. The PIL algorithm resides in compiled object form to allow verification at the object level.

**PIL Application**

The executable application to be run on the target platform. The PIL application is created by linking the PIL algorithm object code with some wrapper code (or test harness) that provides an execution framework that interfaces to the PIL algorithm.

The wrapper code includes the `string.h` header file so that the `memcpy` function is available to the PIL application. The PIL application uses `memcpy` to facilitate data exchange between Simulink and the simulation target.

---

**Note** The PIL algorithm code under test uses `string.h` It is independent of the use of `string.h` by the wrapper code. It is entirely dependent on the implementation of the algorithm in the generated code.

---

## Configuring a PIL Simulation

**In this section...**

### Configuring a Top-Model PIL Simulation

To configure and run a top-model PIL simulation for your target environment:

1. Open your model.

2. Select **Simulation > Processor-in-the-Loop (PIL)**. This option is available only if the model is configured for an ERT target, that is, `get_param(`*`model`*`,'IsERTTarget')='on'`. For information on configuring an ERT target for the model, see "Real-Time Workshop Pane: General".

3. If you have not already done so, use the **Data Import/Export** pane of the Configuration Parameters dialog box to:

   - Specify stimulus signals (or test vectors) for your top model through the **Input** check box and field.
   - Configure logging for model outputs, using either *output logging* or *signal logging*:
     - Specify *output logging* through the **Output** check box and field.
     - Specify *signal logging* through the **Signal logging** check box and field.

       The software logs only signals that are connected to root-level inports and outports. See "Verifying Signals with PIL Testing" on page 40-15.

       If the root outports of your model are connected to bus signals, then outport logging is not available. Use signal logging for bus signals connected to root outports.

You can log signals connected to inports or outports of the top model only if you name these signals. If you select **Signal logging** but do not name signals connected to inports or outports of the top model, then the signal logging object (for example, `logsout`) will not hold signal data.

For information about the **Data Import/Export** pane, see "Importing and Exporting Data" and "Data Import/Export Pane".

4 Start the simulation.

---

**Note** You cannot:

- Close the model while the simulation is running. To interrupt the simulation, from the Command Window, press **Ctrl+C**.
- Alter the model during the simulation. You can move blocks and lines as long as it does not alter the behavior of the model.

---

You can run a top-model PIL simulation using the command `sim(`*`model`*`)`.

---

**Note** The software supports `sim` command options `SrcWorkspace` and `DstWorkspace` for the values `'base'` and `'current'`, but not `'parent'`. For more information on the `sim` command and its options, see "Simulation" in the Simulink documentation.

---

When running a top model in PIL simulation mode, the software ignores the Simulation mode setting for any Model block within the top model. For example, if the top model contains a Model block, the simulation mode of this block may be set to `'Normal'`, `'Accelerator'` or `'PIL'`. This has no effect on the top model PIL simulation.

You control exactly how the code compiles and executes in the target environment through PIL connectivity configurations. See "Using PIL Mode for Software-in-the-Loop (SIL) Verification" on page 40-29, and "Creating a Connectivity Configuration for a Target" on page 40-34.

## Configuring PIL Mode in the Model Block

To use processor-in-the-loop (PIL) mode in your model, select the Model block simulation mode `Processor-in-the-Loop (PIL)`. This executes the referenced model as compiled code in the target environment.

You control exactly how the code compiles and executes in the target environment through PIL connectivity configurations. See "Using PIL Mode for Software-in-the-Loop (SIL) Verification" on page 40-29, and "Creating a Connectivity Configuration for a Target" on page 40-34.

## Using PIL Mode for Software-in-the-Loop (SIL) Verification

- "Using the Default PIL Connectivity Configuration for SIL" on page 40-29
- "Compatible Models" on page 40-30
- "Host-Based SIL and PIL Demo" on page 40-31

### Using the Default PIL Connectivity Configuration for SIL

Real-Time Workshop Embedded Coder software provides a default host-based connectivity configuration, `Software-in-the-Loop (SIL)`, which you can use with top-model or Model block PIL. With the SIL connectivity configuration, you can quickly get started with PIL and explore its capabilities without any third-party tools.

---

**Note** You can use the SIL connectivity configuration with *no configuration required* for any model that meets the requirements in "Compatible Models" on page 40-30.

---

The SIL connectivity configuration provides a connectivity implementation that:

1. Builds a host-based PIL application by invoking a host compiler.
2. Launches the PIL application as a separate process on the host machine.

3 Communicates with the PIL application through TCP/IP communications.

For more information about host-based PIL, see:

- "Compatible Models" on page 40-30
- "Host-Based SIL and PIL Demo" on page 40-31

For more information about connectivity configurations, see "What Is a PIL Connectivity Configuration?" on page 40-34.

## Compatible Models

You can use the SIL connectivity configuration with any Simulink model that meets the following specification:

1. The model specifies either the `ert.tlc` or `autosar.tlc` system target file.

   **Note** You can only use `autosar.tlc` for Model block PIL (and not top-model PIL).

2. The model specifies one of the following template makefiles:

   a `ert_default_tmf`

   b `ert_unix.tmf`

   c `ert_vc.tmf`

   d `ert_vcx64.tmf`

   e `ert_lcc.tmf`

   The software does not support the Watcom compiler template makefile (`ert_watc.tmf`).

3. The model specifies one of the following hardware implementation device types:

   a Generic: 32-bit x86 compatible

   b Generic: Custom

**c** Generic: MATLAB Host Computer (available only as an `Emulation hardware` choice)

**d** Generic: 32-bit Embedded Processor

### Host-Based SIL and PIL Demo

The `rtwdemo_sil_pil` model shows you how to compare results from Normal mode simulation and PIL and SIL mode execution for the same model. You run the simulation to compare the simulation behavior with the behavior of the corresponding generated code. This uses the SIL connectivity configuration, so the generated code is compiled for and executed on your host workstation.

The model demonstrates PIL where the target is your host machine. To target a different processor or use a communications channel other than TCP/IP, you must create your own PIL configuration. See “Creating a Connectivity Configuration for a Target” on page 40-34.

## Verifying a SIL or PIL Configuration

You might need to change model settings to configure the model correctly for SIL or PIL. To find out what settings you must change, use the `cgv.Config` class. Using the `cgv.Config` class, you can review your model configuration and determine which settings you must change to configure the model correctly for SIL or PIL. By default, `cgv.Config` changes configuration parameter values to the value that it recommends, but does not save the model. Alternatively, you can specify that `cgv.Config` use one of the following approaches:

- Change configuration parameter values to the values that `cgv.Config` recommends, and save the model. Specify this approach using the `SaveModel` property.
- List the values that `cgv.Config` recommends for the configuration parameters, but do not change the configuration parameters or the model. Specify this approach using the `ReportOnly` property.

**Note**

- To execute the model in the target environment successfully, you might need to make additional modifications to the configuration parameter values or the model.
- Do not use referenced configuration sets in models that you are changing using `cgv.Config`. If the model uses a referenced configuration set, update the model with a copy of the configuration set. Use the `Simulink.ConfigSetRef.getRefConfigSet` method. For more information, see `Simulink.ConfigSetRef` in the Simulink documentation.
- If you use `cgv.Config` on a model that executes a callback function, the callback function might change configuration parameter values each time the model loads. The callback function might revert changes that `cgv.Config` made. When this change occurs, the model might no longer be set up correctly for SIL or PIL. For more information, see "Using Callback Functions".

For more information about the `cgv.Config` class, see `cgv.Config`.

## How To Verify a SIL or PIL Configuration

To verify that your model is configured correctly:

1 Construct a `cgv.Config` object that changes the configuration parameter values without saving the model. For example, to configure your model for SIL:

```
c = cgv.Config('vdp', 'connectivity', 'sil');
```

---

**Tip**

- You can obtain a list of changes without changing the configuration parameter values. When you construct the object, include the `'ReportOnly', 'on'` property name and value pair.
- You can change the configuration parameter values and save the model. When you construct the object, include the `'SaveModel', 'on'` property name and value pair.

---

**2** Determine and change the configuration parameter values that the object recommends using the `configModel` method. For example:

```
c.configModel();
```

**3** Display a report of the changes that `configModel` makes. For example:

```
c.displayReport();
```

**4** Review the changes.

**5** To apply the changes to your model, save the model.

## Creating a Connectivity Configuration for a Target

**In this section...**

### What Is a PIL Connectivity Configuration?

You can use PIL connectivity configurations and the target connectivity API to customize PIL to work with any target environment.

Use a connectivity configuration to define:

- A configuration name
- A connectivity API implementation
- Settings that define the set of Simulink models that the configuration is compatible with, for example, the set of models that have a particular system target file, template makefile, and hardware implementation.

You can use the API to integrate third party tools for:

- Building the PIL application; an executable for the target hardware)
- Downloading and running the executable
- Communicating with the executable

A particular connectivity configuration name is associated with a single connectivity API implementation. Many different connectivity configurations can coexist and be available for use with PIL simulations. You register each connectivity configuration to Simulink by creating an `sl_customization.m` file and placing it on the MATLAB path.

To run a PIL simulation, the software must first determine which of the available connectivity configurations to use. The software looks for a connectivity configuration that is compatible with the model under test. If the software finds multiple or no compatible connectivity configurations, you see an error message describing how to resolve the problem.

You can use any of the following connectivity configuration options:

- Default host-based connectivity configuration

  The target environment is the host machine. See "Using PIL Mode for Software-in-the-Loop (SIL) Verification" on page 40-29
- Custom connectivity configuration

  The target environment is a different processor.

  See:

  1. "Overview of the Target Connectivity API" on page 40-35
  2. "Creating a Connectivity API Implementation" on page 40-38
  3. "Registering a Connectivity API Implementation" on page 40-38

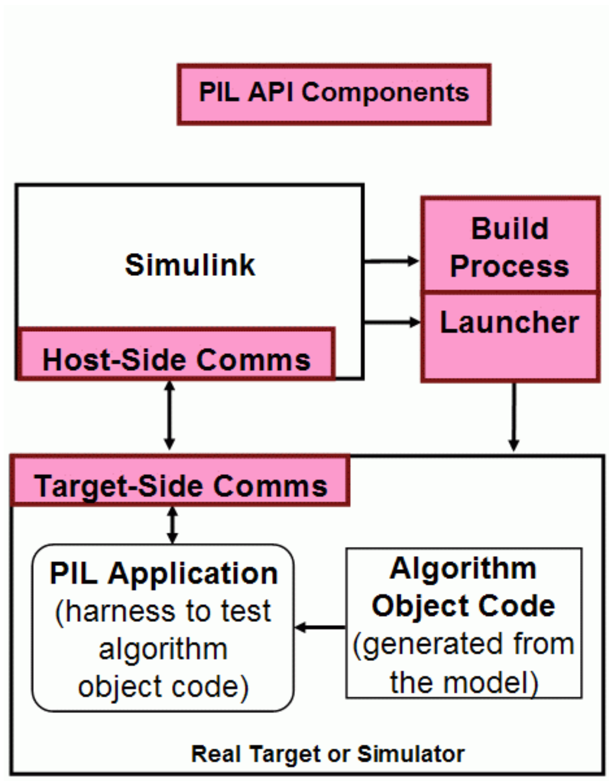
## Overview of the Target Connectivity API

- "Target Connectivity API Components" on page 40-35
- "Communications rtiostream API" on page 40-36

### Target Connectivity API Components

The following diagram shows what functions the Target Connectivity API components perform:

- Configuring the build process
- Controlling communication between Simulink and the target
- Downloading, starting, and stopping the application on the target


PIL API Components
Simulink
Host-Side Comms
Build Process
Launcher
Target-Side Comms
PIL Application (harness to test algorithm object code)
Algorithm Object Code (generated from the model)
Real Target or Simulator

## Communications rtiostream API

The communications part of the target connectivity API builds upon the `rtiostream` API, described in this section.

You can use the `rtiostream` API to implement a communication channel to enable exchange of data between different processes. This communication channel is required to enable processor-in-the-loop (PIL) on a new target.

PIL requires a host-target communications channel. This communications channel comprises separate driver code running on each of the host and target. The `rtiostream` API defines the signature of both target-side and host-side functions that must be implemented by this driver code.

The API is independent of the physical layer that sends the data. Possible physical layers include RS232, Ethernet, or Controller Area Network (CAN).

A full `rtiostream` implementation requires both host-side and target-side drivers. Real-Time Workshop software includes host-side drivers for the default TCP/IP implementation (all platforms) as well as a Windows only version for serial communications. To use the TCP/IP `rtiostream` communications channel, you must provide, or obtain from a third party, target-specific TCP/IP device drivers. You must also do this if you require serial communications. For other communication channels and platforms, there is no default implementation provided by Real-Time Workshop software. You must provide both the host-side and the target-side drivers.

The `rtiostream` API comprises the following functions:

- `rtIOStreamOpen`
- `rtIOStreamSend`
- `rtIOStreamRecv`
- `rtIOStreamClose`

You can use `rtiostream_wrapper` to test the `rtiostream` shared library methods from M-code.

To see how the `rtiostream` functions fit into the workflow of creating a connectivity implementation, see the next section, "Creating a Connectivity API Implementation" on page 40-38.

## Creating a Connectivity API Implementation

To create a target connectivity API implementation, you must create a subclass of `rtw.connectivity.Config`.

- You must instantiate `rtw.connectivity.MakefileBuilder`. This class configures the build process.
- You must create a subclass of `rtw.connectivity.Launcher`. This class downloads and executes the application using a third-party tool.
- Configure your `rtiostream` communications implementation:
  - On the target-side, integrate the driver code implementing `rtiostream` functions directly into the Real-Time Workshop build process, by creating a subclass of `rtw.pil.RtIOStreamApplicationFramework`.
  - On the host-side, compile the driver code into a shared library. You load and initialize this shared library by instantiating (or optionally, customizing) `rtw.connectivity.RtIOStreamHostCommunicator`.

For all the classes, methods, and functions in the Target Connectivity API, see the following reference section: "Processor-in-the-Loop" in the Real-Time Workshop Embedded Coder Function Reference.

## Registering a Connectivity API Implementation

Register the new connectivity API implementation to Simulink as a connectivity configuration, by creating or adding to an `sl_customization.m` file. By doing this, you also define the set of Simulink models that the new connectivity configuration is compatible with.

For details, see `rtw.connectivity.ConfigRegistry` in the Real-Time Workshop Embedded Coder Function Reference.

## Demos of the Target Connectivity API

For step-by-step examples, see the following demos:

- `rtwdemo_custom_pil`

  This M-file demo shows you how to create a custom PIL implementation using the target connectivity APIs. You can examine the code that configures the build process to support PIL, a tool to use for downloading and execution, and a communication channel between host and target. Follow the steps to activate a full host-based PIL configuration.

- `rtwdemo_rtiostream`

  This M-file demo shows you how to implement a communication channel for use with the Real-Time Workshop Embedded Coder product and your own target support package. This communication channel enables exchange of data between different processes. PIL simulation requires this because it requires exchange of data between the Simulink software running on your host machine and deployed code executing on target hardware.

  The rtiostream interface provides a generic communication channel that you can implement in the form of target connectivity drivers for a range of connection types. The demo shows how to configure your own target-side driver for TCP/IP, to operate with the default host-side TCP/IP driver. The default TCP/IP communications allow high bandwidth communication between host and target, suitable for transferring data such as video.

  The demo also shows how to implement custom target connectivity drivers, for example, using serial, CAN, or USB for both host and target sides of the communication channel.

## PIL Simulation Support and Limitations

**In this section...**

## PIL Simulation Support

*Top-model and Model block processor-in-the-loop (PIL)* simulation modes are Real-Time Workshop Embedded Coder features. You can also use top-model and Model block PIL with Embedded IDE Link software specific to AltiumTASKING.

The *PIL block* works with the general Embedded IDE Link product. For more details on the differences between top-model PIL, Model block PIL and the PIL block, see "Choosing a PIL Simulation Approach" on page 40-6.

The following tables describe feature support for top-model PIL, Model block PIL and the PIL block. "Yes" indicates a supported feature.

This is not a complete list of supported features, but provides information on selected features of interest for PIL, especially unsupported features and limitations.

| **Feature Support** | **Top-Model PIL** | **Model Block PIL Mode** | **PIL Block** |
|---|---|---|---|
| Testing of deployment object code | Yes | Yes | Yes |
| Target Connectivity API | Yes | Yes | No |

## Code Source Support

| Code Source | Code Interface | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|---|
| Top model | Standalone | Yes | No | Yes |
| Atomic subsystem | Standalone | No | No | Yes |
| Virtual subsystem | Standalone | No | No | Yes, but recommend atomic subsystem. See "Algebraic Loop Issues" on page 40-47. |
| Model block | Model reference Real-Time Workshop target | No, but you can include Model blocks inside your top model. | Yes. See "Cannot Use Multirate Model Block PIL Inside Conditionally Executed Subsystem" on page 40-43 | No, but you can include Model blocks inside your model. |
| Enabled/ Triggered subsystem | Standalone | No | No | Yes |
| Export Functions subsystem | Export Functions | No | No | No |
| Legacy code | Custom | See "Custom Code Interfaces" on page 40-43. | See "Custom Code Interfaces" on page 40-43. | See "Custom Code Interfaces" on page 40-43. |
| Embedded MATLAB Coder | Embedded MATLAB Coder | See "Custom Code Interfaces" on page 40-43. | See "Custom Code Interfaces" on page 40-43. | See "Custom Code Interfaces" on page 40-43. |

For more information on code interfaces, see "PIL Code Interfaces" on page 40-21.

### Custom Code Interfaces

The MathWorks does not provide direct PIL support for code interfaces such as legacy code and Embedded MATLAB Coder. However, you can incorporate these interfaces into Simulink as an S-function (for example, using the Legacy Code Tool, S-Function Builder, or hand-written code), and then verify them using PIL.

### PIL Does Not Check Real-Time Workshop Error Status

PIL does not check the Real-Time Workshop error status of the generated code under test. This error status flags exceptional conditions during execution of the generated code.

The Real-Time Workshop error status can also be set by blocks in the model (for example, custom blocks developed by a user). It is a limitation that PIL cannot check this error status and report back errors.

### Cannot Use Multirate Model Block PIL Inside Conditionally Executed Subsystem

You see an error if you place your Model block (in processor-in-the-loop (PIL) simulation mode) in a conditionally executed subsystem and the referenced model is multirate (that is, has multiple sample times). Single rate referenced models (with only a single sample time) are not affected.

## Block Support

| Blocks | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| Model block | Yes, you can include Model blocks inside your top model. | Yes | Yes, you can include Model blocks inside your subsystem or model. |
| Signal Processing Blockset | Yes | Yes | Yes |
| Video and Image Processing Blockset™ | Yes | Yes | Yes |

| Blocks | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| Embedded MATLAB block | Yes | Yes | Yes |
| Driver blocks | Yes, but not recommended. | Yes, but not recommended. | Yes, but not recommended. |
| To File blocks | No | No | No |
| To Workspace blocks | No | No | No |
| Merge blocks | Yes. | Yes. Cannot connect PIL outputs to Merge blocks. See “Merge Block Issue” on page 40-44. | Yes. Cannot connect PIL outputs to Merge blocks. See “Merge Block Issue” on page 40-44. |
| Stop block | No. PIL ignores the Stop Simulation block and continues simulating. | No. PIL ignores the Stop Simulation block and continues simulating. | No. PIL ignores the Stop Simulation block and continues simulating. |

### Run-Time Display Limitation

Scope blocks, and all types of run-time display, such as the display of port values and signal values, have no effect when you specify them in models executing in PIL mode. The result during simulation is the same as if the constructs did not exist.

### Merge Block Issue

If you connect PIL outputs to a Merge block, you see an error because S-function memory is not reusable.

```
The signal from 'mpil_enabled/Subsystem' output port 1 is
required to be persistent, hence this signal cannot be
connected to a Merge block.
```

### Other Top-Model PIL Limitations

PIL does not support Callbacks (model or block ) `InitFcn`, `StartFcn`, `StopFcn`.

## Configuration Parameters Support

| Configuration Parameters | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| ERT-based system target file | Yes | Yes | Yes |
| AUTOSAR system target file | No | Yes, but see “AUTOSAR Support” on page 40-46. | No |
| GRT-based system target file | No | No | No |
| GRT compatible call interface | No; see “Missing Code Interface Description File Errors” on page 40-46. | No; see “Missing Code Interface Description File Errors” on page 40-46. | No; see “Missing Code Interface Description File Errors” on page 40-46. |
| Function Prototype Control | Yes | Yes | Yes |
| Reusable code format | Yes, but see the special cases in “Imported Data Definitions” on page 40-52. | N/A | Yes, but see the special cases in “Imported Data Definitions” on page 40-52. |
| Target Function Library | Yes | Yes | Yes |
| C++ | No; see “Missing Code Interface Description File Errors” on page 40-46. | No; see “Missing Code Interface Description File Errors” on page 40-46. | No; see “Missing Code Interface Description File Errors” on page 40-46. |
| Generate ASAP2 file | Yes | Yes | Yes |
| Generate example main | N/A | N/A | N/A |
| MAT-file logging | No | No | No |
| Signal logging | Yes, but only for signals connected to root-level inports and outports. | No, but see “Verifying Signals with PIL Testing” on page 40-15. | No, but see “Verifying Signals with PIL Testing” on page 40-15. |

| Configuration Parameters | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| 'Simplified' model initialization | Yes | No | Yes |
| Single output/update | Yes, but see "Algebraic Loop Issues" on page 40-47. | Yes, but see "Algebraic Loop Issues" on page 40-47. | Yes, but see "Algebraic Loop Issues" on page 40-47. |
| Configuration set reference | Yes | Yes | Depends on the use of the Embedded IDE Link product. |

- "Missing Code Interface Description File Errors" on page 40-46
- "AUTOSAR Support" on page 40-46
- "Algebraic Loop Issues" on page 40-47

## Missing Code Interface Description File Errors

PIL requires a code interface description file, which is generated during the code generation process for the component under test. If the code interface description file is missing, PIL simulation cannot proceed and you see an error reporting that the file does not exist. This error can occur if you select these unsupported options in your configuration parameters:

- **GRT compatible call interface**
- **Target Language** option **C++ encapsulated**

Make sure that you have not selected these options.

## AUTOSAR Support

PIL does supports testing components of AUTOSAR models that are modeled as model reference components. These model reference components are implemented as standard model reference Real-Time Workshop targets and do not contain any special AUTOSAR behavior.

For example, you can simulate a top-level AUTOSAR model containing PIL components, or you can create a second top-level model for testing of individual components.

## Algebraic Loop Issues

For more information on algebraic loops, see:

- “Algebraic Loops” in the Simulink documentation.
- The Algebraic Loops section in “Simulation Considerations That Affect Code Generation” in the Real-Time Workshop documentation.
- The Introduction section in “Creating Subsystems” in the Real-Time Workshop documentation.

There are three ways that PIL simulation can introduce algebraic loops that do not exist for a normal simulation:

- “Algebraic Loops Caused by Code Generation for a Virtual Subsystem” on page 40-47
- “Algebraic Loops Caused by “Single output/update function”” on page 40-47
- “Algebraic Loops Caused by PIL Scheduling Limitations” on page 40-48

**Algebraic Loops Caused by Code Generation for a Virtual Subsystem.** If you generate code for a virtual subsystem, the Real-Time Workshop software treats the subsystem as atomic and generates the code accordingly. The resulting code can change the execution behavior of your model, for example, by applying algebraic loops, and introduce inconsistencies to the simulation behavior.

Declare virtual subsystems as atomic subsystems to ensure consistent simulation and execution behavior for your model.

See “Creating Subsystems” in the Real-Time Workshop documentation.

**Algebraic Loops Caused by “Single output/update function”.** The “single output/update function” in Real-Time Workshop optimization can introduce algebraic loops because it introduces direct feedthrough via a combined output and update function.

This option is not compatible with the **Minimize algebraic loop occurrences** option (in the Subsystem Parameters dialog box and **Model Referencing** pane of the Configuration Parameters dialog box). This option allows Real-Time Workshop to remove algebraic loops by partitioning generated code appropriately between output and update functions to avoid direct feedthrough.

**Algebraic Loops Caused by PIL Scheduling Limitations.** The S-function scheduling mechanism that the software uses to execute the PIL component has the following limitations:

- Direct feedthrough is always set to true.
- Separate output and update functions in the PIL component are always executed from the `mdlOutputs` S-function callback.

These limitations mean that PIL can introduce algebraic loops that do not exist in normal simulation, and you might get incorrect results. If this happens, you see a warning or error about the introduced algebraic loop and PIL results may differ from simulation results. You will not see or warning or error if the algebraic loop setting is “none” in the Configuration Parameters dialog box (under Diagnostics on the Solver pane).

A workaround is to break the algebraic loop by inserting a Unit Delay block so that the algebraic loop does not occur. Then, you can use PIL successfully.

## I/O Support

| I/O | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| Tunable parameters (Model reference arguments) | N/A | Yes, except for tunable structure parameters. See "Tunable Parameters and PIL" on page 40-52. | N/A |
| Tunable parameters (Workspace variables) | No | Yes, except for tunable structure parameters. See "Tunable Parameters and PIL" on page 40-52. | No |
| Virtual buses | No | Yes | Yes, but some limitations at PIL component boundary; see "PIL Block Virtual Bus Support Limitations" on page 40-56. |
| Nonvirtual buses | Yes, but see "Top-Model PIL Bus Limitations" on page 40-56. | Yes | Yes |
| MUX/DEMUX | No | Yes | Yes, but see "PIL Block MUX Support Limitations" on page 40-57. |
| Vector/2D/ Multidimensional | Yes | Yes | Yes |
| Complex data | Yes | Yes | Yes |
| Fixed-point data | Yes | Yes | Yes |

| I/O | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| Complex fixed-point data | Yes | Yes | Yes |
| Fixed-point data type override | Not at PIL component boundary. See "Fixed-Point Tool Data Type Override" on page 40-56 | Not at PIL component boundary. See "Fixed-Point Tool Data Type Override" on page 40-56. | Not at PIL component boundary. See "Fixed-Point Tool Data Type Override" on page 40-56. |
| Goto/From I/O | N/A | N/A | Goto / From blocks must not cross the PIL component boundary. You can use Goto / From blocks to route buried signals up to top-level Inports and Outports *inside* the PIL component. |
| Global data store I/O | Yes. See "Global Data Store Support" on page 40-52 and "Imported Data Definitions" on page 40-52. | Yes. See "Global Data Store Support" on page 40-52 and "Imported Data Definitions" on page 40-52. | Yes. See "Global Data Store Support" on page 40-52 and "Imported Data Definitions" on page 40-52. |
| Local data store I/O | No. See "Imported Data Definitions" on page 40-52. | No. See "Imported Data Definitions" on page 40-52. | No. See "Imported Data Definitions" on page 40-52. |
| Non-port-based sample times | Yes | Yes | Yes |
| Continuous sample times | Not at PIL component boundary. | No | Not at PIL component boundary. |
| Outputs with constant sample time | Yes | No | Yes |

| I/O | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| Non-auto-storage classes for data (such as signals, parameters, data stores) | Yes. See "Imported Data Definitions" on page 40-52. | Yes. See "Imported Data Definitions" on page 40-52. | Yes. See "Imported Data Definitions" on page 40-52. |
| Simulink data objects | Yes | Yes | Yes |
| Simulink numeric type and alias type | Yes | Yes | Yes |
| Simulink enumerated data | Yes | Yes | Yes |
| Custom storage classes | Yes, but see "Imported Data Definitions" on page 40-52, and "Unsupported Custom Storage Classes" on page 40-54. | Yes, but see "Imported Data Definitions" on page 40-52, and "Unsupported Custom Storage Classes" on page 40-54. | Yes, but see "Imported Data Definitions" on page 40-52, and "Unsupported Custom Storage Classes" on page 40-54. |
| Variable-size signals | No. See "Variable-Size Signals and PIL" on page 40-55. | No. See "Variable-Size Signals and PIL" on page 40-55. | No. See "Variable-Size Signals and PIL" on page 40-55. |

- "Tunable Parameters and PIL" on page 40-52
- "Global Data Store Support" on page 40-52
- "Imported Data Definitions" on page 40-52
- "Unsupported Custom Storage Classes" on page 40-54
- "Unsupported Implementation Errors" on page 40-54
- "Variable-Size Signals and PIL" on page 40-55
- "Fixed-Point Tool Data Type Override" on page 40-56
- "Top-Model PIL Bus Limitations" on page 40-56

- “PIL Block Virtual Bus Support Limitations” on page 40-56
- “PIL Block MUX Support Limitations” on page 40-57

## Tunable Parameters and PIL

You can tune parameters during a Model block PIL mode simulation exactly as you do in Normal simulation mode.

For more information, see “Global Tunable Parameters” and “Using Model Arguments” in the Simulink model reference documentation.

**Tunable Parameters Limitation.** You cannot tune parameters during PIL simulation if the parameters have an associated storage class that applies "`static`" scope or the "`const`" keyword (for example, `Custom`, `Const`, or `ConstVolatile`). Parameter changes are ignored.

If the storage class also specifies that the parameter is imported, then you must manually define and initialize the value of the parameter. See “Imported Data Definitions” on page 40-52).

## Global Data Store Support

PIL supports global data stores. PIL components that access global data stores must be single rate. You see an error if your PIL component has multiple sample times and accesses global data stores. To avoid the error, either remove accesses to global data stores or make the component single rate.

## Imported Data Definitions

You can use signals, parameters, data stores, etc., that specify storage classes with imported data definitions.

**Model Block PIL.** The PIL application automatically defines storage for imported data associated with:

- Signals at the root level of the component (on the I/O boundary)
- Parameters, except data with "`const`" type qualifier
- Global data stores

A PIL limitation is that PIL does not define storage for other imported data storage. You must define the storage through custom code included by the component under test or through the PIL `rtw.pil.RtIOStreamApplicationFramework` API. For example, the PIL application does not define imported data storage for data associated with:

- Internal signals (not on the I/O boundary)
- Local data stores
- Parameters (data with "`const`" type qualifier)

**Top-Model PIL and PIL Block.**

The PIL application automatically defines storage for imported data associated with:

- Signals at the root level of the component (on the I/O boundary)
- Global data stores

A PIL limitation is that it does not define storage for other imported data storage. You must define the storage through custom code included by the component under test or through the PIL `rtw.pil.RtIOStreamApplicationFramework` API. For example, the PIL application does not define imported data storage for data associated with:

- Internal signals (not on the I/O boundary)
- Local data stores
- Parameters; you must define and initialize parameters

Top-Model PIL and the PIL block can produce errors if you select the Real-Time Workshop option **Generate reusable code**, and either:

- You have not selected **Inline parameters** and the model contains parameters, or
- You have selected **Inline parameters** and the model contains parameters with `SimulinkGlobal` storage class.

If either of these conditions are met then PIL produces an error similar to the following:

```
Parameter "t_pil_lib_alg/t_pil_lib_alg/Unit Delay:Dialog:X0"
is not defined in the code associated with the PIL component,
and is therefore not supported for PIL.
Please change the parameter's storage class and / or the
code generation configuration settings so that the parameter
becomes defined in the code associated with the PIL component.
```

## Unsupported Custom Storage Classes

PIL does not support the following non-addressable custom storage classes:

- `BitField`
- `GetSet`

PIL also does not support signals and parameters with imported grouped custom storage classes.

## Unsupported Implementation Errors

You may see errors like the following if you are using a signal or parameter implementation that PIL does not support:

```
The following data interfaces have
implementations that are not supported by PIL.
```

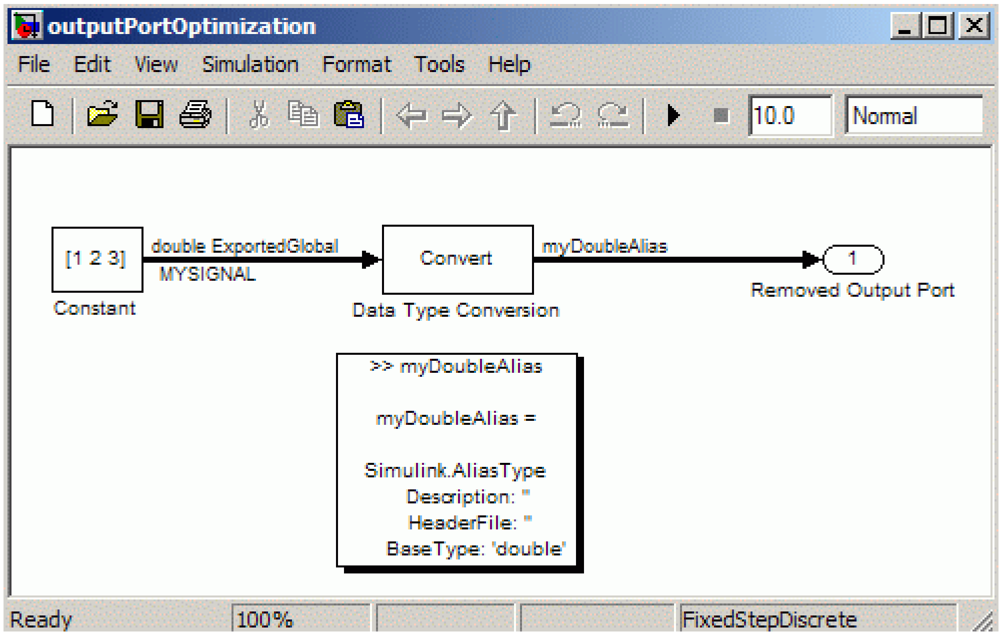
*`data interfaces`* may be `inports`, `outports` or `parameters`.

This error message has the following possible causes:

- The signal or parameter specifies an unsupported custom storage class. See “Unsupported Custom Storage Classes” on page 40-54.
- The model’s output port has been optimized through virtual output port optimization. See “Using Virtualized Output Ports Optimization” on page 20-24. The error occurs because the properties (for example, data type, dimensions) of the signal or signals entering the virtual root output port have been modified by routing the signals in one of the following ways:
  - Through a Mux block

- Through a block that changes the signal's data type. To check the consistency of data types in the model, display Port Data Types by selecting **Format > Port/Signal Displays > Port Data Types**.
- Through a block that changes the signal dimensions. To check the consistency of data types in the model, display dimensions by selecting **Format > Port/Signal Displays > Signal Dimensions**.

The following example illustrates a model that causes this error due to changing the output port signal's data type.



```
>> myDoubleAlias

myDoubleAlias =

Simulink.AliasType
   Description: ''
    HeaderFile: ''
      BaseType: 'double'
```

## Variable-Size Signals and PIL

PIL treats variable-size signals at the I/O boundary of the PIL component as fixed-size signals which can lead to errors during propagation of signal sizes. To avoid such errors, use only fixed-size signals at the I/O boundary of the PIL component.

### Fixed-Point Tool Data Type Override

PIL does not support signals with data types overridden by the Fixed-Point Tool **Data type override** parameter at the PIL component boundary.

You may see an exception message like the following:

```
Simulink.DataType object 'real_T' is not in scope
from 'mpil_mtrig_no_ic_preread/TmpSFcnForModelReference_unitInTopMdl'.
 This error message is related to a hidden S-Function block.
```

There is no resolution for this issue.

### Top-Model PIL Bus Limitations

The software does not support grounded or unconnected signals at the outputs of a top model.

You must enable the strict bus mode for top-model PIL:

1. In the model window, select **Simulation > Configuration Parameters > Diagnostics > Connectivity**.
2. Set **Mux blocks used to create bus signals** to `error`.

### PIL Block Virtual Bus Support Limitations

The PIL block supports virtual buses except for the following cases:

- You see an error if the PIL component is a top model with a root level outport that is configured to output a virtual bus. A root level outport will output a virtual bus, regardless of the type of the bus that drives it, if it specifies a bus object and the **Output as nonvirtual bus in parent model** check box is not selected.
- You see an error if a right-click subsystem build expands the bus into individual signals.
- For right-click subsystem builds only, the PIL block changes the output of outports driven by virtual buses (with associated bus objects) into nonvirtual buses. You do not see an error message in this case.

To avoid these limitations, use nonvirtual buses at the PIL component boundary.

### PIL Block MUX Support Limitations

The PIL block supports mux signals, except mixed data-type mux signals that expand into individual signals during a right-click subsystem build. You see an error for unsupported cases.

## Hardware Implementation Support

| Hardware Implementation | Real-Time Workshop Embedded Coder | Embedded IDE Link |
|---|---|---|
| Different host and target data-type size | Not at PIL component boundary. See “Hardware Implementation Settings” on page 40-57. | Not at PIL component boundary. See “Hardware Implementation Settings” on page 40-57. |
| Word-addressable targets | No | Yes |
| Multiword data type word order different to target byte order | No | Yes |
| Multiword | No | No |
| Size of target `'long'` > 32 bits | No | No |

### Hardware Implementation Settings

PIL requires that, in the Simulink Configuration Parameters dialog box, you correctly configure the Hardware Implementation settings for the target environment.

Specify byte ordering for non-8-bit targets.

For more information, see the following sections:

- “Host/Target Data Type Size Mismatch” on page 40-58

- "Data Type Size Mismatch Issues (Real-Time Workshop® Embedded Coder)" on page 40-58
- "Data Type Size Mismatch Issues (Embedded IDE Link)" on page 40-59

**Host/Target Data Type Size Mismatch.** PIL supports only data types that have the same size on the host and the target at the PIL I/O boundary.

The data types used at the PIL I/O boundary are restricted based on the following rule: PIL supports the data type only if the data-type size on the host (Simulink) is the same as the data-type size on the target.

- For `boolean`, `uint8`, and `int8`, the size is 8-bits.
- For `uint16` and `int16`, the size is 16-bits.
- For `uint32` and `int32`, the size is 32-bits.
- For `single`, the size is 32-bits.
- For `double`, the size is 64-bits.

Examples of unsupported data types are:

- `single` and `double` on targets with 24-bit floating-point types
- `double` on targets with 32-bit double, that is, the same size as `single`

**Warning PIL does not always detect unsupported data types (see "Data Type Size Mismatch Issues (Real-Time Workshop® Embedded Coder)" on page 40-58 and "Data Type Size Mismatch Issues (Embedded IDE Link)" on page 40-59). In such cases, data transfer between host and target is incorrect and unexpected data transfer errors occur during the PIL simulation.**

To resolve issues with Simulink data types that have different sizes on the host and target, do not use them at the PIL I/O boundary. Instead, use a Simulink data type that maps directly onto a target data type. This resolution is more efficient.

**Data Type Size Mismatch Issues (Real-Time Workshop Embedded Coder).** PIL mode makes the following assumptions about the target environment:

- The target is byte addressable.
- Sizes of data types on the host and target match.
- Word order of multiword data types on the target is the same as the target byte order.

**Warning PIL does not detect violations of these assumptions. If the settings for the target environment violate any of these assumptions, unexpected data transfer errors occur during the PIL simulation.**

To resolve issues with Simulink data types that have different sizes on the host and target, do not use them at the PIL I/O boundary. Instead, use a Simulink data type that maps directly onto a target data type. This resolution is more efficient.

Some known violations with predefined hardware implementation settings are:

- Unsupported word addressable targets: TI's C2000™, Freescale™ DSP563xx
- Unsupported data types owing to word order: TASKING Infineon® C166® (single and double have reversed word order)
- Unsupported data types owing to size mismatch: TASKING 8051 (double > is only 4 bytes)

**Data Type Size Mismatch Issues (Embedded IDE Link).** The Embedded IDE Link product registers the following information about the target environment to Simulink:

- Whether the target is byte addressable.
- The sizes of data types on the target.
- The word order of multiword data types on the target.

This allows PIL to support target environments with unusual hardware characteristics.

PIL can detect data types used at the PIL component boundary that have a host/target data type size mismatch. In such cases, an error indicates that an unsupported data type is being used. This avoids unexpected data transfer errors during simulation.

To resolve issues with Simulink data types that have different sizes on the host and target, do not use them at the PIL I/O boundary. Instead, use a Simulink data type that maps directly onto a target data type. This resolution is more efficient.

Some target compilers allow the sizes of target data types to be changed from their default size. For example, an IEEE double data type is most likely 8 bytes by default, but an optimization option may be provided to treat it as a 4 byte IEEE single precision type instead. The registration of target data type sizes done by the Embedded IDE Link product is typically statically defined to match the compiler's default data type size, and therefore does not support changing the data type size from that default size.

**Warning** **If you use a nondefault compiler configuration, the target data type sizes registered by the Embedded IDE Link product and the actual target data type sizes may differ. In such cases, data transfer between host and target is incorrect and unexpected data transfer errors occur during the PIL simulation.**

To resolve this issue, either:

- Do not use compiler options that change the default size of target data types.
- Use the single data type in Simulink rather than double, if your aim is to treat double-precision floating-point types (8 bytes) as single-precision floating-point types (4 bytes).

## Other Feature Support

| Other Features | Top-Model PIL | Model Block PIL Mode | PIL Block |
|---|---|---|---|
| Multiplatform support (such as Linux®) | Yes | Yes | Depends on the use of the Embedded IDE Link product. |
| Execution profiling | Depends on PIL configuration. | Depends on PIL configuration. | Yes (if Embedded IDE Link product support) |
| Stack profiling | Depends on PIL configuration. | Depends on PIL configuration. | Yes (if Embedded IDE Link product support) |
| C code coverage report | Depends on PIL configuration. | Depends on PIL configuration. | Yes (if Embedded IDE Link product support) |

## PIL Block Limitations

### Out of Date PIL Application

The PIL block indicates that the PIL application executable is out of date only when the PIL block detects that new code has been generated for the PIL algorithm under test.

No indication that the PIL application executable is out of date is given under the following circumstances:

1. A component of the PIL application executable, such as a C library, is updated after generating code for the PIL algorithm. In this case, click the PIL block **Build** button to bring the PIL application executable up to date. You do not need to regenerate code for the PIL algorithm.

2. A model referenced by the PIL algorithm is rebuilt after generating code for the PIL algorithm. In this case, regenerate code for the PIL algorithm and then click the PIL block **Build** button to bring the PIL application executable up to date.

# Verifying Numerical Equivalence of Results with Code Generation Verification

## Verifying Numerical Equivalence with Code Generation Verification

**In this section...**

### Code Generation Verification Overview

You can use Code Generation Verification (CGV) to verify the numerical equivalence of results when you execute a model in different modes of execution. CGV supports executing the model in simulation, Software-In-the-Loop (SIL), and Processor-In-the-Loop (PIL). For more information about SIL, see Chapter 37, "Verifying Generated Source Code With Software-In-the-Loop Simulation". For more information about PIL, see Chapter 40, "Verifying Compiled Object Code with Processor-in-the-Loop Simulation".

**Note** CGV helps you verify the numerical equivalence of results for a given set of inputs. CGV can detect numerical deviations for the given set of inputs only, but cannot by itself prove the numerical correctness of the generated code. The completeness of the input data that you provide to CGV determines the validity of the results.

### Verifying Numerical Equivalence with CGV Workflow

Before verifying numerical equivalence:

- Configure your model for SIL or PIL simulation. For more information, see "Configuring a PIL Simulation" on page 40-27.

- Verify that you have configured the model correctly for SIL or PIL simulation using `cgv.Config`. For more information, see “Verifying a SIL or PIL Configuration” on page 40-31.
- Configure your model for code generation. For more information, see Preparing Models for Code Generation on page 1.
- Save the data that you use as the inputs for running the model to a MAT-file.

To verify numerical equivalence:

1. Set up the tests for the first execution environment. For example, simulation.
2. Run the tests for the first execution environment.
3. Set up the tests for the second execution environment. For example, top-model PIL.
4. Run the tests for the second execution environment.
5. Compare the outputs of the first and second execution environments for numerical equivalence.

## Example of Verifying Numerical Equivalence with Matched Outputs

The following example walks you through configuring, executing, and comparing the `rtwdemo_iec61508` model in simulation and SIL modes. The example illustrates comparing output data that is numerically equivalent (matched). A second example that illustrates comparing nonnumerically equivalent (mismatched) output data follows (see “Example of Verifying Numerical Equivalence with Mismatched Outputs” on page 41-12).

This example contains three parts:

- “Configuring the Model” on page 41-4
- “Executing the Model” on page 41-5
- “Comparing Outputs” on page 41-6

## Configuring the Model

The first step to verifying numerical equivalence is to check that your model is configured correctly.

1 Open the `rtwdemo_iec61508` model.

2 Save the model to your working directory. Name the model `rtwdemo_iec61508_cgv`.

3 Create a `cgv.Config` object to check and modify configuration parameter values, and save the model for top-model SIL mode of execution.

```
cgvCfg = cgv.Config('rtwdemo_iec61508_cgv', 'LogMode', 'SaveOutput', ...
    'connectivity', 'sil', 'SaveModel', 'on');
```

4 Determine and change the configuration parameter values that the object recommends. This method also saves the model because you specified in the object creation to save the model.

```
cgvCfg.configModel();
```

5 Display a report of the changes that `configModel` makes. You view the changes to determine what the object did to the model.

```
cgvCfg.displayReport();
```

6 Modify additional configuration parameters to make the model compatible with top-model SIL.

```
set_param('rtwdemo_iec61508_cgv', 'SaveFormat', 'StructureWithTime');

% Configure the inports to receive data that is configured in the MAT-file.
set_param('rtwdemo_iec61508_cgv', 'LoadExternalInput', 'on');
set_param('rtwdemo_iec61508_cgv', 'ExternalInput', 'uIn');

% Do not display the code generation report.
set_param('rtwdemo_iec61508_cgv', 'GenerateReport', 'off');

% Save these changes.
save_system('rtwdemo_iec61508_cgv');
```

7 Create the input data.

```
InputData  = 'rtwdemo_cgvScript_data';
x.time = (0:.1:4)';
values = sin( 2.5* x.time) + 1;
x.signals(1).values = uint16(values * 32767/2);
x.signals(2).values = uint16(values * 32767/4);
x.signals(3).values = int16(values * 32767/2);
x.signals(4).values = int16(values * 11000/2);
uIn = x;
save(InputData, 'uIn');
```

## Executing the Model

When you verify numerical equivalence using a script, you must set up and execute the model for each mode of execution.

1. If you have not done so already, create and configure the `rtwdemo_iec61508_cgv` model, and create input data as described in "Configuring the Model" on page 41-4.

2. Create a handle to the `cgv.CGV` object that specifies the `rtwdemo_iec61508_cgv` model. Specify the first mode of execution to be simulation, and to save the data using the **Data Import/Export > Output** parameter.

   ```
   cgvObjSim = cgv.CGV('rtwdemo_iec61508_cgv', 'LogMode', 'SaveOutput');
   ```

3. Specify the input data.

   ```
   cgvObjSim.addInputData(1,InputData);
   ```

4. You may optionally specify:

   - The configuration set to use with the model.
   - M- or MAT-files to load or execute at the start of the test run.
   - A folder to store the output data for each input.
   - A callback function that executes at the start of the test run.
   - The output data file name.

   For the purposes of this tutorial, do not specify these optional settings. The `cgv.CGV` object uses the default folder location and file name.

5 Execute the model.

```
cgvObjSim.run();
```

6 Get the output data associated with the input data.

```
outputDataSim = cgvObjSim.getOutputData(1);
```

7 Repeat the prior steps for the next mode of execution, top-model SIL.

```
cgvObjSil = cgv.CGV('rtwdemo_iec61508_cgv', 'LogMode', 'SaveOutput', ...
    'connectivity', 'sil');
cgvObjSil.addInputData(1,InputData);
cgvObjSil.run();
outputDataSil = cgvObjSil.getOutputData(1);
```

## Comparing Outputs

After setting up and running the test, compare the outputs. The MathWorks provides the `compareResults` and `setupAndPlot` functions that you can use to compare the outputs. To use these functions and compare outputs:

1 If you have not already done so, configure and test the model as described in "Configuring the Model" on page 41-4 and "Executing the Model" on page 41-5.

2 In your current working folder, create a `compareResults.m` file.

3 In the `compareResults.m` file, paste the following function to compare the results. This function displays a message in the MATLAB Command Window for each matching output, and creates a plot of each mismatched output.

```
function out = compareResults(tolerance, data1, data2, data1BaseName, ...
    data2BaseName)

    lowerLeftX = 20;
    lowerLeftY = 50;
    if nargin < 5
        data2BaseName = inputname( 3);
    end
    if nargin < 4
        data1BaseName = inputname( 2);
    end

    out = true;
    if isa( data1, 'Simulink.ModelDataLogs')
        startAt = 3;
    elseif isa( data1, 'Simulink.TsArray')
        startAt = 6;
    elseif isa( data1, 'Simulink.Timeseries')
        if ~isequal( data1.Data, data2.Data)
            out = false;
            % A time series can have multidimension data.
            [highest, indx] = max(abs(double(data1.Data - data2.Data)));
            lenIndx = length(indx);
            [srcName1, outportName] = strtok(data1BaseName, '.');
            outportName = outportName(2:end);
            srcName2 = strtok(data2BaseName, '.');
            if lenIndx == 1
                if highest > tolerance
                    disp( ['Delta found at ' data1BaseName ...
                        ', greatest delta ' sprintf( '%f', highest) ...
                        ' at index ' sprintf( '%d', indx)]);

                    setupAndPlot(srcName1, srcName2, ...
                        outportName, data1.Time, data1.Data, data2.Data, ...
                        lowerLeftX, lowerLeftY);
                end
            else
                for i = 1:lenIndx
                    if highest(i) > tolerance
                        disp( ['Delta found at ' data1BaseName '.Data(:,' ...
                            sprintf( '%d', i) ...
                            '), greatest delta ' sprintf( '%f', highest(i)) ...
                            ' at index ' sprintf( '%d', indx(i))]);

                        setupAndPlot(srcName1, srcName2, ...
                            outportName, data1.Time, ...
                            data1.Data(:,i), data2.Data(:,i), ...
                            lowerLeftX, lowerLeftY);
                    end
                end
            end
            return;
        end
        disp( ['TimeSeries: ' data1BaseName ': OK']);
        return;
    elseif isa( data1, 'struct')
        fieldArray = fieldnames( data1);
        if any( strcmp( 'signals', fieldArray))
            for i = 1:length(data1.signals)
                data1Val = data1.signals(i).values;
                data2Val = data2.signals(i).values;
                if ~isequal( data1Val, data2Val) && ...
                        any(abs( real(data1Val - data2Val)) > tolerance)

                    outportName = data1.signals(i).blockName;
                    disp( ['struct: ' data1BaseName '.signals(' ...
                        sprintf( '%d', i) ') from ' outportName ': error']);
                    setupAndPlot(data1BaseName, data2BaseName, ...
                        outportName, data1.time, ...
                        data1Val, data2Val, lowerLeftX, lowerLeftY);
                    out = false;
                    return;
                end
            end
            disp( ['struct: ' data1BaseName ': OK']);
        else
            disp( ['Unknown struct at ' data1BaseName]);
        end
        return;
    else
        if ~isequal( data1, data2) && ...
                any(abs(real(data1 - data2)) > tolerance)
            out = false;
            disp(['Difference found at signal ' data1BaseName]);
        else
            disp(['Data at: ' data1BaseName ': OK']);
        end
        return;
    end
    fieldArray = fieldnames( data1);
    for j = startAt:length(fieldArray)
        field = char(fieldArray(j));
        data1Clone = data1.( field);
        if isa( data1Clone, 'Simulink.SubsysDataLogs')
            return; % CGV ignores subsystem logs, which are not available in PIL
        end
        try
            data2Clone = data2.( field);
        catch ME
            disp( [ '' data2BaseName '.' field ''': not there']);
            out = false;
            return;
        end

        new1BaseName = [data1BaseName '.' field];
        new2BaseName = [data2BaseName '.' field];

        if ~compareResults(tolerance, data1Clone, data2Clone, new1BaseName,...
                new2BaseName)
            out = false;
        end
    end
```

**4** In your current working folder, create a `setupAndPlot.m` file.

**5** In the `setupAndPlot.m` file, paste the following functions to compare the results. These functions create a plot of the outputs.

```
function setupAndPlot( data1BaseName, data2BaseName, outportName, xTime, ...
        data1, data2, lowerLeftX, lowerLeftY)
    Title = ['CGV results: ' outportName];
    figure('Name', Title, 'OuterPosition', [lowerLeftX, lowerLeftY, 500, 500]);

    datavec = data1;
    datavec(:,2) = data2;
    timevec = xTime;
    timevec(:,2) = xTime;
    namevec = {data1BaseName, data2BaseName};
    plotDelta( outportName, datavec, timevec, namevec);

function plotDelta( outportName, datavec, timevec, namevec)

    % Expand the Y axis end points by 10% for readability.
    axisMin = double(min( [datavec(:,1)' datavec(:,2)']));
    axisMax = double(max( [datavec(:,1)' datavec(:,2)']));
    axisDelta = axisMax - axisMin;
    axisLower = axisMin - 1 - ceil( abs(axisDelta) * 10 / 100);
    axisUpper = axisMax + 1 + floor( abs(axisDelta) * 10 / 100);
    % Plot the data in the upper subplot
    sh1 = subplot(2,1,1);
    stairs(timevec, datavec);
    set(sh1, 'YLimMode', 'manual', 'YLim', [ axisLower axisUpper]);

    % Determine the mismatch by subtracting the results.
    % Subtraction of 16-bit values might cause overflow and saturation errors.
    % Therefore, convert all values to double.
    % Note: Fixed-point or integer values that are represented in less than
    % 52-bits can be converted to a double with no loss of precision.
    delta = double(datavec(:,1)) - double(datavec(:,2));
    axisMin = min( delta);
    axisMax = max( delta);
    axisDelta = axisMax - axisMin;
    axisLower = axisMin - 1 - ceil( abs(axisDelta) * 10 / 100);
    axisUpper = axisMax + 1 + floor( abs(axisDelta) * 10 / 100);
    % Plot the mismatch in the lower subplot
    sh2 = subplot(2,1,2);
    h2 = stairs(timevec(:,1),delta);
    set(sh2, 'YLimMode', 'manual', 'YLim', [ axisLower axisUpper]);

    % Add axes labels
    differenceLabel = 'Numeric difference';
    % Turn off TeX support to keep underbars in axes labels.
    title(sh1,outportName, 'interpreter', 'none');
    title(sh2,differenceLabel);

    % Add legends
    if length( namevec) == 2
        legend(sh1, char(namevec(1)), char(namevec(2)));
        legend(sh2, [ char(namevec(1)) ' - ' char(namevec(2))]);
    end
% enddoeexample setupAndPlot
```

6 Save the `setupAndPlot.m` file.

7 Compare the outputs of the first model in simulation and SIL modes using the `compareResults` function. The `compareResults` function displays a message in the MATLAB Command Window for each matching output, and creates a plot of each mismatched output.

```
tolerance = 1e-10;
compareResults(tolerance, outputDataSim, outputDataSil);
```

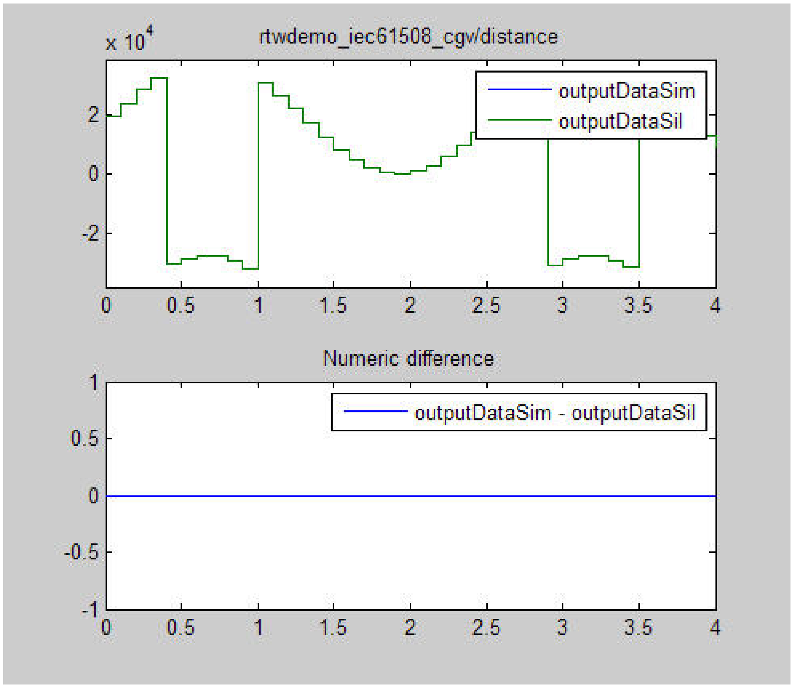
Since there are no mismatched outputs, `compareResults` only displays a message at the Command Window.

```
struct: outputDataSim: OK
```

8 To see a plot of the outputs, use the `setupAndPlot` function:

```
setupAndPlot('outputDataSim', 'outputDataSil', ...
    outputDataSim.signals(1).blockName, outputDataSim.time, ...
    outputDataSim.signals(1).values, outputDataSil.signals(1).values, 50, 50);
```

The following plot displays the data from the first outport, `distance`, in both executions. `outputDataSim` (in blue) displays the results from executing the `rtwdemo_iec61508_cgv` model in simulation mode. `outputDataSilErr` (in green) displays the results from executing the model in SIL mode. The lower plot displays the numerical difference between the results.



## Example of Verifying Numerical Equivalence with Mismatched Outputs

This example illustrates a comparison of nonnumerically equivalent (mismatched) outputs. You create a different version of the `rtwdemo_iec61508` model, execute the model in SIL mode, and compare the output with the output of the `rtwdemo_iec61508_cgv` model.

1 To get output data for the `rtwdemo_iec61508_cgv` model, if you have not already done so, complete the steps in “Configuring the Model” on page 41-4 and “Executing the Model” on page 41-5.

2 Save a copy of the `rtwdemo_iec61508_cgv` model as `rtwdemo_iec61508_cgv_saturate`, so you can create and modify a second version of the model.

3 In the Add2 Block Parameters dialog box, select **Saturate on integer overflow**, or use the following command:

```
set_param('rtwdemo_iec61508_cgv_saturate/Add2', 'SaturateOnIntegerOverflow', 'on');
```

When you select **Saturate on integer overflow**, if the Add2 block results in sums greater than 32767, the output saturates to `32767`.

4 Save `rtwdemo_iec61508_cgv_saturate`:

```
save_system('rtwdemo_iec61508_cgv_saturate');
```

5 Create a handle to a `cgv.CGV` object for the `rtwdemo_iec61508_cgv_saturate` model, and specify top-model SIL:

```
cgvObjSilErr = cgv.CGV('rtwdemo_iec61508_cgv_saturate', ...
    'LogMode', 'SaveOutput', 'connectivity', 'sil');
```

6 Specify the input data:

```
cgvObjSilErr.addInputData(1,InputData);
```

7 Execute the model:

```
cgvObjSilErr.run();
```

8 Get the output data associated with the input data:

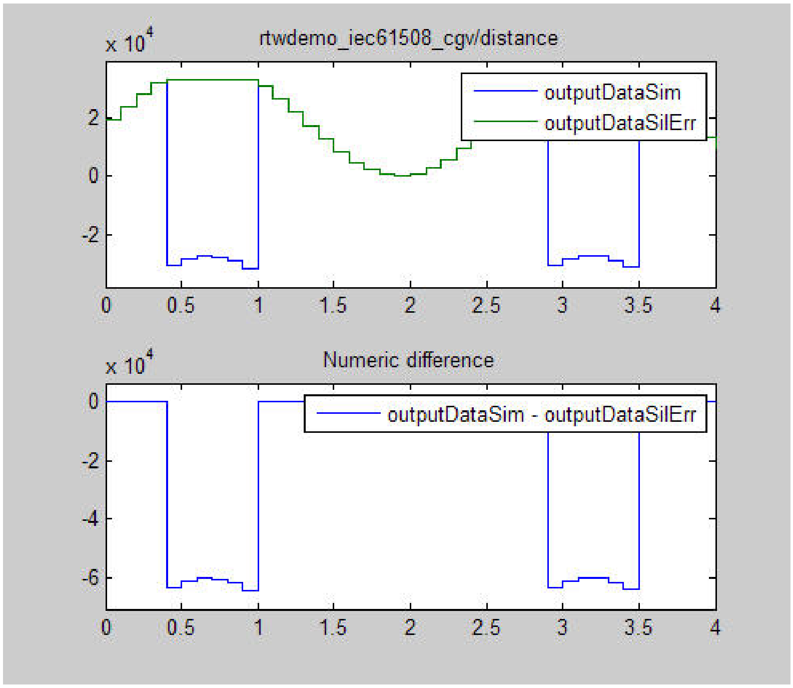
```
outputDataSilErr = cgvObjSilErr.getOutputData(1);
```

9 If you have not already done so, create the `compareResults` function as described in “Comparing Outputs” on page 41-6.

10 Compare the outputs of the first model in simulation mode and the second model in SIL mode:

```
compareResults(tolerance, outputDataSim, outputDataSilErr);
```

The following plot displays the data from the first outport, distance, in both executions. `outputDataSim` (in blue) displays the results from executing the `rtwdemo_iec61508_cgv` model. `outputDataSilErr` (in green) displays the results from executing the `rtwdemo_iec61508_cgv_saturate` model. The lower plot displays the numerical difference between the results.



# Examples

Use this list to find examples in the documentation.

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