NASA MARSHALL SPACE FLIGHT CENTER

Simulink Code Generation

Tutorial for generating C code from Simulink Models using Simulink Coder

José Carlos Molina Fraticelli

4/25/2012

Contents

1. Introduction

This document explains all the necessary steps in order to generate optimized C code from Simulink (Ref. [2]) Models. This document also covers some general information on good programming practices, selection of variable types, how to organize models and subsystems, and finally how to test the generated C code and compare it with data from MATLAB (Ref. [1]).

(NOTE: This guide was prepared using MATLAB/Simulink Ver. R2011b (Ref. [1]).)

2. Good Programming Practices in Simulink

Below are some guidelines to follow when creating Simulink (Ref. [2]) Models:

- Create bus objects for subsystems with many outputs and inputs. It makes organizing a model simpler by requiring less cabling and also makes management of the data contained in the bus easier when debugging as errors usually show up in a single location.
- Avoid using Mux blocks to create Bus signals. Always use a Bus Creator blocks.
- Avoid Crossing Cables when possible: There are a variety of ways to avoid crossing cables which can make debugging Simulink (Ref. [2]) models complicated. Some of these include: Organizing Subsystem Inputs to match cabling going into the subsystem, Goto and From blocks, Bus Creator blocks, Bus Selector blocks, among others.
- Determine variable types ahead of time. Simulink (Ref. [2]) defaults all data types to 64-bit doubles by default. This can sometimes be a problem for code generation as not all targets can support these types of variables and it can be hard to change these once a model is created. This will save a lot of time trying to find problematic typecasts.
- Use MATLAB (Ref. [1]) structures when working with Bus Signals.
- Determine whether a model is a sub-function or a subsystem.
- Avoid Algebraic Loops. They are problematic for code generation as stated by Mathworks. If the algebraic loop cannot be avoided use a Unit Delay Block to break up the loop. (NOTE: Verify that adding this block has not changed the output of the model.)
- Avoid using different sampling times between models. This is not supported by code generation.
- Avoid using variable-step solvers. The only valid solver for code generation is the Fixed Step Solver with a discrete time step.
- Build models from the ground up with code generation in mind.
- Test models as a standalone piece both in simulation and in the generated code and ensure it is working before adding additional models.
- Avoid using equal names for buses, data, constants and models. This can cause serious problems with code generation. Use a naming standard to clearly define what every object is or isn’t.
- Rename models such as “Foo One Model”; to Foo_One_Model. This will help avoid problems with code generation.

- If a model name is too long try shortening it. Model names should not exceed 20 characters.
- Align models and objects that are part of the model using the alignment tools available in Simulink (Ref. [2]) these can be accessed by selecting two or more model objects and selecting align blocks. This can help clean up models immensely
- Make sure the warning indicator on MATLAB (Ref. [1]) function blocks is green. Try to fix all warnings pointed to by this indicator. Also always add the %#codegen pragma directive below the function name declaration and before any code.
- Don’t use Goto and From blocks between different models. Use a signal line instead.
- Avoid the use of extremely memory intensive blocks such as ‘Fuzzy Logic controllers’ if generating code for embedded platforms such as microcontrollers; as the generated code will not fit in the stack due to the high amount of floating point variables required.
- Avoid excessive unnecessary variables. Memory is at a premium in embedded hardware as opposed to a desktop computer.
- Use consistent signal names. This can help ease debugging immensely.
- Align all inputs to the left of the model and all outputs to the right of the model. This can help find problematic inputs/outputs faster.

3. Choosing Variable Data Types

In order to determine the correct data type for a variable one must determine what that variable will be used for. Simulink (Ref. [2]), by default, will generate all variables as 64-bit doubles. This can cause problems for embedded platforms with a low memory footprint such as microcontrollers which is where generated code is usually targeted to. Below are some tips in order to determine which variable type is viable for each action:

- boolean: If the variable is to be used as a ON/OFF switch then this variable type should be used
- int8: If the variable does not exceed 8 bits and is a character then this variable type should be used
- int16: If the variable does not exceed 16 bits and is an integer then this variable data type should be used
- int32: If the variable does not exceed 32 bits and is an integer then this variable data type should be used
- single: If the variable is a single precision floating point number then this variable data type should be used
- double: If the variable is a double precision floating point number then this variable data type should be used. (NOTE: This is the default variable type for Simulink (Ref. [2]))
- If the variables to be defined contain many elements then a structure must be created to house these elements. A Bus must be created from said structure and then used as the data type of the variable.

4. Hardware Implementation data type information

Below is a table listing device specific information for Hardware Implementation of the Simulation and Generated code. This information is set in the Hardware Implementation pane located in the Simulation Configuration Parameters:

Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
ARM Compatible										
ARM 7/8/9/10	8	16	32	32	32	Long	Float	x	x	x
Microchip										
dsPIC	8	16	16	32	16	x	x	Little Endian	Zero	Set
Texas Instruments										
MSP430	8	16	16	32	16	x	x	Little Endian	Zero	Set

Table 1: Hardware Implementation Partial
(NOTE: For a complete Hardware Implementation table refer to Appendix A.)

5. Naming Standards

To remain consistent on which object is what, and also to make debugging of problems easier, it is important to establish a naming standard. This naming standard must be applied to models, constants, variables and buses. An example of this standard is listed below and can be used as is or with some modifications if required:

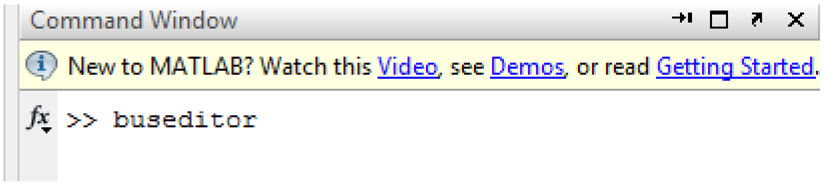
- If the object in question is a model then the name of that model should be in the form of: “Name_Model”
- If the object in question is a constant then the name of that constant should be in the form of: “Name_Constant”
- If the object in question is a bus then the name of that bus should be in the form of: “Name_Bus”

- If the object in question is a signal then the name of that signal should be in the form of: “Name_Signal”
- If the object in question is a function then the name of that signal should be in the form of: “Name_Func”
- If the object in question is a subsystem input then the name of that input should be in the form of: "Name_Input"
- If the object in question is a subsystem input then the name of that input should be in the form of: "Name_Output"

6. Creation of practice model for code generation

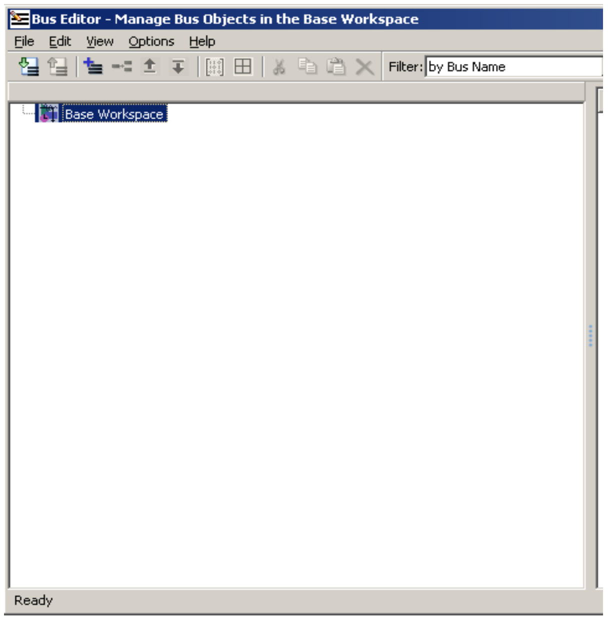
In this section a new practice model will be created in order to demonstrate the necessary steps to do successful code generation from any Simulink (Ref. [2]) model.

Open up MATLAB (Ref. [1]) and type the ‘buseditor’ command on the command window in order to access the Bus Editor.

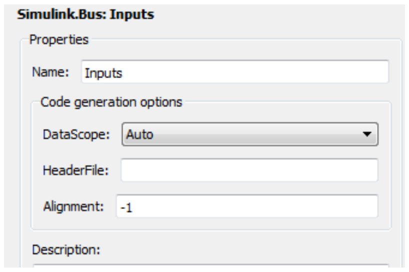

Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

```
>> buseditor
```

Bus Editor GUI:



Once here click on File > Add Bus, (or alternatively Ctrl+B), while having the Base Workspace selected. A new Bus Object will be created in the MATLAB (Ref. [1]) workspace. Rename this Bus Object to Inputs by modifying the Name Field in the Bus Editor:


Simulink.Bus: Inputs

Properties

Name: Inputs

Code generation options

DataScope: Auto

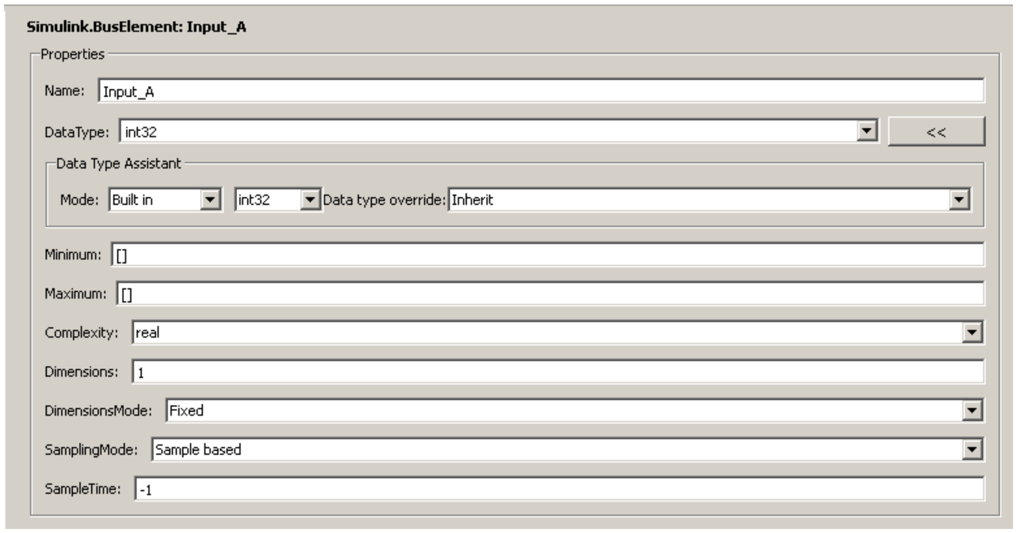
HeaderFile:

Alignment: -1

Description:

Click Apply at the bottom of this window.

Now add two new elements to this Bus by going to File>Add/Insert Element (or alternatively Ctrl+E) while having this Bus Object selected. These elements will be called Input_A and Input_B respectively and will be of type int32:


Simulink.BusElement: Input_A

Properties

Name: Input_A

DataType: int32

Data Type Assistant

Mode: Built in | int32 | Data type override: Inherit

Minimum: []

Maximum: []

Complexity: real

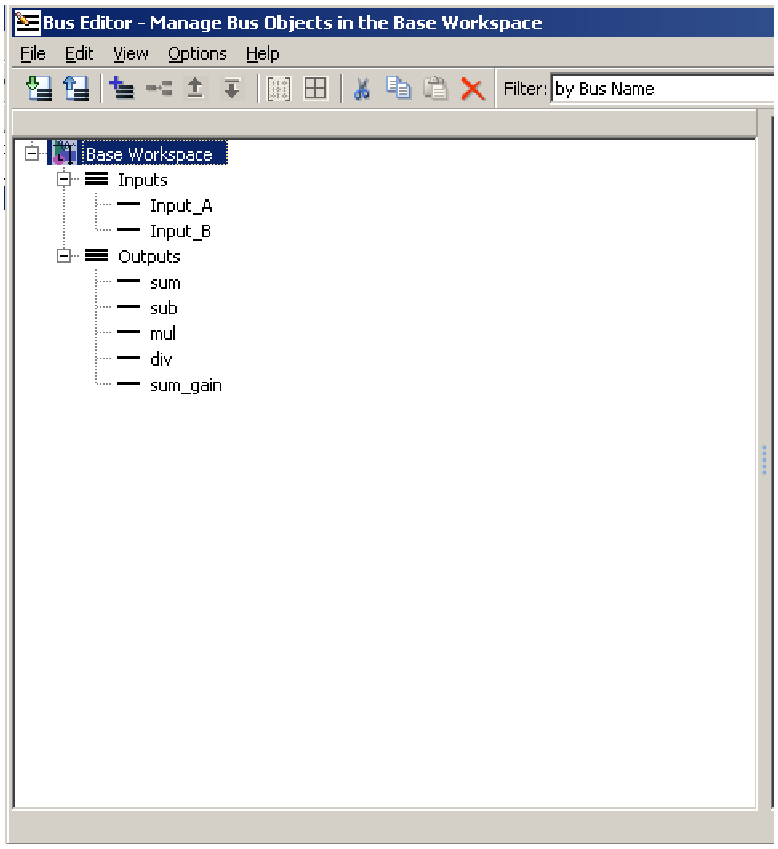
Dimensions: 1

DimensionsMode: Fixed

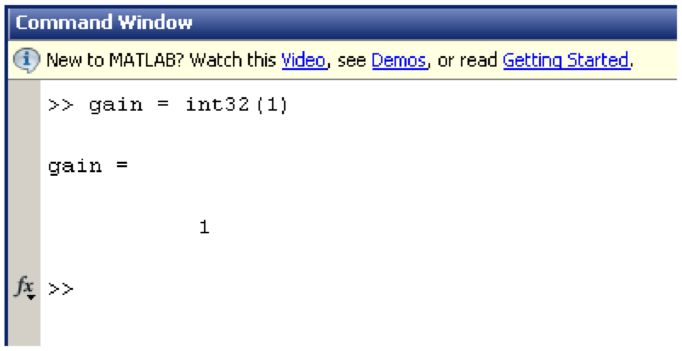
SamplingMode: Sample based

SampleTime: -1

Now repeat the previous process for the Outputs Bus but this time add five elements sum of type int32, sub of type int32, mul of type int32, div of type double, and sum_gain of type int32. Once finished the Bus Editor Window should contain the following objects:

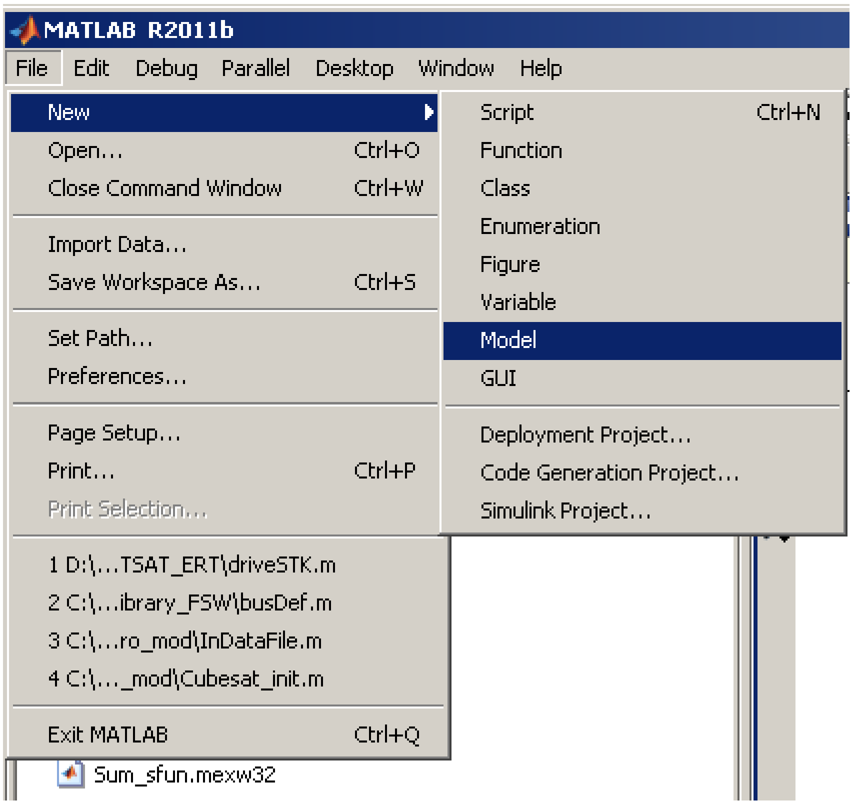

Bus Editor - Manage Bus Objects in the Base Workspace
File Edit View Options Help
Filter: by Bus Name
Base Workspace
Inputs
Input_A
Input_B
Outputs
sum
sub
mul
div
sum_gain

Go back to the workspace and write the following command in the command window: ‘gain = int32(1)’. You should see the following now:

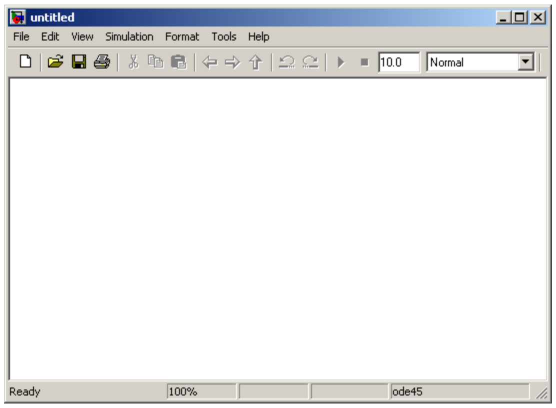

Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

```
>> gain = int32(1)

gain =

           1

>>
```

Now that the workspace contains all necessary bus objects and variables with their defined data types proceed to create a new model for Simulink (Ref. [2]) by going to File>New>Model at the top toolbar:



Now this new model should be open:

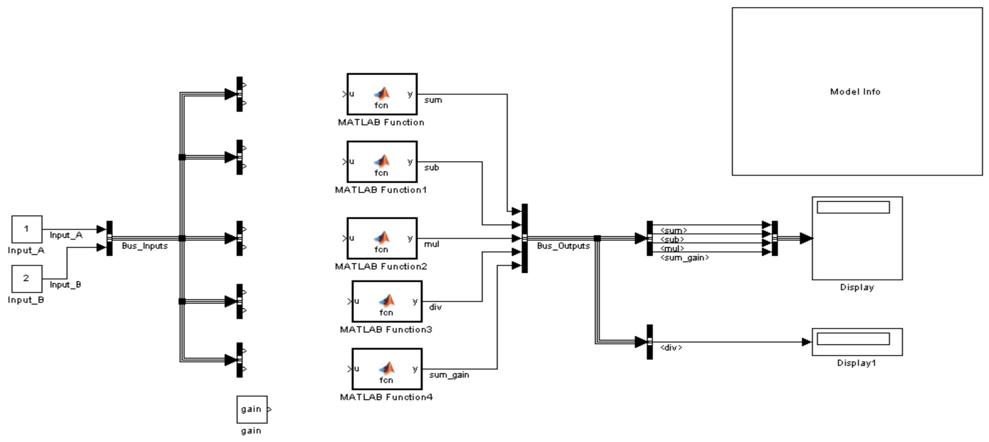


Bring up the Simulink (Ref. [2]) Library Browser and add the following blocks to the model:

- 3 Bus Creator Blocks

- 3 Constant Blocks
- 7 Bus Selector Blocks
- 2 Display Blocks
- 5 MATLAB (Ref. [1]) Function Blocks
- 1 Model Info Block

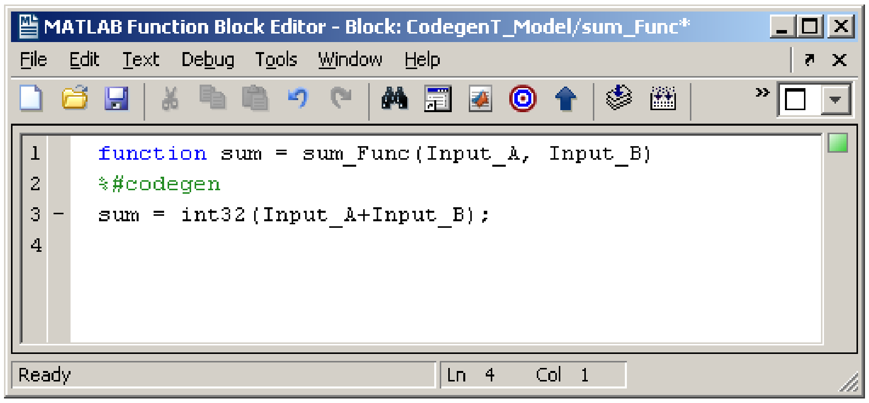
Once these are added to the model organize them in the following manner:



Make sure that the Output data types of the Input_A, Input_B and gain constants are of type int32. (NOTE: Set the gain constant value to ‘gain’)

Open the first of the MATLAB (Ref. [1]) Function blocks and write the following code inside:

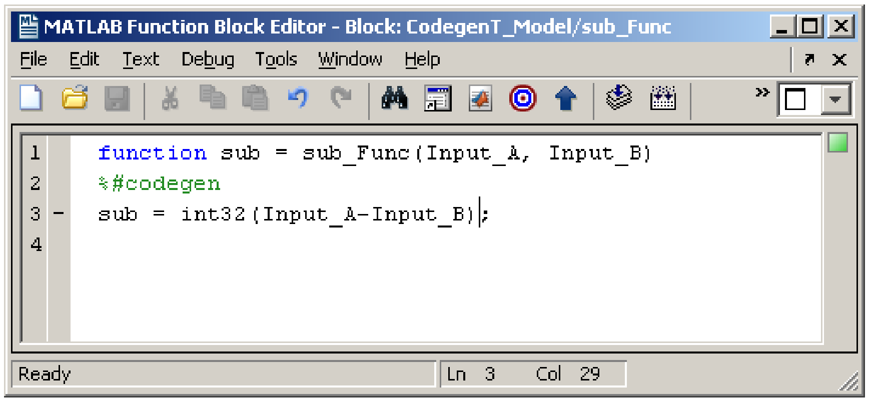
sum_func:


MATLAB Function Block Editor - Block: CodegenT_Model/sum_Func*
File
Edit
Text
Debug
Tools
Window
Help
Ready
Ln 4
Col 1

```
function sum = sum_Func(Input_A, Input_B)
%#codegen
sum = int32(Input_A+Input_B);
```

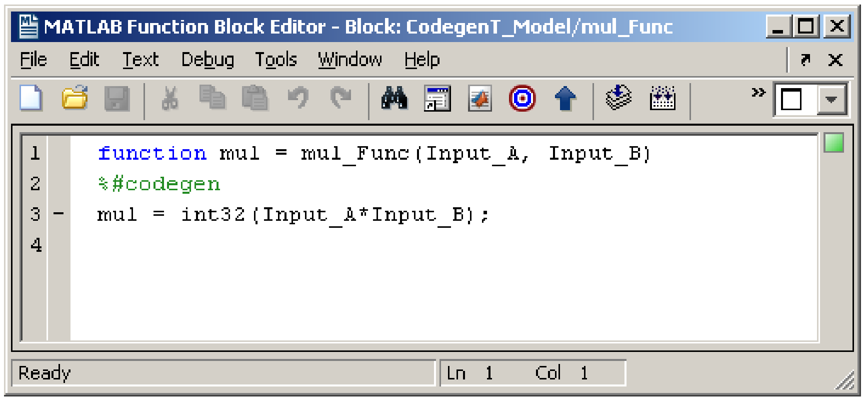
For the next four blocks write the following code in order from top to bottom:

sub_func:


MATLAB Function Block Editor - Block: CodegenT_Model/sub_Func
File Edit Text Debug Tools Window Help
Ready
Ln 3 Col 29

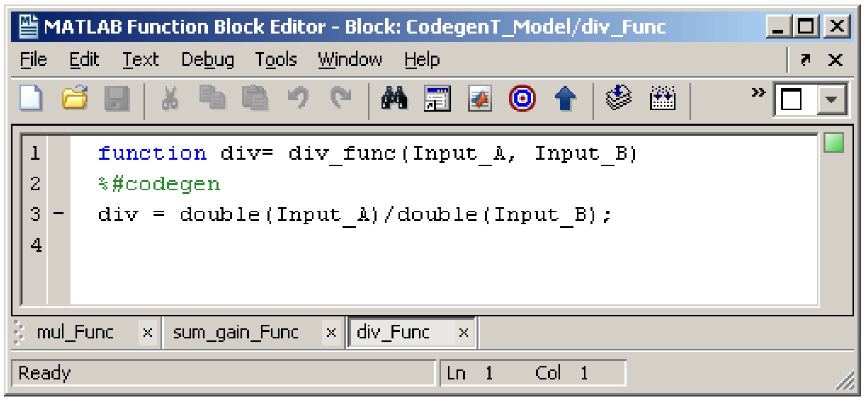
```
function sub = sub_Func(Input_A, Input_B)
%#codegen
sub = int32(Input_A-Input_B);
```

mul_func:


MATLAB Function Block Editor - Block: CodegenT_Model/mul_Func
File Edit Text Debug Tools Window Help
Ready
Ln 1 Col 1

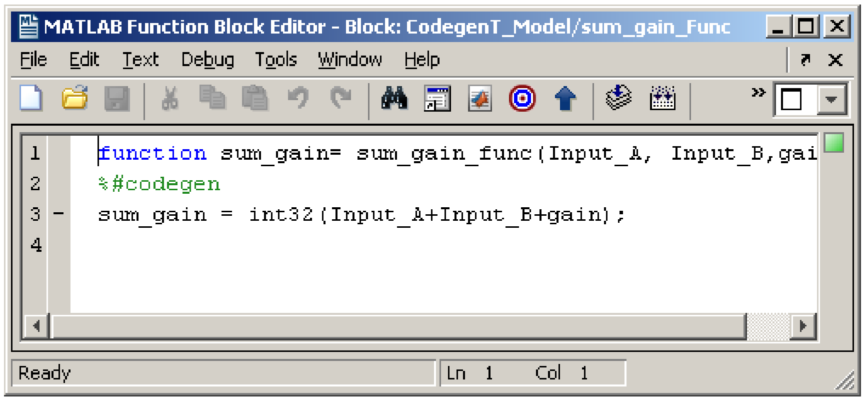
```
function mul = mul_Func(Input_A, Input_B)
%#codegen
mul = int32(Input_A*Input_B);
```

div_func:


MATLAB Function Block Editor - Block: CodegenT_Model/div_Func
File Edit Text Debug Tools Window Help
mul_Func
sum_gain_Func
div_Func
Ready
Ln 1 Col 1

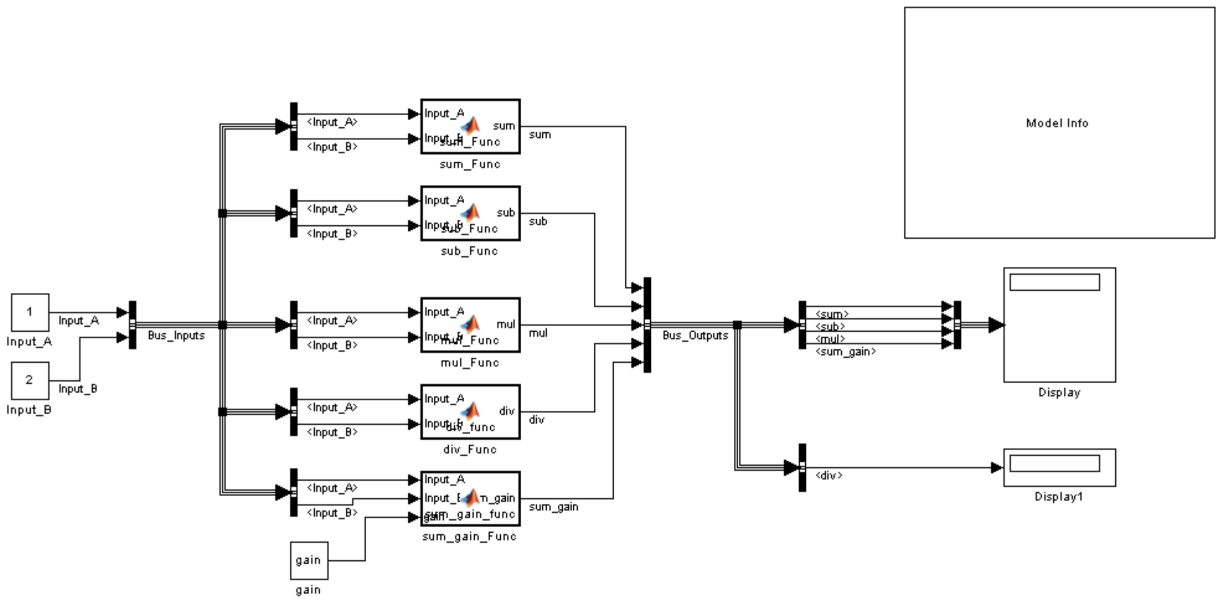
```
function div= div_func(Input_A, Input_B)
%#codegen
div = double(Input_A)/double(Input_B);
```

sum_gain_func:


MATLAB Function Block Editor - Block: CodegenT_Model/sum_gain_Func
File Edit Text Debug Tools Window Help
Ready
Ln 1 Col 1

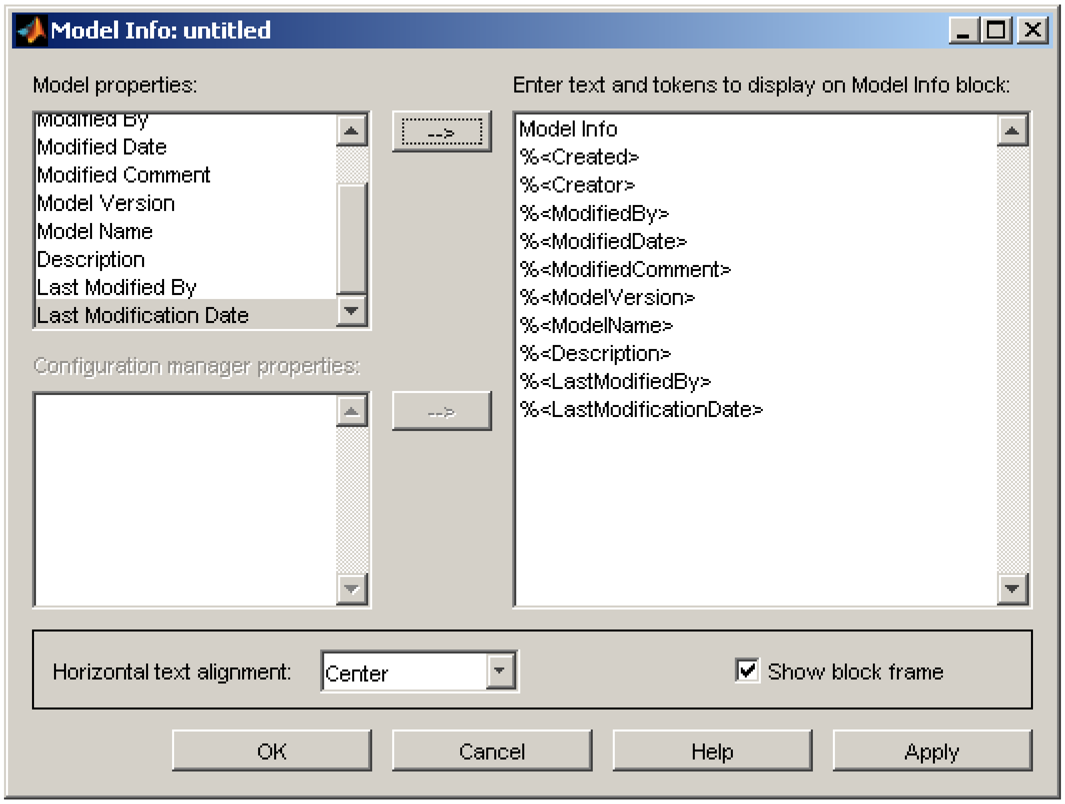
```
function sum_gain= sum_gain_func(Input_A, Input_B,gai
%#codegen
sum_gain = int32(Input_A+Input_B+gain);
```

Connect the model as shown below:



(NOTE: Make sure the First Bus Creator on the left has a data type of ‘Bus: Inputs’ and that the following Bus Creator to the right has a datatype of ‘Bus: Outputs’ as can be seen on the above. Also be sure to label all signal cables with their corresponding names)

Configure the Model Info Block with the following tokens then click Apply and OK:


Model Info: untitled

Model properties:

Modified By
Modified Date
Modified Comment
Model Version
Model Name
Description
Last Modified By
Last Modification Date

Configuration manager properties:

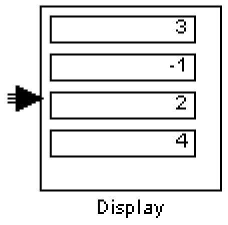
Enter text and tokens to display on Model Info block:

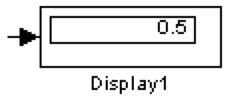
```
Model Info
%<Created>
%<Creator>
%<ModifiedBy>
%<ModifiedDate>
%<ModifiedComment>
%<ModelVersion>
%<ModelName>
%<Description>
%<LastModifiedBy>
%<LastModificationDate>
```

Horizontal text alignment: Center

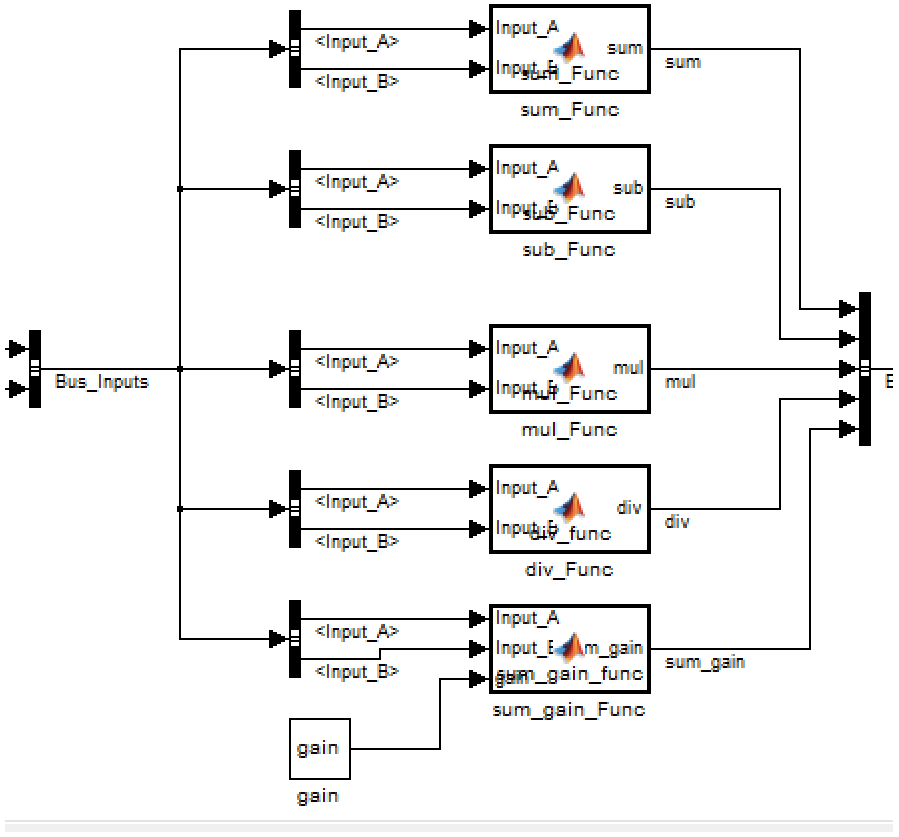
[✓] Show block frame

Run the model and look at the output seen on the display block; if the Input Constant values of Input_A and Input_B are set to 1 and 2 respectively then the output of the simulation should be $um = 3,\ sub = -1,\ mul = 2,\ sum_{gain} = 4\ and\ div = 0.5$:

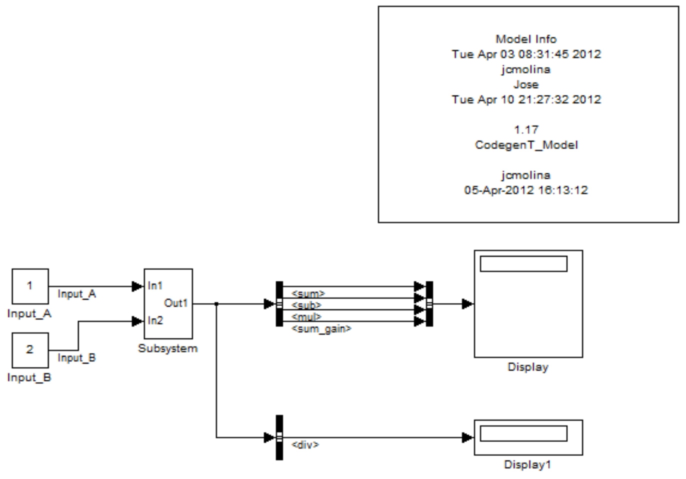




Select this section of the model and right click it. Afterwards select Create Subsystem from the popup menu:

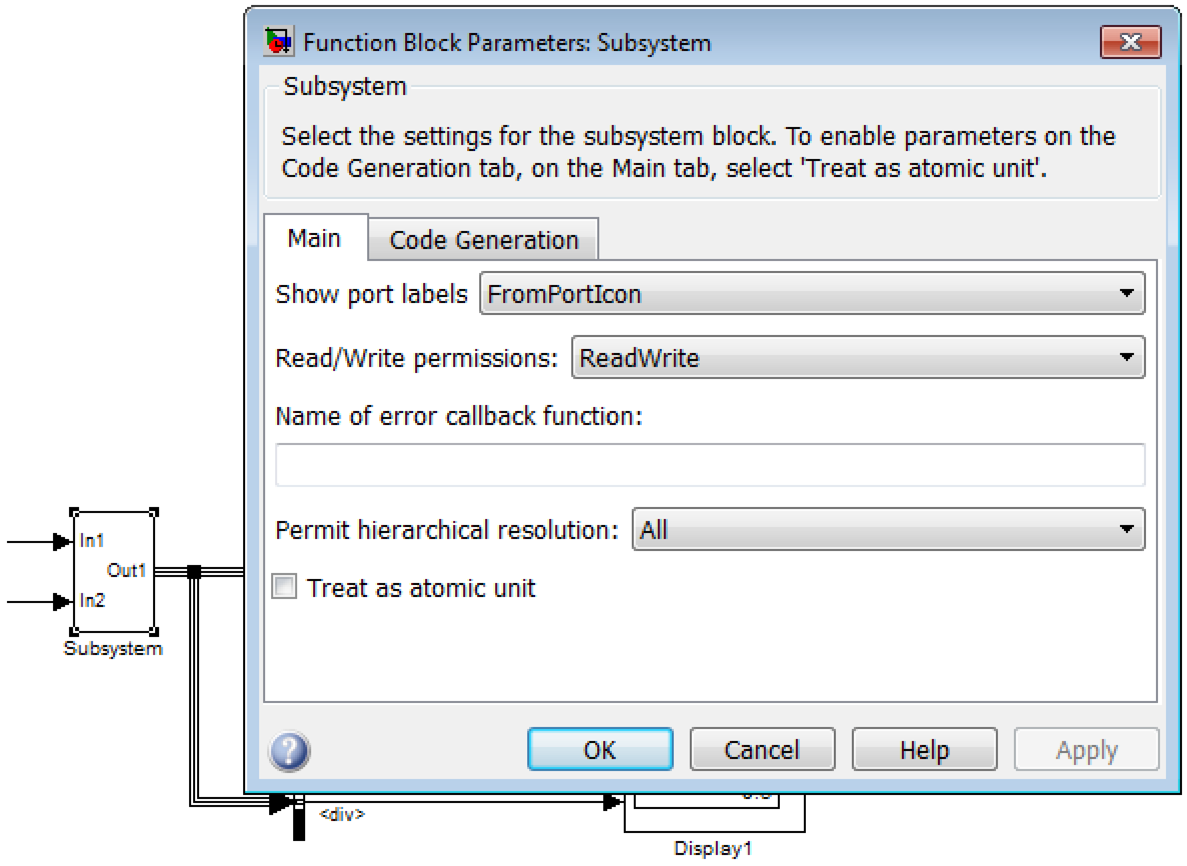


The model should now look as follows. Save this model as CodegenT_Model:



7. Preparing practice model for code generation

Now that the CodegenT_Model is finished and running it is time to prepare it for code generation. To start right click on the Subsystem Model and select Subsystem Parameters:



Function Block Parameters: Subsystem

Subsystem

Select the settings for the subsystem block. To enable parameters on the Code Generation tab, on the Main tab, select 'Treat as atomic unit'.

Show port labels: FromPortIcon

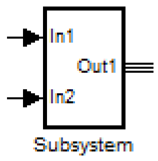
Read/Write permissions: ReadWrite

Name of error callback function:

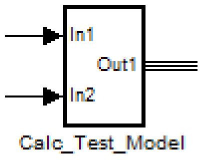
Permit hierarchical resolution: All

☐ Treat as atomic unit

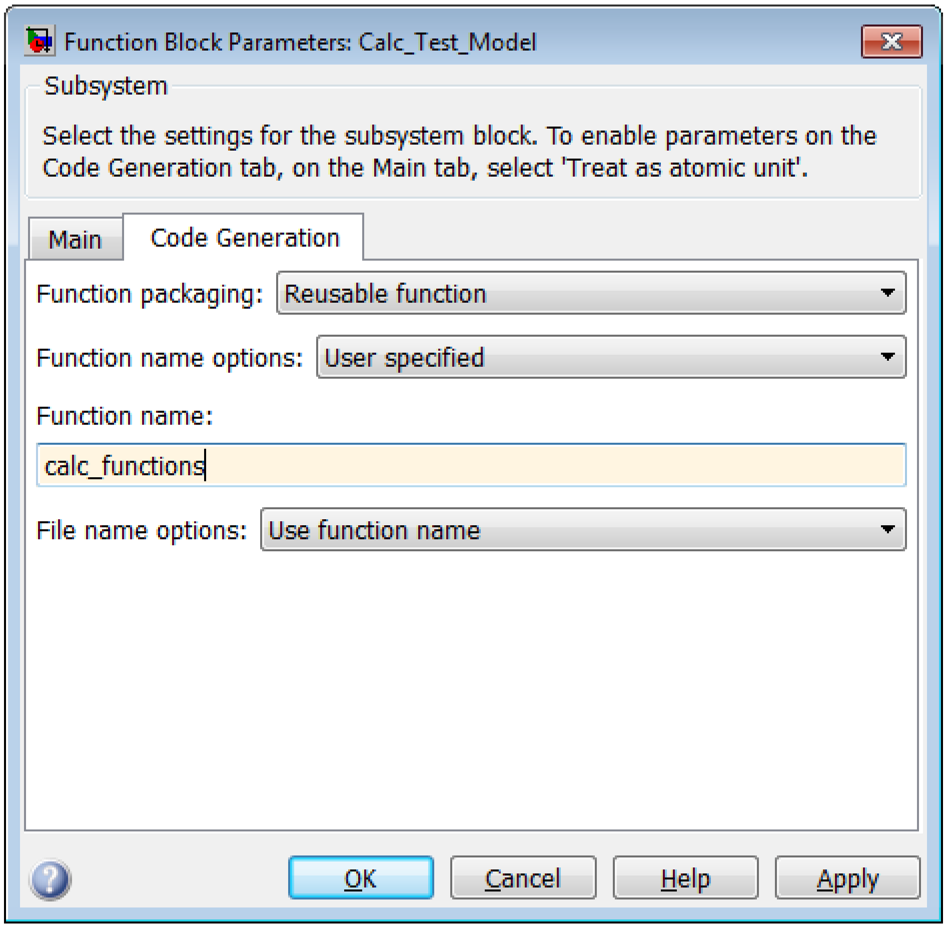
Check the box that is labeled "Treat as atomic unit"; click Apply then OK. This will change the borders of the Subsystem to a bold line indicating that the system is now atomic and will execute as a single unit inside the simulation. Systems must be atomic in order to be generated as re-usable C functions using Real-Time Workshop. The Subsystem model should now look as follows (NOTE: Changing a Subsystem to an atomic representation can change simulation output; always verify that the simulation is still working before generating code from it.):



Rename the Subsystem model to Calc_Test_Model:



Once again right click on the model and open the Subsystem Parameters, go to the Code Generation Tab which is enabled when the Subsystem is declared as atomic and choose the "Reusable Function" option on the "Function packaging" dropdown list. Afterwards two more dropdown lists will appear "Function name options" and "File name options"; For the first dropdown list choose "User Specified" and write the following name in the provided text space "calc_functions". Afterwards choose the "Use function name" option for the "File name options" dropdown list. Finally click Apply then OK to close the subsystem parameters:


Function Block Parameters: Calc_Test_Model

Subsystem

Select the settings for the subsystem block. To enable parameters on the Code Generation tab, on the Main tab, select 'Treat as atomic unit'.

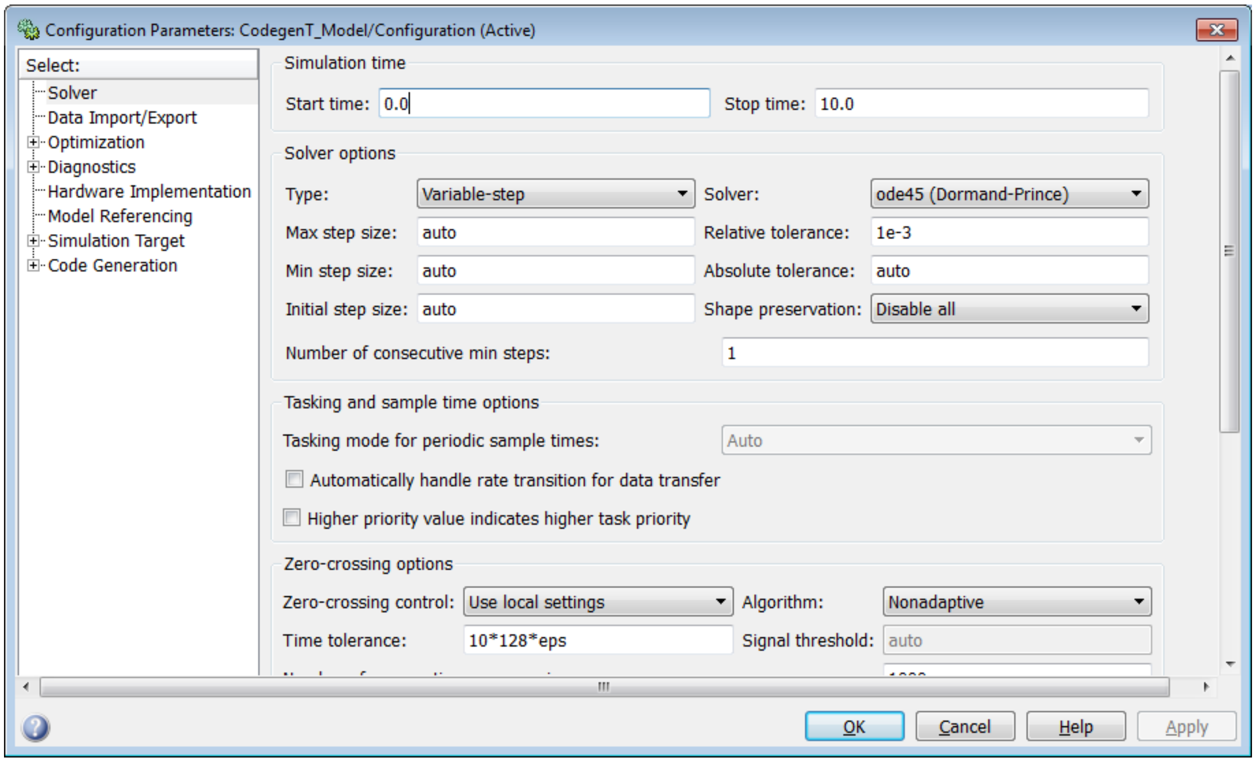
Function packaging: Reusable function

Function name options: User specified

Function name: calc_functions

File name options: Use function name

Next go to the top toolbar in Simulink (Ref. [2]) and click on Simulation > Configuration Parameters. The following window will open:



Simulation time

Start time: 0.0 Stop time: 10.0

Solver options

Type: Variable-step Solver: ode45 (Dormand-Prince)
Max step size: auto Relative tolerance: 1e-3
Min step size: auto Absolute tolerance: auto
Initial step size: auto Shape preservation: Disable all
Number of consecutive min steps: 1

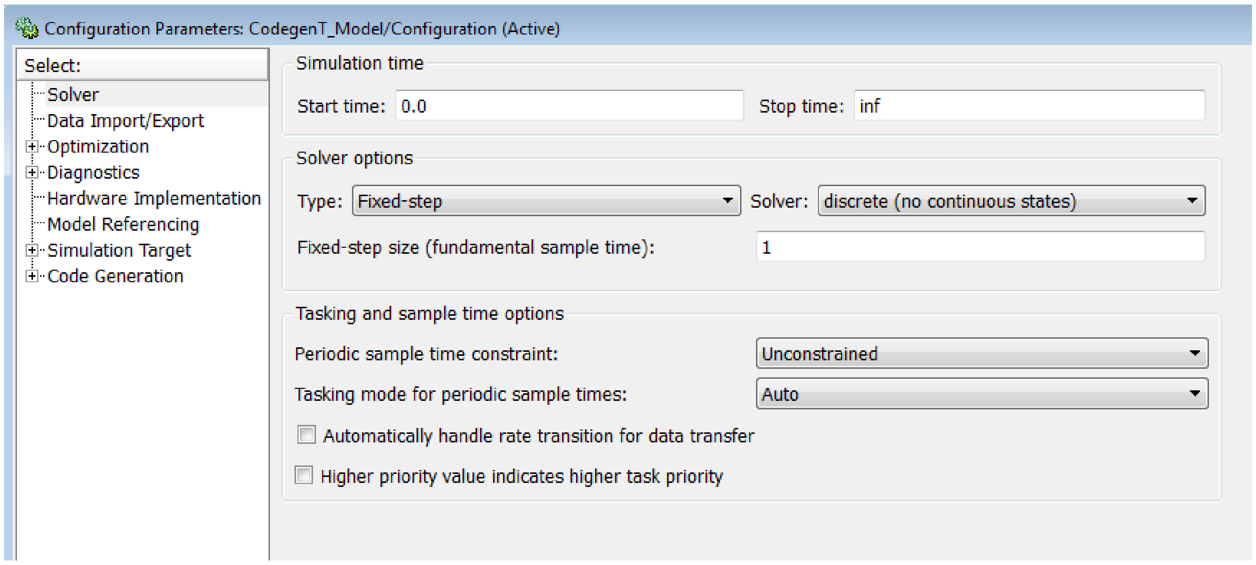
Tasking and sample time options

Tasking mode for periodic sample times: Auto
☐ Automatically handle rate transition for data transfer
☐ Higher priority value indicates higher task priority

Zero-crossing options

Zero-crossing control: Use local settings Algorithm: Nonadaptive
Time tolerance: 10*128*eps Signal threshold: auto

These are all the available properties for the simulation. For code generation only some of these properties need to be modified. To start off set the Solver pane options as shown below:



Simulation time

Start time: 0.0 Stop time: inf

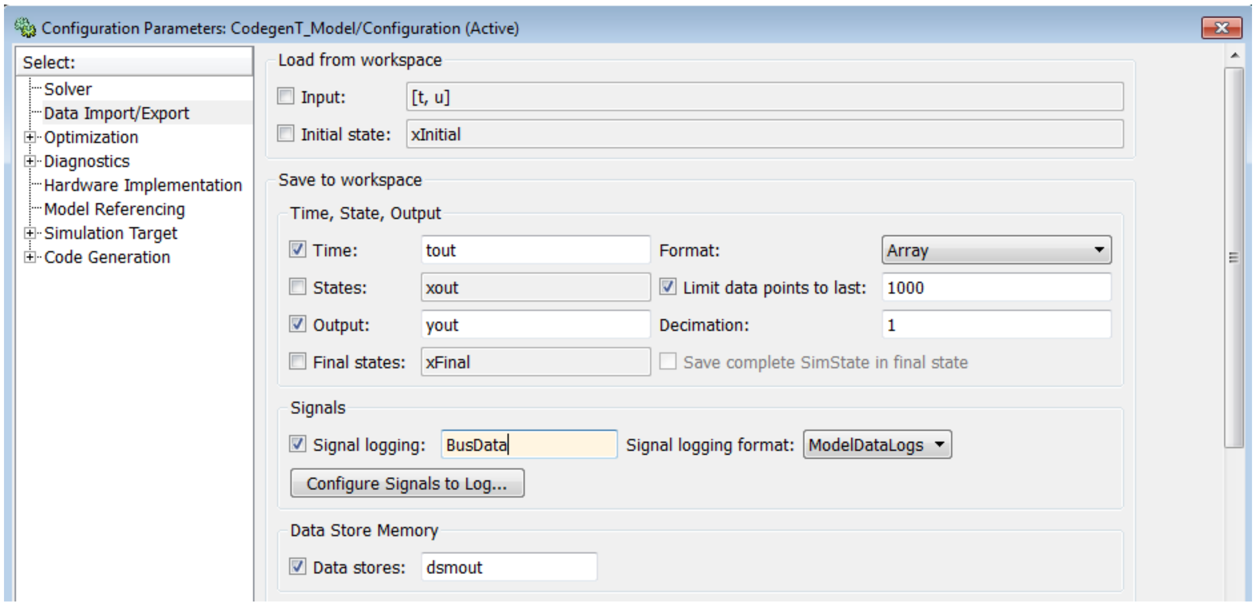
Solver options

Type: Fixed-step Solver: discrete (no continuous states)
Fixed-step size (fundamental sample time): 1

Tasking and sample time options

Periodic sample time constraint: Unconstrained
Tasking mode for periodic sample times: Auto
☐ Automatically handle rate transition for data transfer
☐ Higher priority value indicates higher task priority

Next in Data Import/Export pane change the signal logging name to BusData (NOTE: Signal logging can be used for debugging and generating files from simulation output data):


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation

Load from workspace
- [ ] Input: [t, u]
- [ ] Initial state: xInitial

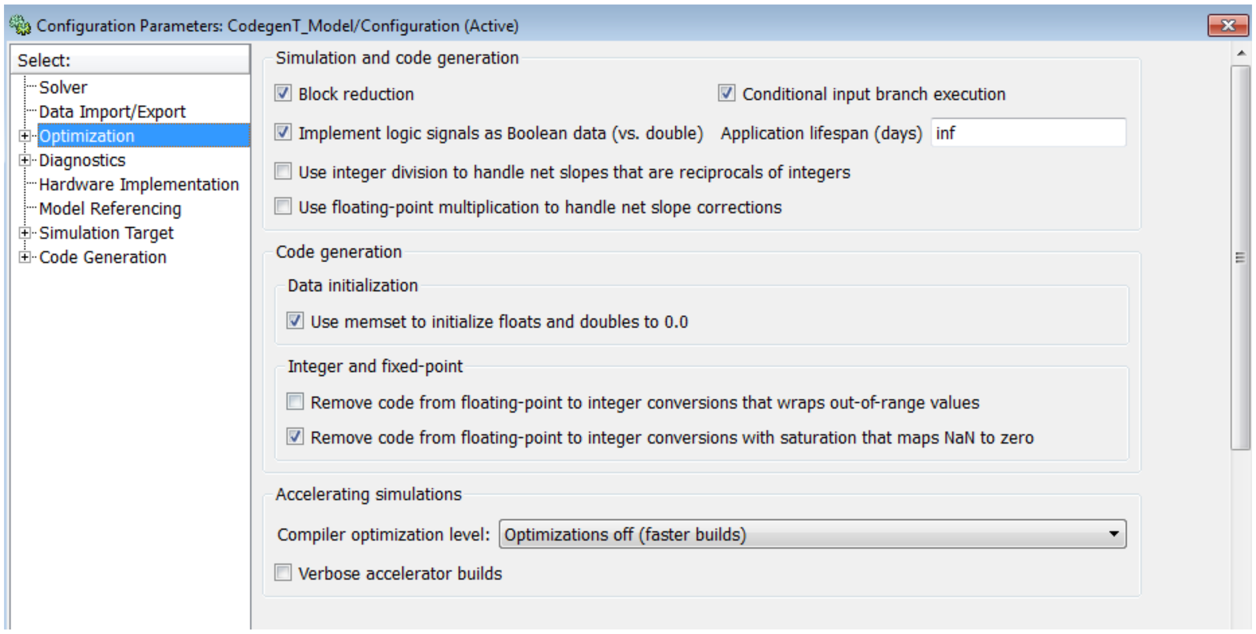
Save to workspace

Time, State, Output
- [✓] Time: tout — Format: Array
- [ ] States: xout — [✓] Limit data points to last: 1000
- [✓] Output: yout — Decimation: 1
- [ ] Final states: xFinal — [ ] Save complete SimState in final state

Signals
- [✓] Signal logging: BusData — Signal logging format: ModelDataLogs
- Configure Signals to Log...

Data Store Memory
- [✓] Data stores: dsmout

For the Optimization pane change the Application lifespan setting to inf:


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation

Simulation and code generation
- [✓] Block reduction
- [✓] Conditional input branch execution
- [✓] Implement logic signals as Boolean data (vs. double)
- Application lifespan (days) inf
- [ ] Use integer division to handle net slopes that are reciprocals of integers
- [ ] Use floating-point multiplication to handle net slope corrections

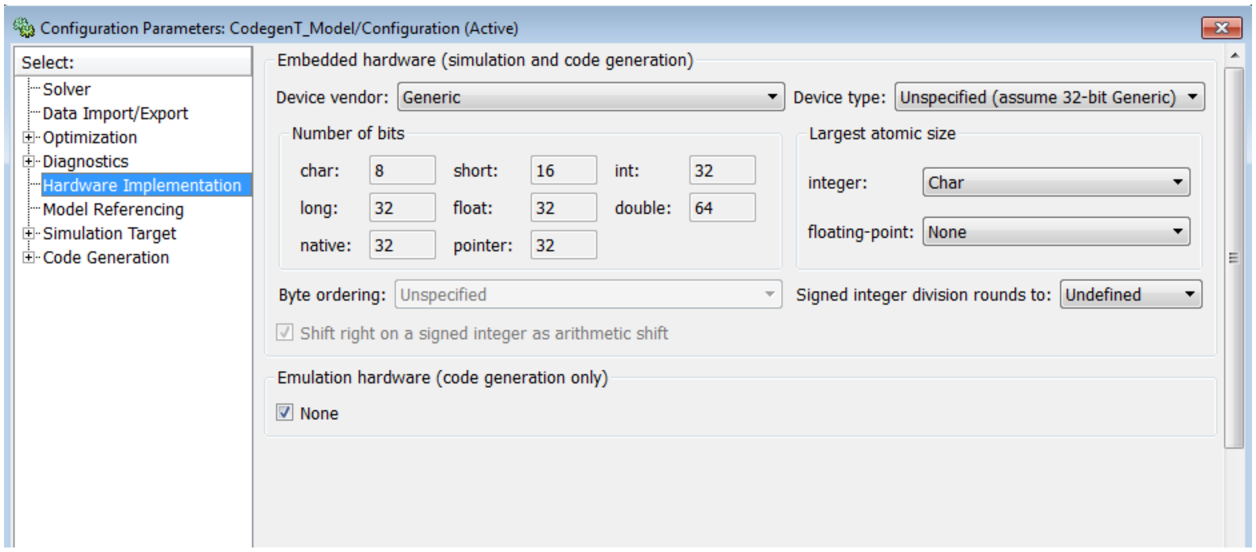
Code generation

Data initialization
- [✓] Use memset to initialize floats and doubles to 0.0

Integer and fixed-point
- [ ] Remove code from floating-point to integer conversions that wraps out-of-range values
- [✓] Remove code from floating-point to integer conversions with saturation that maps NaN to zero

Accelerating simulations
- Compiler optimization level: Optimizations off (faster builds)
- [ ] Verbose accelerator builds

Jump over to the Hardware Implementation pane and set the settings of this pane as outlined in Table 1 based on the Hardware for which the code will be generated (NOTE: For this example Unspecified (32-bit generic) will be used):


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation

Embedded hardware (simulation and code generation)

Device vendor: Generic
Device type: Unspecified (assume 32-bit Generic)

Number of bits

char:	8	short:	16	int:	32
long:	32	float:	32	double:	64
native:	32	pointer:	32		

Largest atomic size

integer: Char
floating-point: None

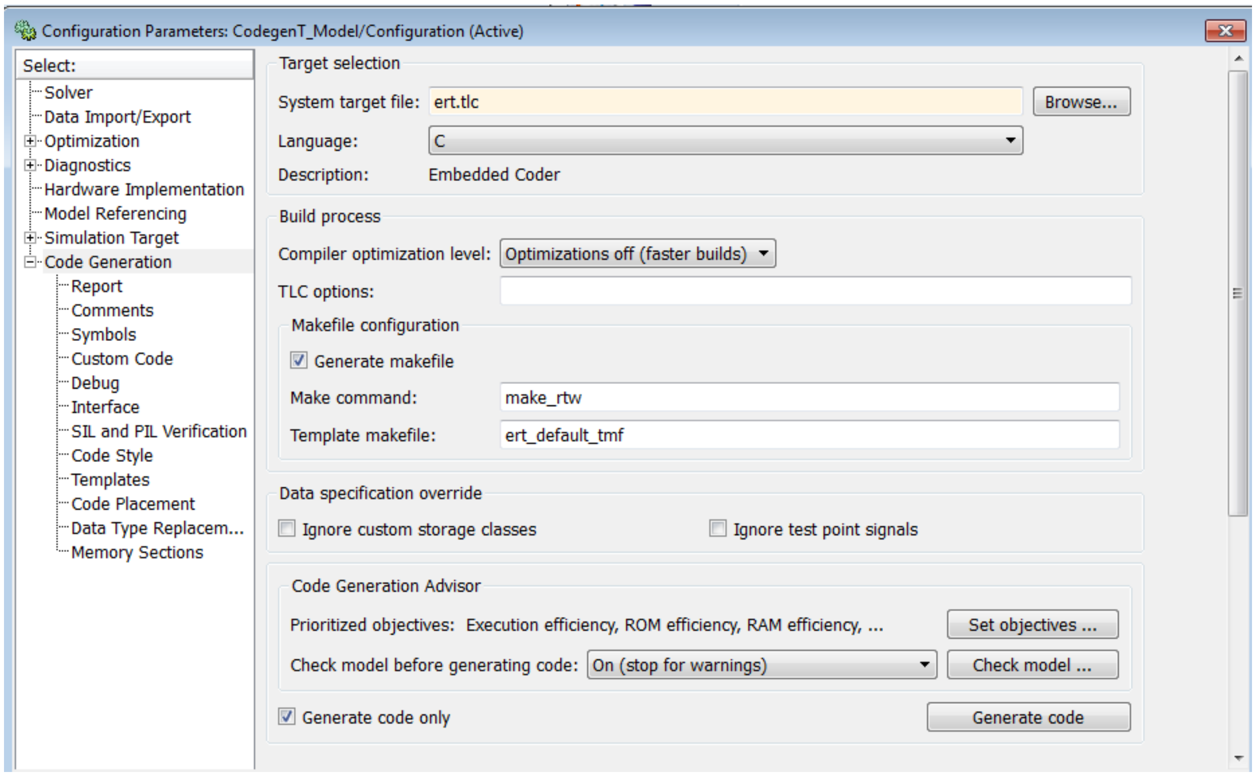
Byte ordering: Unspecified
Signed integer division rounds to: Undefined

☑ Shift right on a signed integer as arithmetic shift

Emulation hardware (code generation only)

☑ None

Go to the Code Generation Pane and select the following options:


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation
  - Report
  - Comments
  - Symbols
  - Custom Code
  - Debug
  - Interface
  - SIL and PIL Verification
  - Code Style
  - Templates
  - Code Placement
  - Data Type Replacem...
  - Memory Sections

Target selection

System target file: ert.tlc
Language: C
Description: Embedded Coder

Build process

Compiler optimization level: Optimizations off (faster builds)
TLC options:

Makefile configuration

☑ Generate makefile
Make command: make_rtw
Template makefile: ert_default_tmf

Data specification override

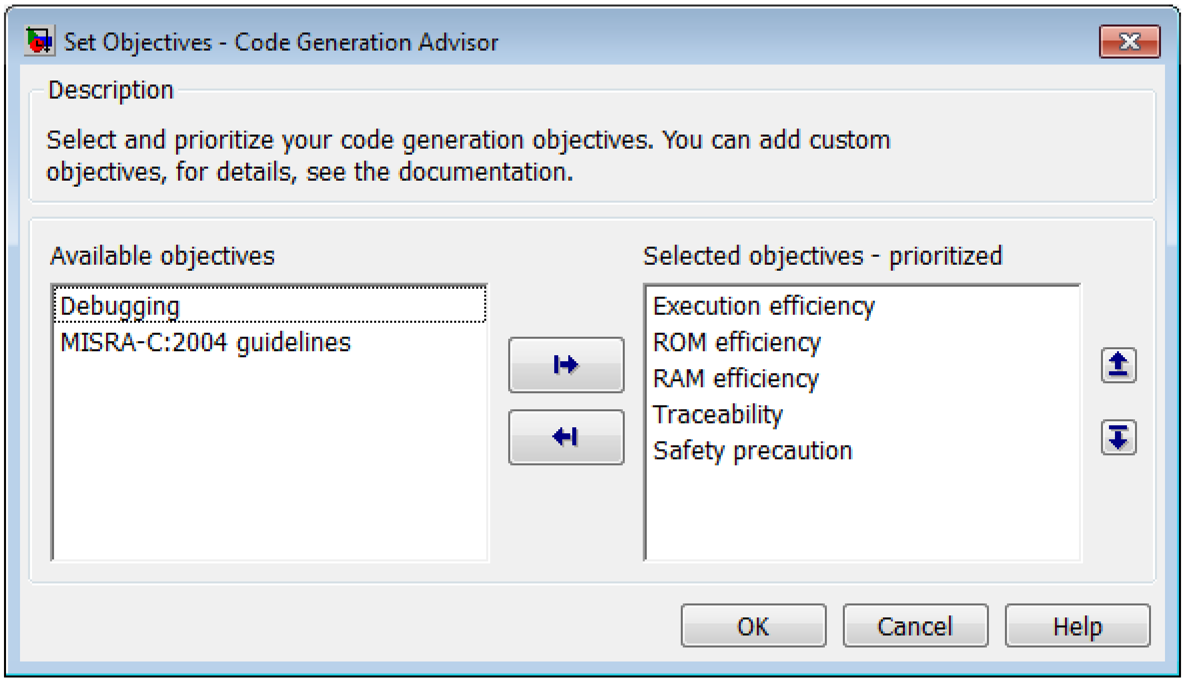
☐ Ignore custom storage classes
☐ Ignore test point signals

Code Generation Advisor

Prioritized objectives: Execution efficiency, ROM efficiency, RAM efficiency, ...
Check model before generating code: On (stop for warnings)

☑ Generate code only

Set Objectives Pop-Up to the desired objectives:


Set Objectives - Code Generation Advisor

Description

Select and prioritize your code generation objectives. You can add custom objectives, for details, see the documentation.

Available objectives

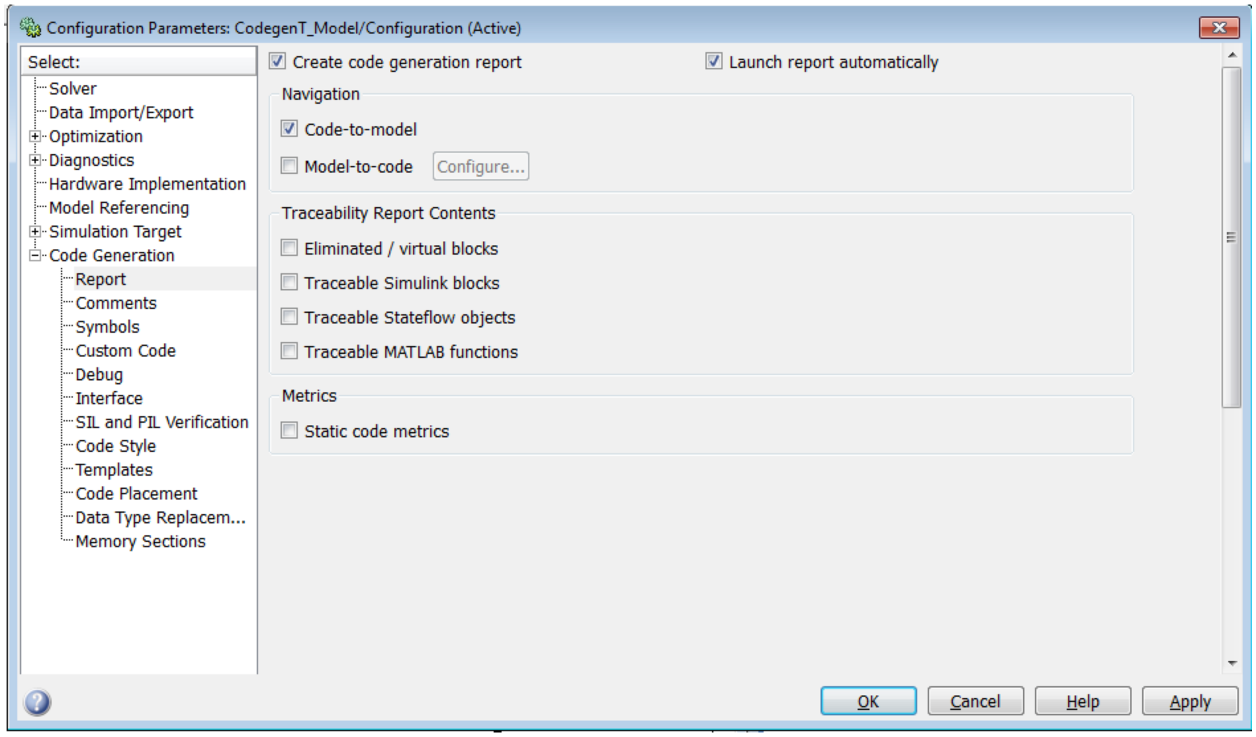
Debugging
MISRA-C:2004 guidelines

Selected objectives - prioritized

Execution efficiency
ROM efficiency
RAM efficiency
Traceability
Safety precaution

Make sure to select the correct target file based on the desired target. For this example ert.tlc Embedded Coder will be used.

Select the Report Pane and set the following options:


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation
  - Report
  - Comments
  - Symbols
  - Custom Code
  - Debug
  - Interface
  - SIL and PIL Verification
  - Code Style
  - Templates
  - Code Placement
  - Data Type Replacem...
  - Memory Sections

[✓] Create code generation report
[✓] Launch report automatically

Navigation

[✓] Code-to-model
[ ] Model-to-code Configure...

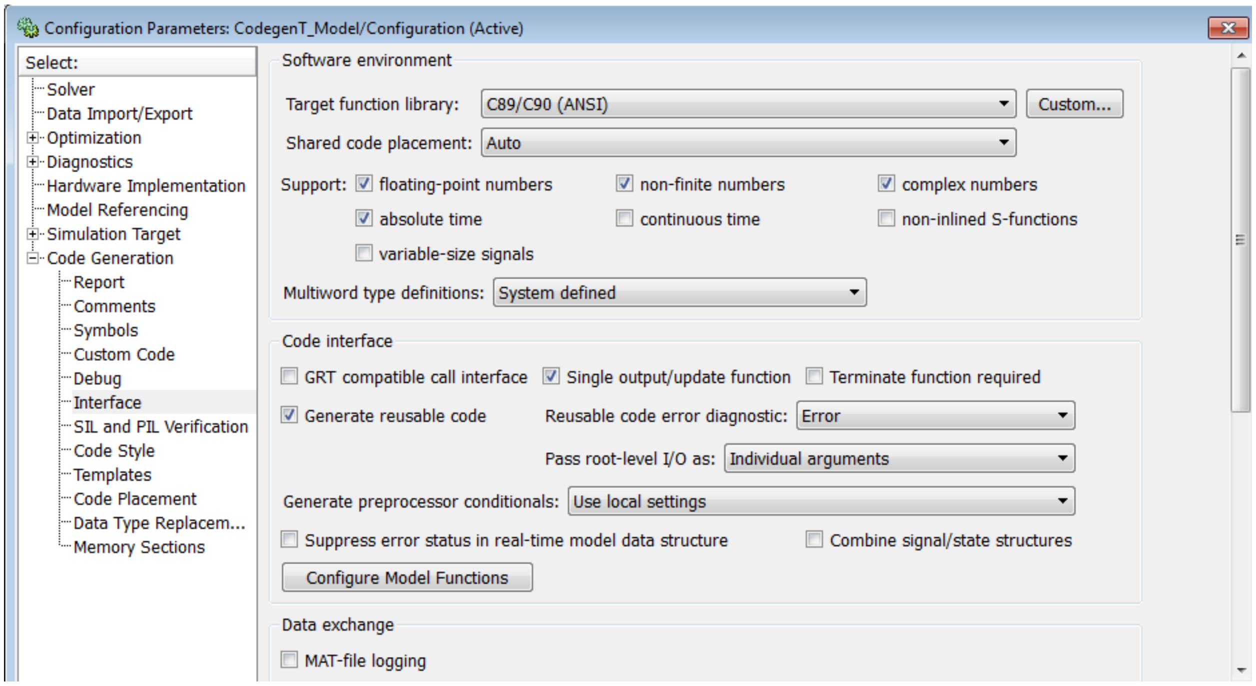
Traceability Report Contents

[ ] Eliminated / virtual blocks
[ ] Traceable Simulink blocks
[ ] Traceable Stateflow objects
[ ] Traceable MATLAB functions

Metrics

[ ] Static code metrics

Go to the Interface pane and select the following options:


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation
  - Report
  - Comments
  - Symbols
  - Custom Code
  - Debug
  - Interface
  - SIL and PIL Verification
  - Code Style
  - Templates
  - Code Placement
  - Data Type Replacem...
  - Memory Sections

Software environment

Target function library: C89/C90 (ANSI) [Custom...]

Shared code placement: Auto

Support: [✓] floating-point numbers [✓] non-finite numbers [✓] complex numbers

[✓] absolute time [ ] continuous time [ ] non-inlined S-functions

[ ] variable-size signals

Multiword type definitions: System defined

Code interface

[ ] GRT compatible call interface [✓] Single output/update function [ ] Terminate function required

[✓] Generate reusable code Reusable code error diagnostic: Error

Pass root-level I/O as: Individual arguments

Generate preprocessor conditionals: Use local settings

[ ] Suppress error status in real-time model data structure [ ] Combine signal/state structures

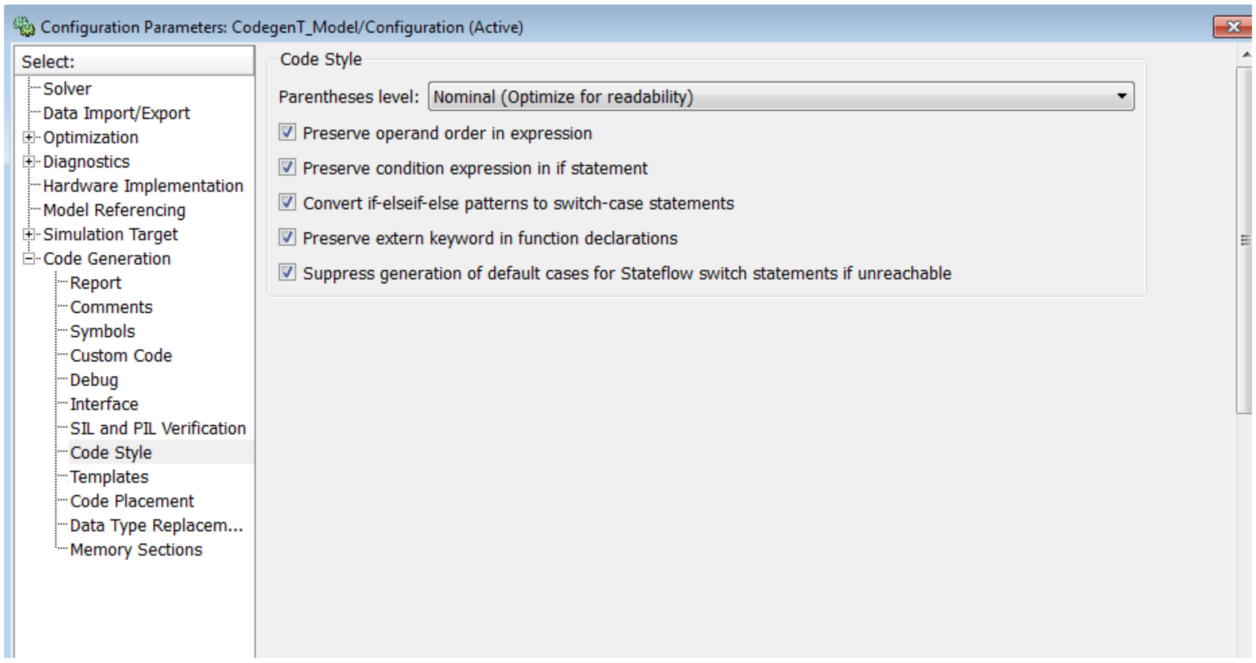
[Configure Model Functions]

Data exchange

[ ] MAT-file logging

Make sure the "Generate reusable code" checkbox is checked in this pane.

Go to the Code Style pane and check all checkboxes. This is done to set the coding style as humanly readable as possible for code generation:


Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation
  - Report
  - Comments
  - Symbols
  - Custom Code
  - Debug
  - Interface
  - SIL and PIL Verification
  - Code Style
  - Templates
  - Code Placement
  - Data Type Replacem...
  - Memory Sections

Code Style

Parentheses level: Nominal (Optimize for readability)

[✓] Preserve operand order in expression

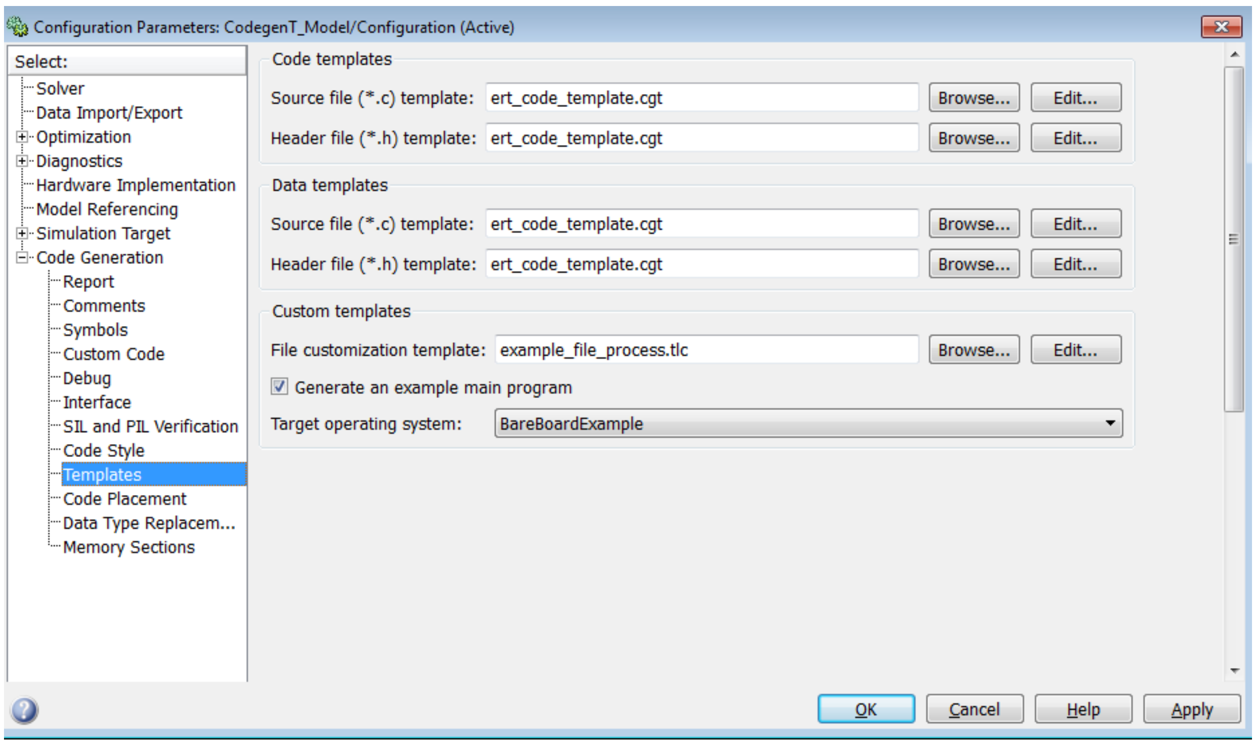
[✓] Preserve condition expression in if statement

[✓] Convert if-elseif-else patterns to switch-case statements

[✓] Preserve extern keyword in function declarations

[✓] Suppress generation of default cases for Stateflow switch statements if unreachable

Next go to the Templates pane and set the following options:



Configuration Parameters: CodegenT_Model/Configuration (Active)

Select:
- Solver
- Data Import/Export
- Optimization
- Diagnostics
- Hardware Implementation
- Model Referencing
- Simulation Target
- Code Generation
  - Report
  - Comments
  - Symbols
  - Custom Code
  - Debug
  - Interface
  - SIL and PIL Verification
  - Code Style
  - Templates
  - Code Placement
  - Data Type Replacem...
  - Memory Sections

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

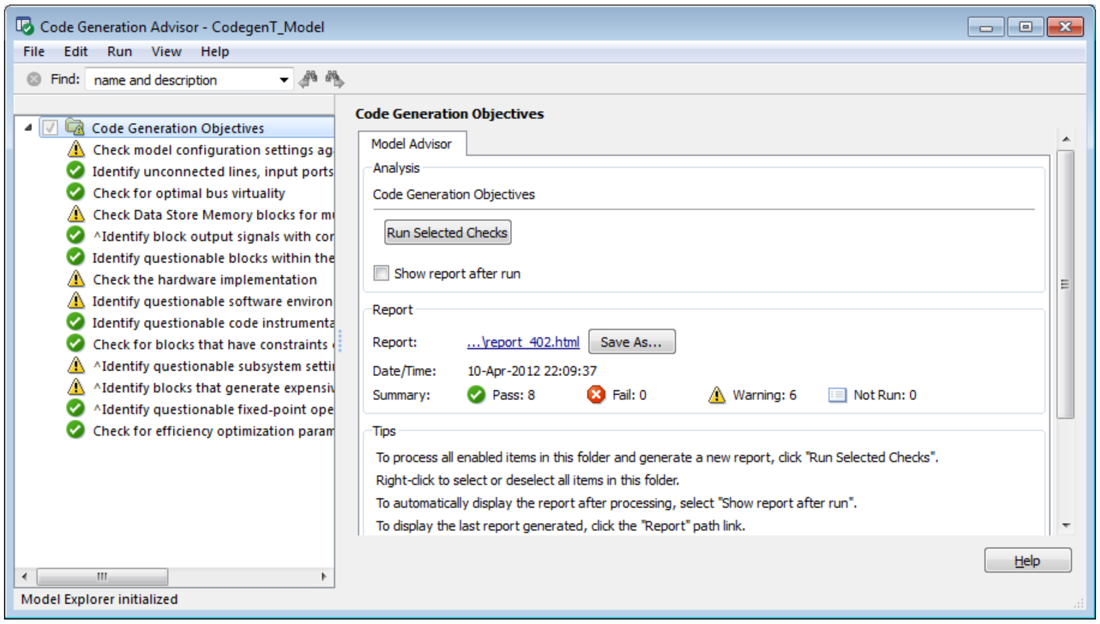
File customization template: example_file_process.tlc

[✓] Generate an example main program

Target operating system: BareBoardExample

In this pane source code generation templates may be selected. This requires advanced knowledge of tlc language. Information on tlc language and files can be found in the MATLAB (Ref. [1]) help window.

Once again return to the Code Generation pane; click Apply then click the generate code button. A model check procedure will now start to verify that all settings are correct for code generation:



Code Generation Advisor - CodegenT_Model

Find: name and description

- Code Generation Objectives
  - ⚠ Check model configuration settings ag
  - ✓ Identify unconnected lines, input ports
  - ✓ Check for optimal bus virtuality
  - ⚠ Check Data Store Memory blocks for m
  - ✓ ^Identify block output signals with cor
  - ✓ Identify questionable blocks within the
  - ⚠ Check the hardware implementation
  - ⚠ Identify questionable software environ
  - ✓ Identify questionable code instrumenta
  - ✓ Check for blocks that have constraints
  - ⚠ ^Identify questionable subsystem setti
  - ⚠ ^Identify blocks that generate expensi
  - ✓ ^Identify questionable fixed-point ope
  - ✓ Check for efficiency optimization param

Code Generation Objectives

Model Advisor

Analysis

Code Generation Objectives

Run Selected Checks

☐ Show report after run

Report

Report: ...\report_402.html

Date/Time: 10-Apr-2012 22:09:37

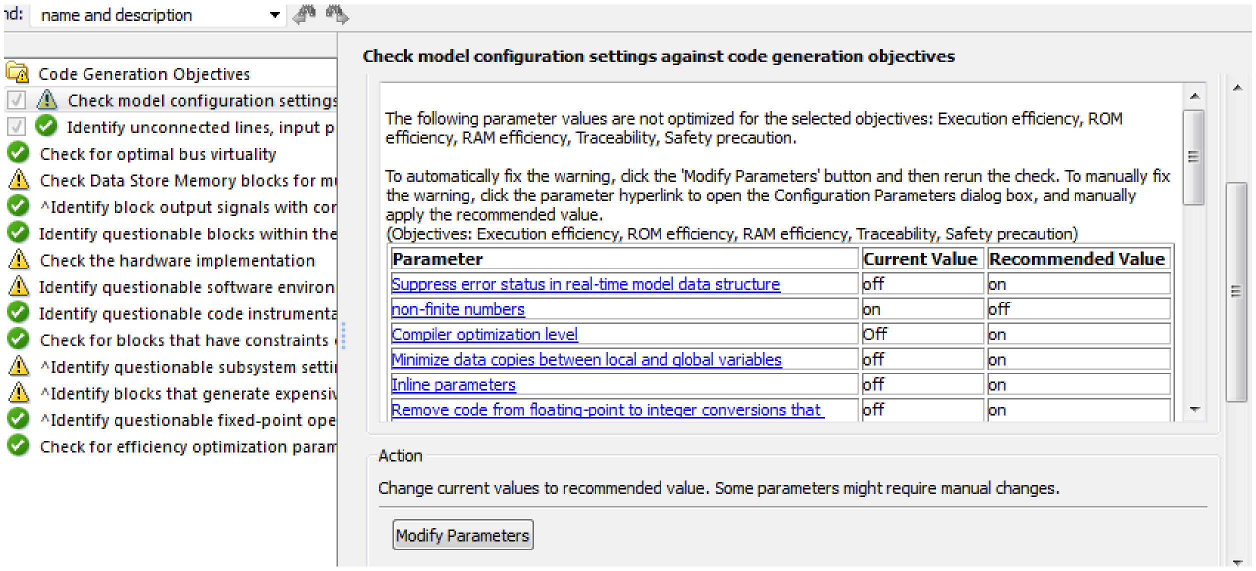
Summary: ✓ Pass: 8 ✗ Fail: 0 ⚠ Warning: 6 Not Run: 0

Tips

To process all enabled items in this folder and generate a new report, click "Run Selected Checks".
Right-click to select or deselect all items in this folder.
To automatically display the report after processing, select "Show report after run".
To display the last report generated, click the "Report" path link.

Model Explorer initialized

Select the first warning symbol on the top of the Code Generation Objectives list and then click on Modify Parameters:



nd: name and description

Code Generation Objectives
- ⚠ Check model configuration settings
- ✓ Identify unconnected lines, input p
- ✓ Check for optimal bus virtuality
- ⚠ Check Data Store Memory blocks for m
- ✓ ^Identify block output signals with co
- ✓ Identify questionable blocks within the
- ⚠ Check the hardware implementation
- ⚠ Identify questionable software environ
- ✓ Identify questionable code instrumenta
- ✓ Check for blocks that have constraints
- ⚠ ^Identify questionable subsystem setti
- ⚠ ^Identify blocks that generate expensiv
- ✓ ^Identify questionable fixed-point ope
- ✓ Check for efficiency optimization param

Check model configuration settings against code generation objectives

The following parameter values are not optimized for the selected objectives: Execution efficiency, ROM efficiency, RAM efficiency, Traceability, Safety precaution.

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: Execution efficiency, ROM efficiency, RAM efficiency, Traceability, Safety precaution)

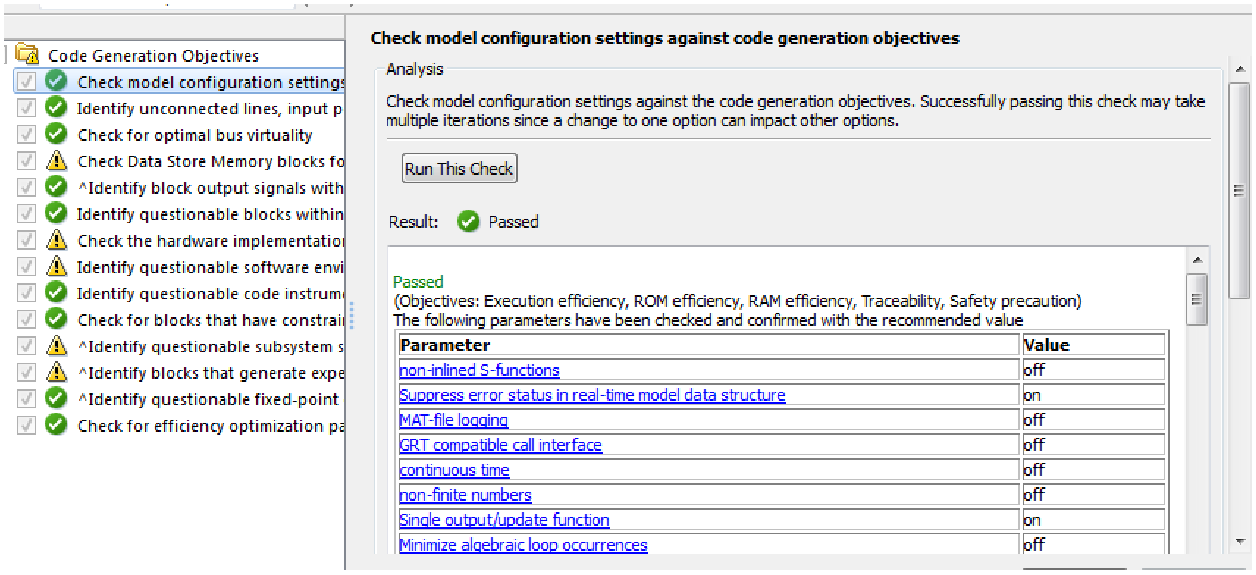
Parameter	Current Value	Recommended Value
Suppress error status in real-time model data structure	off	on
non-finite numbers	on	off
Compiler optimization level	Off	on
Minimize data copies between local and global variables	off	on
Inline parameters	off	on
Remove code from floating-point to integer conversions that	off	on

Action

Change current values to recommended value. Some parameters might require manual changes.

Modify Parameters

This will set the conflicting parameters to the correct settings for code generation. Once this is done click on Run This Check will in the same window:



Code Generation Objectives
- ✓ Check model configuration settings
- ✓ Identify unconnected lines, input p
- ✓ Check for optimal bus virtuality
- ⚠ Check Data Store Memory blocks fo
- ✓ ^Identify block output signals with
- ✓ Identify questionable blocks within
- ⚠ Check the hardware implementatio
- ⚠ Identify questionable software envi
- ✓ Identify questionable code instrum
- ✓ Check for blocks that have constrai
- ⚠ ^Identify questionable subsystem s
- ⚠ ^Identify blocks that generate expe
- ✓ ^Identify questionable fixed-point
- ✓ Check for efficiency optimization pa

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

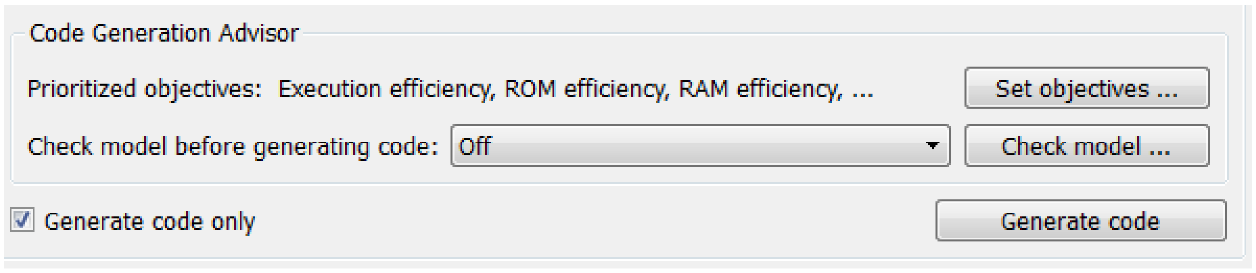
Result: ✓ Passed

Passed
(Objectives: Execution efficiency, ROM efficiency, RAM efficiency, Traceability, Safety precaution)
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
Single output/update function	on
Minimize algebraic loop occurrences	off

Do the same procedure for the remaining warnings if necessary based on individual model configurations. In the case of this simple example it is not necessary to fix all warnings as they are only there to prevent what could be future issues but not really simulation errors.

Once done here go back to the Configuration Parameters and change the "Check model before generating code" dropdown list to the "Off" setting in order to bypass the model advisor. Click Apply then OK to save these changes then close the Configuration Parameters:



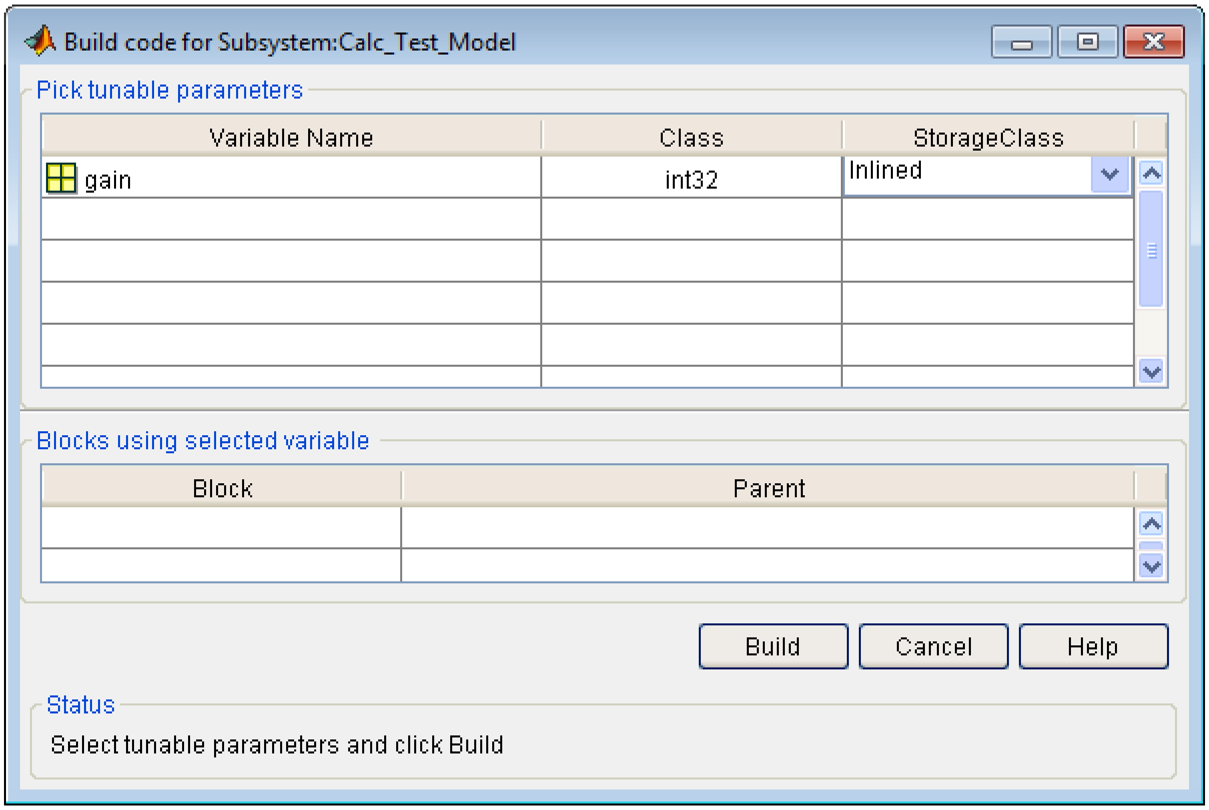
Code Generation Advisor

Prioritized objectives: Execution efficiency, ROM efficiency, RAM efficiency, ...

Check model before generating code: Off

☑ Generate code only

Right click on the Calc_Test_Model Subsystem and go to Code Generation > Build Subsystem. If there are not conflicts the following window should appear. (NOTE: It is possible an error message might pop-up due to an unset or incorrectly set configuration parameter option. This is normal and can be easily fixed by changing the conflicting parameter):



Build code for Subsystem:Calc_Test_Model

Pick tunable parameters

Variable Name	Class	StorageClass
gain	int32	Inlined

Blocks using selected variable

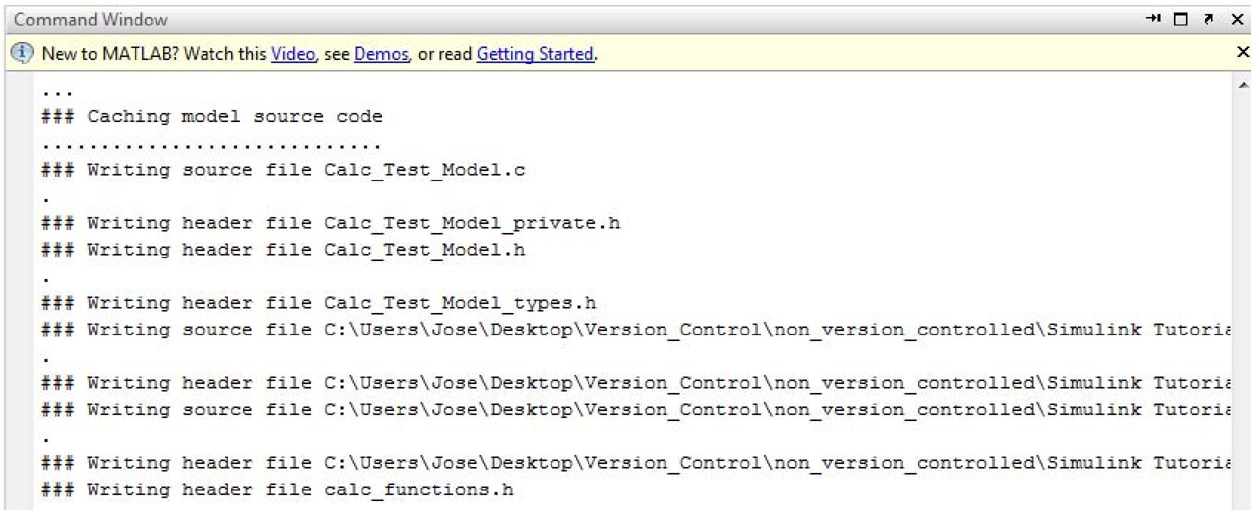
Block	Parent

Status

Select tunable parameters and click Build

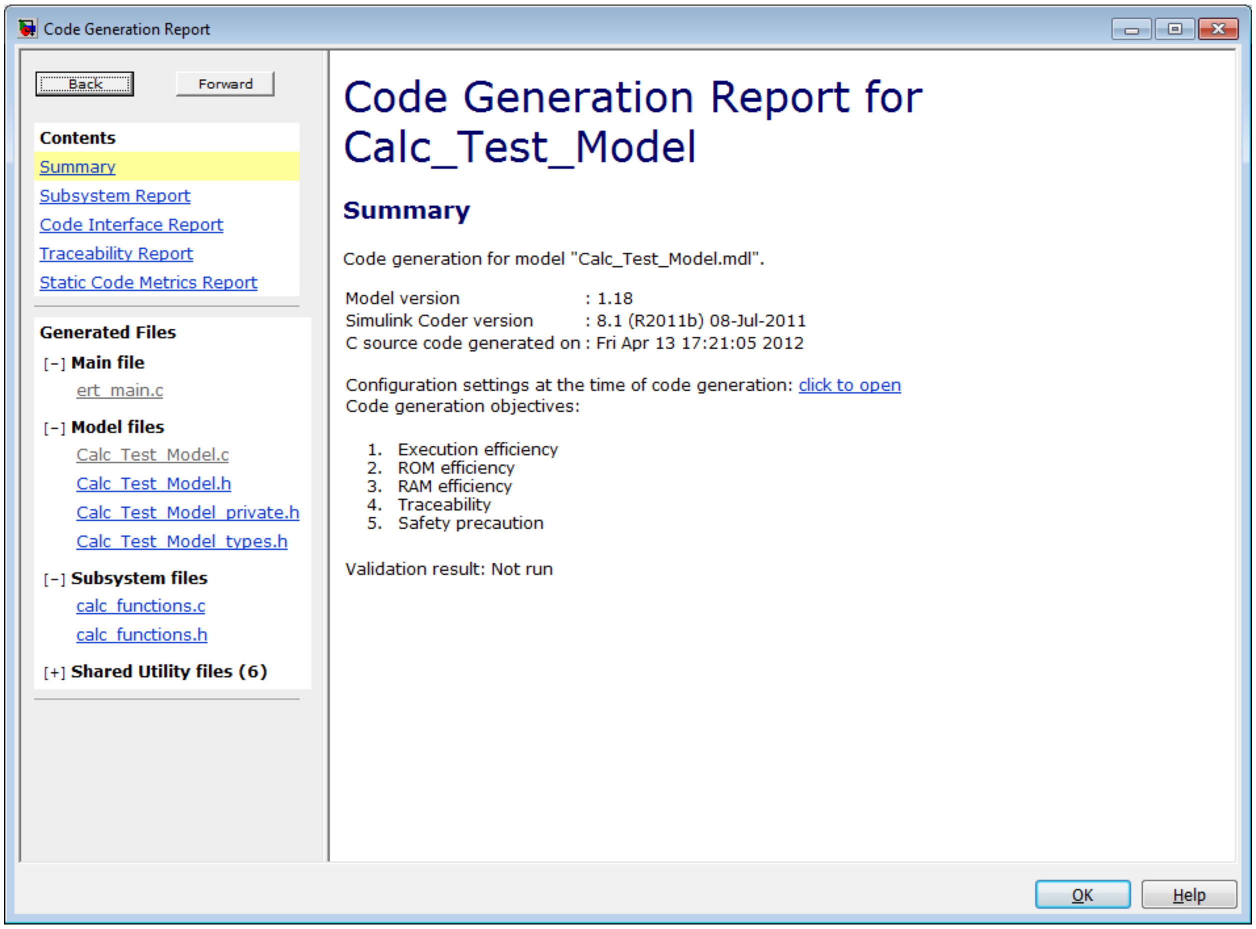
This window contains all workspace constants that are to be used in the generated code and offer storage options for the generated code. In the case of this example the variable gain can be left as "Inlined". Click on Build and the code generation process will start.

The code generation progress should be shown in the command window as seen below:


Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

```
...
### Caching model source code
.............................
### Writing source file Calc_Test_Model.c
.
### Writing header file Calc_Test_Model_private.h
### Writing header file Calc_Test_Model.h
.
### Writing header file Calc_Test_Model_types.h
### Writing source file C:\Users\Jose\Desktop\Version_Control\non_version_controlled\Simulink Tutoria
.
### Writing header file C:\Users\Jose\Desktop\Version_Control\non_version_controlled\Simulink Tutoria
### Writing source file C:\Users\Jose\Desktop\Version_Control\non_version_controlled\Simulink Tutoria
.
### Writing header file C:\Users\Jose\Desktop\Version_Control\non_version_controlled\Simulink Tutoria
### Writing header file calc_functions.h
```

If all goes well the following Code Generation Report should show up:



Code Generation Report for Calc_Test_Model

Summary

Code generation for model "Calc_Test_Model.mdl".

```
Model version                    : 1.18
Simulink Coder version           : 8.1 (R2011b) 08-Jul-2011
C source code generated on : Fri Apr 13 17:21:05 2012
```

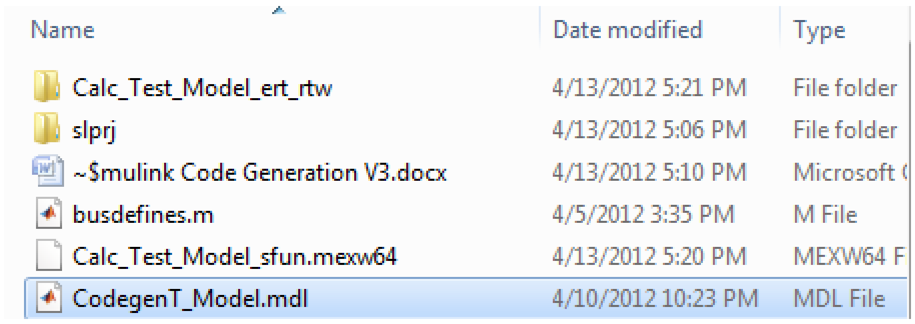
Configuration settings at the time of code generation: click to open
Code generation objectives:

1. Execution efficiency
2. ROM efficiency
3. RAM efficiency
4. Traceability
5. Safety precaution

Validation result: Not run

From here the generated code can be evaluated and can also be traced back to the Simulink (Ref. [2]) Model. For more information on the Code Generation Report consult the MATLAB (Ref. [1]) help window.

Now on the current MATLAB (Ref. [1]) path there should be two folders called Calc_Test_Model_ert_rtw and slprj respectively:

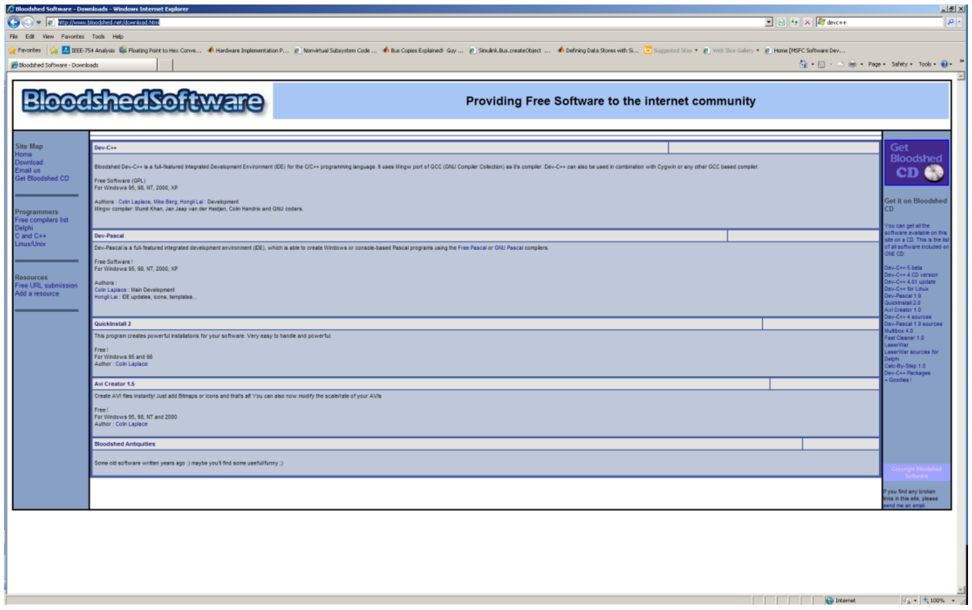


Name	Date modified	Type
Calc_Test_Model_ert_rtw	4/13/2012 5:21 PM	File folder
slprj	4/13/2012 5:06 PM	File folder
~$mulink Code Generation V3.docx	4/13/2012 5:10 PM	Microsoft (
busdefines.m	4/5/2012 3:35 PM	M File
Calc_Test_Model_sfun.mexw64	4/13/2012 5:20 PM	MEXW64 F
CodegenT_Model.mdl	4/10/2012 10:23 PM	MDL File

These folders contain all the generated code from the Simulink (Ref. [2]) Model; copy and paste these folders to any desired location for the next section of the tutorial where the code will be compiled and executed.

8. Compiling and Executing generated code

Now that the code is generated the next step is to test the code by compiling it and creating an executable to run it. For this section of the tutorial a C IDE and compiler are required. This tutorial will use Bloodshed Software's Dev-C++ IDE [2] but these steps can be done in any IDE with any compiler. Dev-C++ (Ref. [3]) can be downloaded from Bloodshed Software's webpage: http://www.bloodshed.net/download.html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Delphi
C and C++
Linux/Unix

Resources
Free URL submission
Add a resource

Dev-C++

Bloodshed Dev-C++ is a full-featured Integrated Development Environment (IDE) for the C/C++ programming language. It uses Mingw port of GCC (GNU Compiler Collection) as it's compiler. Dev-C++ can also be used in combination with Cygwin or any other GCC based compiler.

Free Software (GPL)
For Windows 95, 98, NT, 2000, XP

Authors : Colin Laplace, Mike Berg, Hongli Lai : Development
Mingw compiler: Mumit Khan, Jan Jaap van der Heidjen, Colin Hendrix and GNU coders.

Dev-Pascal

Dev-Pascal is a full-featured integrated development environment (IDE), which is able to create Windows or console-based Pascal programs using the Free Pascal or GNU Pascal compilers.

Free Software !
For Windows 95, 98, NT, 2000, XP

Authors :
Colin Laplace : Main Development
Hongli Lai : IDE updates, icons, templates...

QuickInstall 2

This program creates powerful installations for your software. Very easy to handle and powerful.

Free !
For Windows 95 and 98
Author : Colin Laplace

Avi Creator 1.5

Create AVI files instantly! Just add Bitmaps or icons and that's all! You can also now modify the scale/rate of your AVIs

Free !
For Windows 95, 98, NT and 2000
Author : Colin Laplace

Bloodshed Antiquities

Some old software written years ago :) maybe you'll find some useful/funny ;)

Get Bloodshed CD

Get it on Bloodshed CD

You can get all the software available on this site on a CD. This is the list of all software included on ONE CD:

Dev-C++ 5 beta
Dev-C++ 4 CD version
Dev-C++ 4.01 update
Dev-C++ for Linux
Dev-Pascal 1.9
QuickInstall 2.0
Avi Creator 1.0
Dev-C++ 4 sources
Dev-Pascal 1.9 sources
Multibox 4.0
Fast Cleaner 1.0
LaserWar
LaserWar sources for Delphi
Calc-By-Step 1.0
Dev-C++ Packages
+ Goodies !

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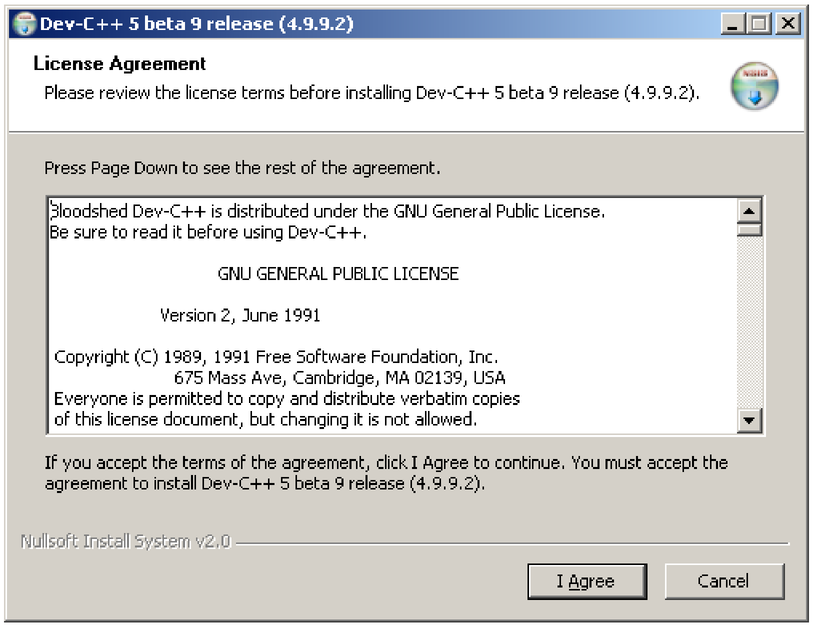
100%

Download the Dev-C++ (Ref. [3]) setup and install it by following the on-screen prompts:


Dev-C++ 5 beta 9 release (4.9.9.2)

License Agreement

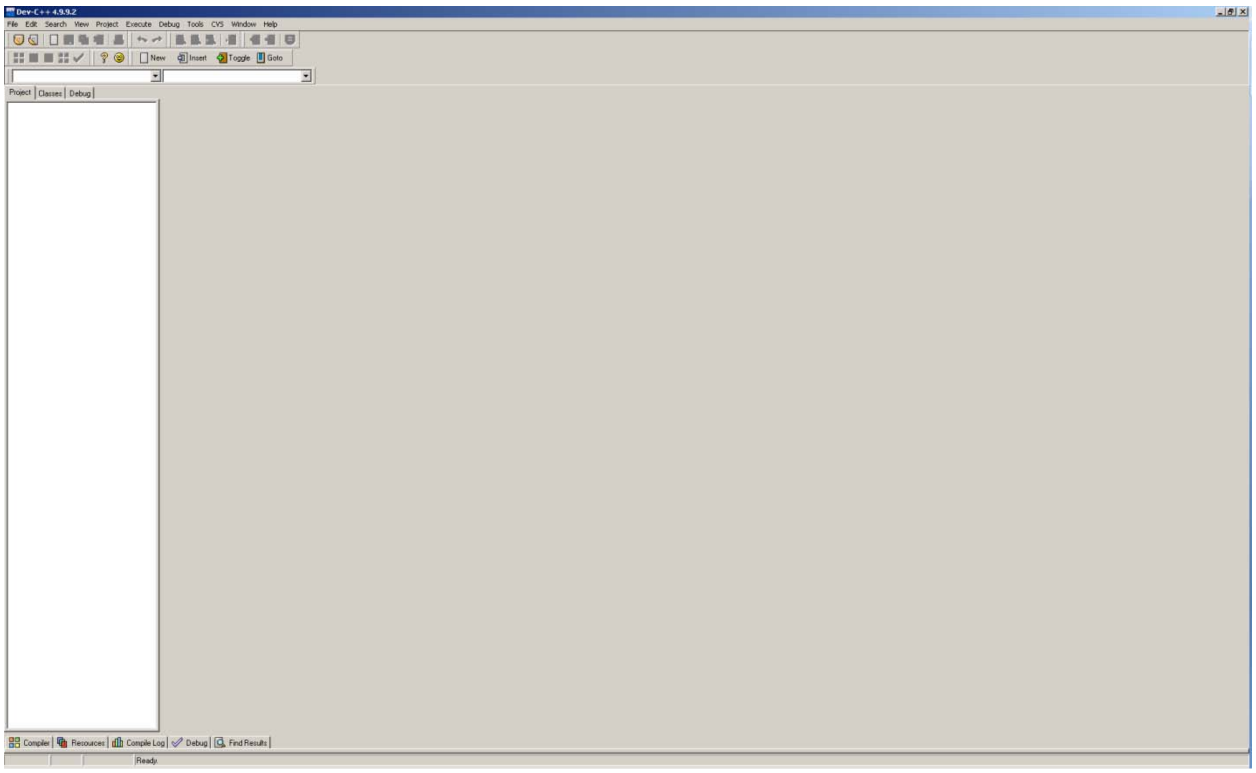
Please review the license terms before installing Dev-C++ 5 beta 9 release (4.9.9.2).

Press Page Down to see the rest of the agreement.

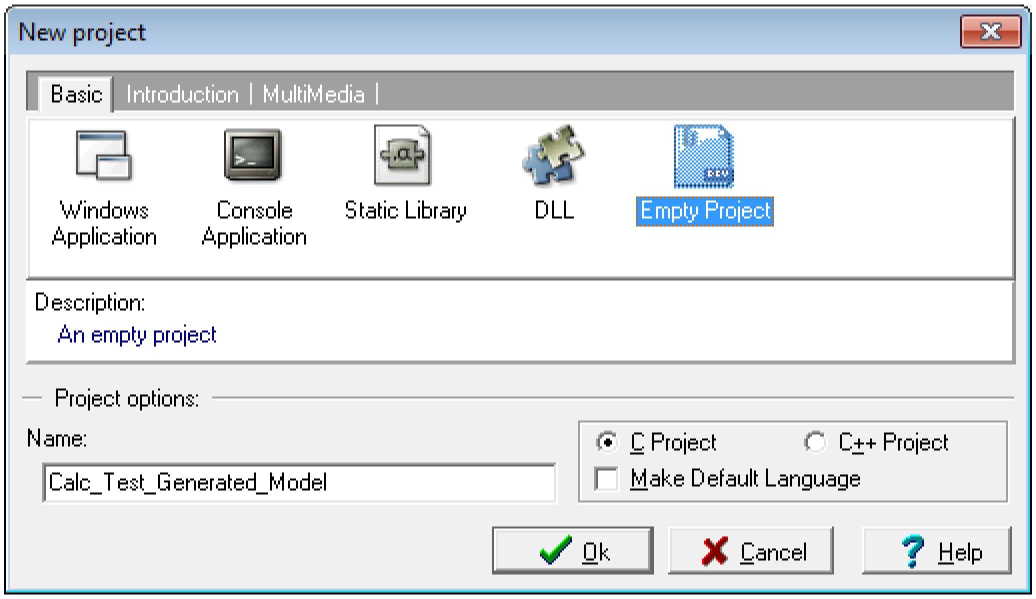
```
Bloodshed Dev-C++ is distributed under the GNU General Public License.
Be sure to read it before using Dev-C++.

                    GNU GENERAL PUBLIC LICENSE

             Version 2, June 1991

Copyright (C) 1989, 1991 Free Software Foundation, Inc.
             675 Mass Ave, Cambridge, MA 02139, USA
Everyone is permitted to copy and distribute verbatim copies
of this license document, but changing it is not allowed.
```

If you accept the terms of the agreement, click I Agree to continue. You must accept the agreement to install Dev-C++ 5 beta 9 release (4.9.9.2).

Once finished with the installation open up the Dev-C++ (Ref. [3]) IDE:


Dev-C++ 4.9.9.2
File Edit Search View Project Execute Debug Tools CVS Window Help
New Insert Toggle Goto
Project Classes Debug
Compiler Resources Compile Log Debug Find Results
Ready

Go to the top toolbar then go to File > New > Project, afterwards select the following options: Empty Project, check C Project and Name the project Calc_Test_Generated_Model:



Description:
An empty project

Project options:

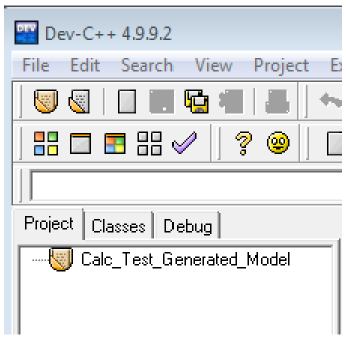
Name: Calc_Test_Generated_Model

[✓ C Project] C++ Project

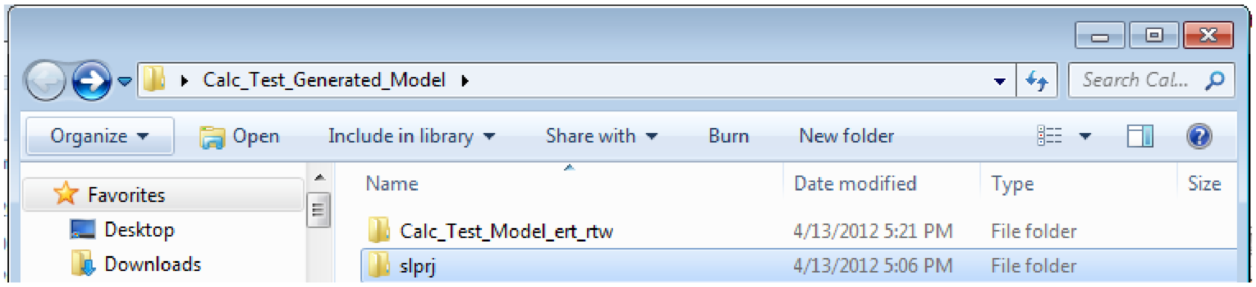
☐ Make Default Language

Click on Ok and a Prompt will come up asking for a location to save the project. Choose any desired location. (NOTE: It is recommended to create a new folder for this project)

After creating the project the left hand tab will contain a root folder with the name of the project. This is where all source code will be located:

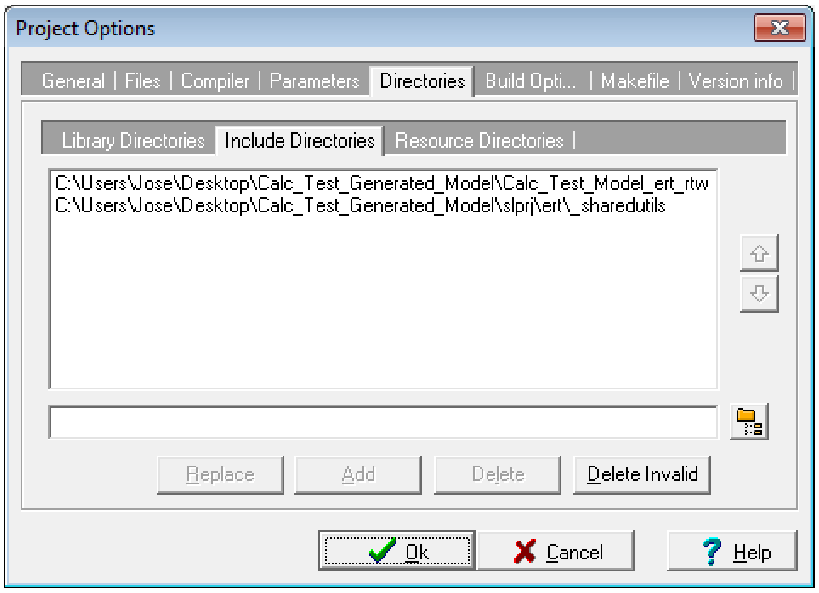


Now drag the copies of the Calc_Test_Model_ert_rtw and the slprj folders into the Calc_Test_Generated_Model project folder in the previously selected location:



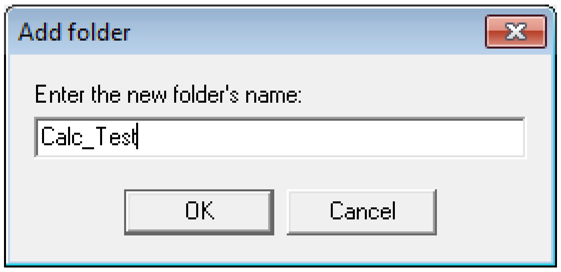
Name	Date modified	Type	Size
Calc_Test_Model_ert_rtw	4/13/2012 5:21 PM	File folder	
slprj	4/13/2012 5:06 PM	File folder	

Next go to the top toolbar then go to Project > Project Options then in the Pop Up window go to the Directories Tab then inside of it go to the Include Directories Sub Tab. Add the following paths to the include directories: ".\Calc_Test_Model_ert_rtw" and ".\slprj\ert_sharedutils" (NOTE: replace the dot with the absolute path to the Calc_Test_Generated_Model folder):


Project Options
General | Files | Compiler | Parameters | Directories | Build Opti... | Makefile | Version info
Library Directories | Include Directories | Resource Directories
Replace
Add
Delete
Delete Invalid
Ok
Cancel
Help

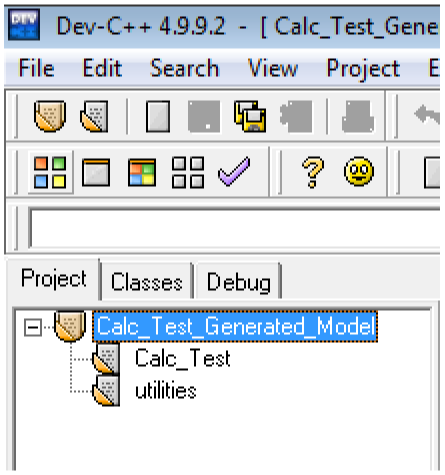
```
C:\Users\Jose\Desktop\Calc_Test_Generated_Model\Calc_Test_Model_ert_rtw
C:\Users\Jose\Desktop\Calc_Test_Generated_Model\slprj\ert\_sharedutils
```

Right click on the Calc_Test_Generated_Model folder on the left hand tab and then click on "Add Folder" call the folder Calc_Test then click OK:

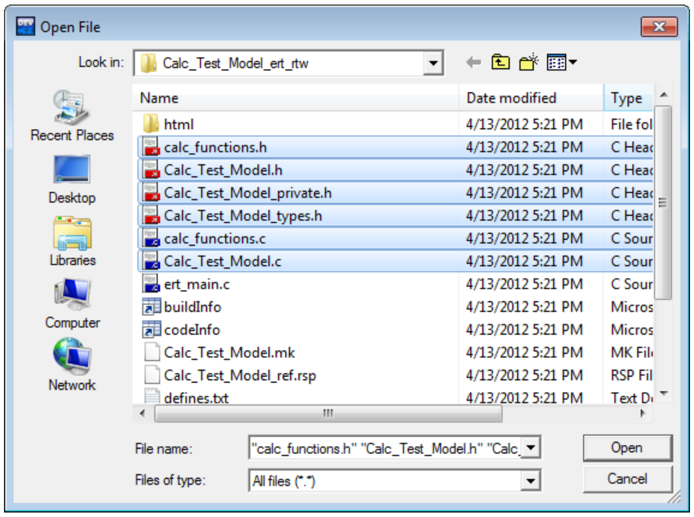


Enter the new folder's name: Calc_Test

Add an additional folder to the top folder called utilities:



Right click on Calc_Test and then click on "Add to project". Browse to the Calc_Test_Model_ert_rtw folder then add all .c and .h files excluding the ert_main.c. Repeat this for the utilities folder by going to slprj\ert_sharedutils. Finally right click on the top Calc_Test_Generated_Model folder and add the ert_main.c from the Calc_Test_Model_ert_rtw folder:



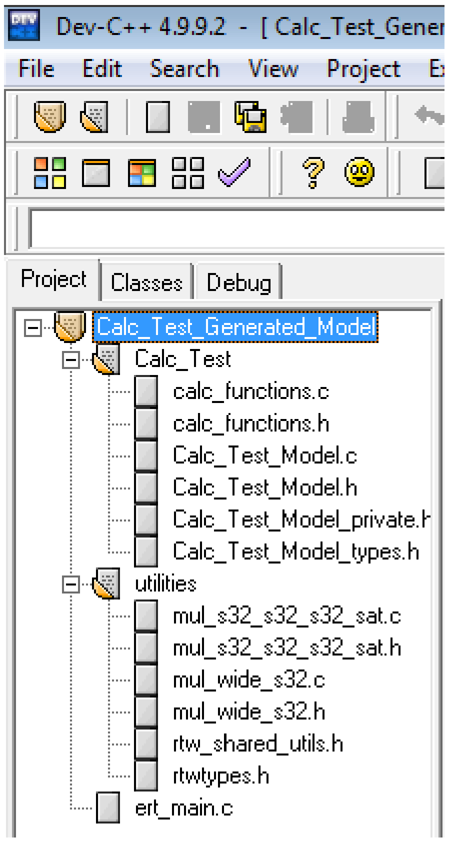
Look in: Calc_Test_Model_ert_rtw

Name	Date modified	Type
html	4/13/2012 5:21 PM	File fol
calc_functions.h	4/13/2012 5:21 PM	C Head
Calc_Test_Model.h	4/13/2012 5:21 PM	C Head
Calc_Test_Model_private.h	4/13/2012 5:21 PM	C Head
Calc_Test_Model_types.h	4/13/2012 5:21 PM	C Head
calc_functions.c	4/13/2012 5:21 PM	C Sour
Calc_Test_Model.c	4/13/2012 5:21 PM	C Sour
ert_main.c	4/13/2012 5:21 PM	C Sour
buildInfo	4/13/2012 5:21 PM	Micros
codeInfo	4/13/2012 5:21 PM	Micros
Calc_Test_Model.mk	4/13/2012 5:21 PM	MK Fil
Calc_Test_Model_ref.rsp	4/13/2012 5:21 PM	RSP Fil
defines.txt	4/13/2012 5:21 PM	Text D

File name: "calc_functions.h" "Calc_Test_Model.h" "Calc_

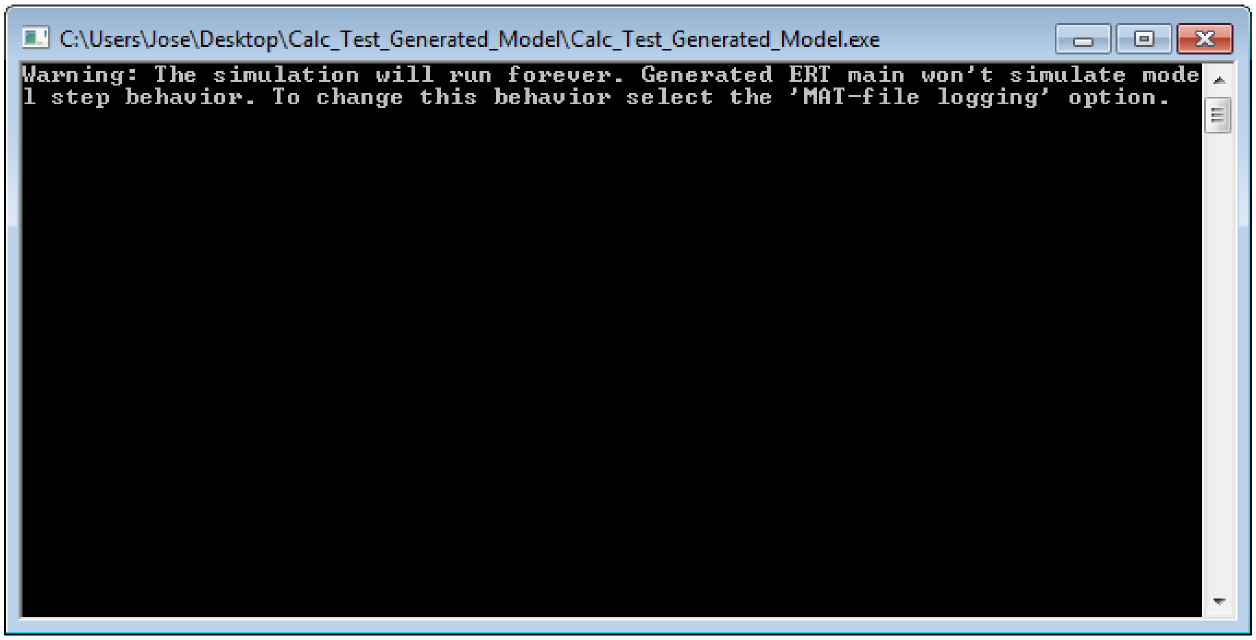
Files of type: All files (*.*)

After adding everything the folders should contain the following:


Dev-C++ 4.9.9.2 - [Calc_Test_Gener
File Edit Search View Project E
Project Classes Debug

```
Calc_Test_Generated_Model
    Calc_Test
        calc_functions.c
        calc_functions.h
        Calc_Test_Model.c
        Calc_Test_Model.h
        Calc_Test_Model_private.h
        Calc_Test_Model_types.h
    utilities
        mul_s32_s32_s32_sat.c
        mul_s32_s32_s32_sat.h
        mul_wide_s32.c
        mul_wide_s32.h
        rtw_shared_utils.h
        rtwtypes.h
    ert_main.c
```

Go to the top toolbar then click on Execute > Compile & Run and if there are no problems the following output should appear:


C:\Users\Jose\Desktop\Calc_Test_Generated_Model\Calc_Test_Generated_Model.exe

```
Warning: The simulation will run forever. Generated ERT main won't simulate mode
l step behavior. To change this behavior select the 'MAT-file logging' option.
```

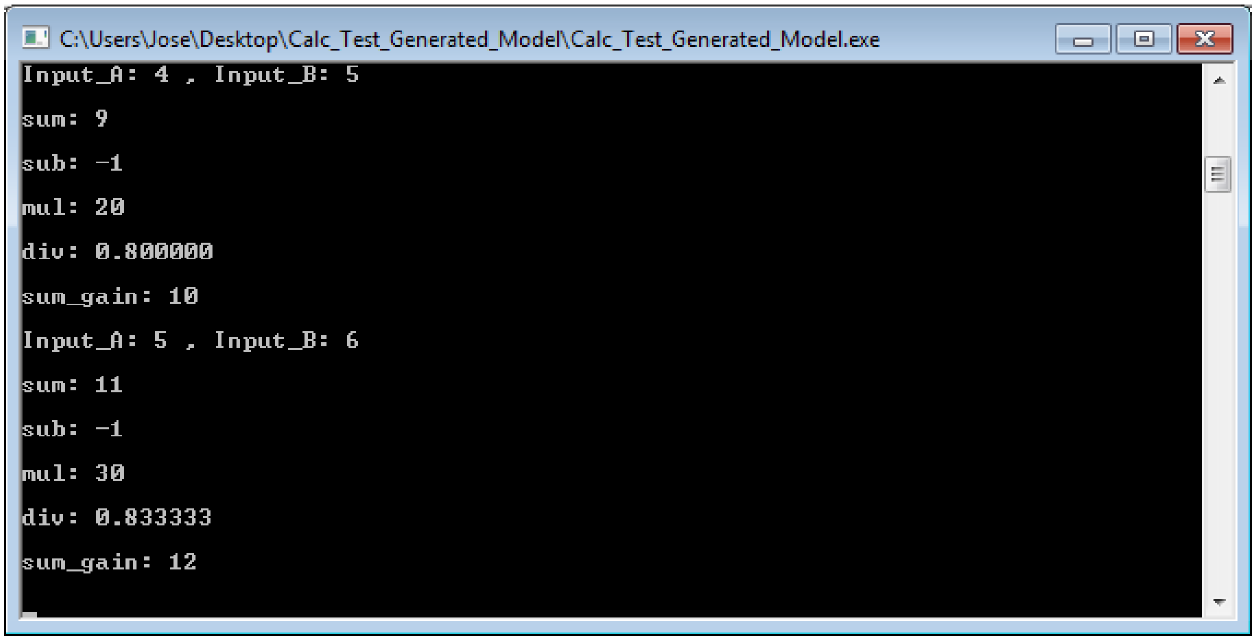
Now that the code is up and running; open the ert_main.c and make the following modifications to the main function:

```
#if 0
  printf("Warning: The simulation will run forever. "
         "Generated ERT main won't simulate model step behavior. "
         "To change this behavior select the 'MAT-file logging' option.\n");
  fflush((NULL));
  while (rtmGetErrorStatus(0) == (NULL)) {
    /*  Perform other application tasks here */
  }
  #else
  int32_T Input_A = 1;
  int32_T Input_B = 2;

  while(1)
  {
         /* Pass input data */
         Calc_Test_Model_U_Input_A = Input_A;
         Calc_Test_Model_U_Input_B = Input_B;

         /* Run Subsystem */
         Calc_Test_Model_step(&Calc_Test_Model_DWork, Calc_Test_Model_U_Input_A,
                              Calc_Test_Model_U_Input_B, &Calc_Test_Model_Y_Out1);

         /* View Output */
```

```
        printf("Input_A: %ld , Input_B: %ld\n\n"
            "sum: %ld\n\n"
            "sub: %ld\n\n"
            "mul: %ld\n\n"
            "div: %lf\n\n"
            "sum_gain: %ld\n\n"
            ,
            Calc_Test_Model_U_Input_A,
            Calc_Test_Model_U_Input_B,
            Calc_Test_Model_Y_Out1.sum,
            Calc_Test_Model_Y_Out1.sub,
            Calc_Test_Model_Y_Out1.mul,
            Calc_Test_Model_Y_Out1.div,
            Calc_Test_Model_Y_Out1.sum_gain);

        Input_A++;
        Input_B++;

        sleep(1000);

    }
    #endif
```

The modifications to the code add the Inputs A and B initialized to 1 and 2 respectively. Then an infinite while loop is started. Inside this loop the Inputs are passed to their corresponding structure elements located in the input variables for the model step function denoted by the _U (e.g. Calc_Test_Model_U_Input_A), next the step function, denoted _step (e.g. Calc_Test_Model_step) is called to run the model. After calling the step function the values are now in the output data structure denoted by the _Y (e.g.:Calc_Test_Model_Y_Out1) and then these can be accessed globally for any purpose.

The output data can then be viewed with the printf function as shown below:


C:\Users\Jose\Desktop\Calc_Test_Generated_Model\Calc_Test_Generated_Model.exe

```
Input_A: 4 , Input_B: 5

sum: 9

sub: -1

mul: 20

div: 0.800000

sum_gain: 10

Input_A: 5 , Input_B: 6

sum: 11

sub: -1

mul: 30

div: 0.833333

sum_gain: 12
```

9. Comparing output of MATLAB with that of the generated code

Once the code is generated and running there is a couple of ways to determine if the output is correct:

- Simple observation of the simulation output can be used in the case of simple calculations as those carried out in this example.
- In the case of more complex calculations a text file can be generated and plotted to compare to output data from the simulation model.
- Text files can be loaded into MATLAB (Ref. [1]) then the difference between these two files can be plotted showing differences in output for each sample.

References

Computer Software

[1] MATLAB, The MathWorks, Inc., Software Package, Ver. R2011b, Natick, Massachusetts, 2011.

[2] Simulink, The MathWorks, Inc., Software Package, Ver. R2011b, Natick, Massachusetts, 2011.

[3] Dev-C++, Bloodshed Software, Software Package, Ver. 5, 2005.

Appendix A Hardware Implementation Table

Key:	float and double (not listed) always equal 32 and 64, respectively
	pointer (not listed) matches the value of int
	Rounds to = Signed integer division rounds to
	Shift right = Shift right on a signed integer as arithmetic shift

Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
Generic										
Unspecified (assume 32-bit Generic) (default)	8	16	32	32	32	x	x	Unspecified	x	Set
Custom	x	x	x	x	x	x	x	x	x	x
16-bit Embedded Processor	8	16	16	32	16	x	x	x	x	Set
32-bit Embedded Processor	8	16	32	32	32	x	x	x	x	Set
32-bit Real Time Simulator	8	16	32	32	32	x	x	x	x	Set
32-bit x86	8	16	32	32	32	x	x	Little	Zero	Set

Key:	float and double (not listed) always equal 32 and 64, respectively									
	pointer (not listed) matches the value of int									
	Rounds to = Signed integer division rounds to									
	Shift right = Shift right on a signed integer as arithmetic shift									
Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
compatible								Endian		
8-bit Embedded Processor	8	16	16	32	8	x	x	x	x	Set
MATLAB Host Computer	8	16	32	Host specific value (32 or 64)	Host specific value (32 or 64)	x	x	Little Endian	x	Set
AMD										
K5/K6/Athlon	8	16	32	32	32	x	x	Little Endian	x	Set
ARM Compatible										
ARM 7/8/9/10	8	16	32	32	32	Long	Float	x	x	x
ARM 11	8	16	32	32	32	Long	Double	x	x	x

Key:	float and double (not listed) always equal 32 and 64, respectively									
	pointer (not listed) matches the value of int									
	Rounds to = Signed integer division rounds to									
	Shift right = Shift right on a signed integer as arithmetic shift									
Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
ARM Cortex	8	16	32	32	32	Char	None	x	x	x
ASIC/FPGA										
ASIC/FPGA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Analog Devices										
Blackfin	8	16	32	32	32	Long	Double	Little Endian	Zero	Set
SHARC	32	32	32	32	32	Long	Double	Big Endian	Zero	Set
TigerSHARC	32	32	32	32	32	Long	Double	Little Endian	Zero	Set
Atmel										
AVR	8	16	16	32	8	x	x	Little Endian	Zero	Set
Freescale										

Key:	float and double (not listed) always equal 32 and 64, respectively									
	pointer (not listed) matches the value of int									
	Rounds to = Signed integer division rounds to									
	Shift right = Shift right on a signed integer as arithmetic shift									
Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
32-bit PowerPC	8	16	32	32	32	Long	Double	Big Endian	Zero	Set
68332	8	16	32	32	32	x	x	Big Endian	x	Set
68HC08	8	16	16	32	8	x	x	Big Endian	x	Set
68HC11	8	16	16	32	8	x	x	Big Endian	x	Set
ColdFire	8	16	32	32	32	x	x	Big Endian	Zero	Set
DSP563xx (16-bit mode)	8	16	16	32	16	x	x	x	x	Set
HC(S)12	8	16	16	32	16	x	x	Big Endian	x	Set
MPC52xx, MPC5500, MPC55xx, MPC5xx, MPC7400, MPC7xxx, MPC82xx, MPC83xx,	8	16	32	32	32	Long	Double	x	Zero	Set

Key:	float and double (not listed) always equal 32 and 64, respectively									
	pointer (not listed) matches the value of int									
	Rounds to = Signed integer division rounds to									
	Shift right = Shift right on a signed integer as arithmetic shift									
Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
MPC86xx, MPC8xx										
MPC85xx	8	16	32	32	32	Long	Float	x	Zero	Set
S12x	8	16	16	32	16	x	x	Big Endian	x	Set
Infineon										
C16x, XC16x	8	16	16	32	16	x	x	Little Endian	Zero	Set
TriCore	8	16	32	32	32	x	x	Little Endian	x	Set
Intel										
8051 Compatible	8	16	16	32	8	x	x	x	x	Clear
x86/Pentium	8	16	32	32	32	x	x	Little Endian	x	Set

Key:	float and double (not listed) always equal 32 and 64, respectively									
	pointer (not listed) matches the value of int									
	Rounds to = Signed integer division rounds to									
	Shift right = Shift right on a signed integer as arithmetic shift									
Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
Microchip										
PIC18	8	16	16	32	8	x	x	Little Endian	Zero	Set
dsPIC	8	16	16	32	16	x	x	Little Endian	Zero	Set
NEC										
V850	8	16	32	32	32	x	x	x	x	x
Renesas										
M16C	8	16	16	32	16	x	x	Little Endian	x	x
M32C	8	16	x	32	x	x	x	Little Endian	x	x
R8C/Tiny	8	16	16	32	16	x	x	Little Endian	x	x
SH-2/3/4	8	16	32	32	32	x	x	x	x	x

Key:	float and double (not listed) always equal 32 and 64, respectively									
	pointer (not listed) matches the value of int									
	Rounds to = Signed integer division rounds to									
	Shift right = Shift right on a signed integer as arithmetic shift									
Device vendor / Device type	Number of bits					Largest atomic size		Byte ordering	Rounds to	Shift right
	char	short	int	long	native	int	float			
SGI										
UltraSPARC IIi	8	16	32	32	32	x	x	Big Endian	x	Set
STMicroelectronics										
ST10/Super10	8	16	16	32	16	x	x	Little Endian	Zero	Set
Texas Instruments										
C2000	16	16	16	32	16	Int	None	x	Zero	Set
C5000	16	16	16	32	16	Int	None	Big Endian	Zero	Set
C6000	8	16	32	40	32	Int	None	x	Zero	Set
MSP430	8	16	16	32	16	x	x	Little Endian	Zero	Set
TMS470	8	16	32	32	x	x	x	x	x	x

Table 2: Hardware Implementation Complete