

C7000 Optimizing C/C++ Compiler

User's Guide



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Read This First

About This Manual

The *C7000 Optimizing C/C++ Compiler User's Guide* explains how to use the following Texas Instruments Code Generation compiler tools:

- Compiler
- Library build utility
- C++ name demangler

The TI compiler accepts C and C++ code conforming to the International Organization for Standardization (ISO) standards for these languages. The compiler supports the 1989, 1999, and 2011 versions of the C language and the 2014 version of the C++ language.

This user's guide discusses the characteristics of the TI C/C++ compiler. It assumes that you already know how to write C/C++ programs. *The C Programming Language* (second edition), by Brian W. Kernighan and Dennis M. Ritchie, describes C based on the ISO C standard. You can use the Kernighan and Ritchie (hereafter referred to as K&R) book as a supplement to this manual. References to K&R C (as opposed to ISO C) in this manual refer to the C language as defined in the first edition of Kernighan and Ritchie's *The C Programming Language*.

This document describes support for the C7100 variant of the C7000™ processor series.

Notational Conventions

This document uses the following conventions:

- Program listings, program examples, and interactive displays are shown in a **special typeface**. Interactive displays use a bold version of the special typeface to distinguish commands that you enter from items that the system displays (such as prompts, command output, error messages, etc.). Here is a sample of C code:

```
#include <stdio.h>
main()
{
    printf("Hello World\n");
}
```

- In syntax descriptions, instructions, commands, and directives are in a **bold typeface** and parameters are in an *italic typeface*. Portions of a syntax that are in bold should be entered as shown; portions of a syntax that are in italics describe the type of information that should be entered.
- Square brackets ([and]) identify an optional parameter. If you use an optional parameter, you specify the information within the brackets. Unless the square brackets are in the **bold typeface**, do not enter the brackets themselves. The following is an example of a command that has an optional parameter:

```
cl7x [options] [filenames] --run_linker [link_options] [object files]
```

- Braces ({ and }) indicate that you must choose one of the parameters within the braces; you do not enter the braces themselves. This is an example of a command with braces that are not included in the actual syntax but indicate that you must specify either the `--rom_model` or `--ram_model` option:

```
cl7x --run_linker {--rom_model | --ram_model} filenames --output_file= name.out  
--library= libraryname
```

Related Documentation

You can use the following books to supplement this user's guide:

ANSI X3.159-1989, Programming Language - C (Alternate version of the 1989 C Standard), American National Standards Institute

ISO/IEC 9899:1989, International Standard - Programming Languages - C (The 1989 C Standard), International Organization for Standardization

ISO/IEC 9899:1999, International Standard - Programming Languages - C (The 1999 C Standard), International Organization for Standardization

ISO/IEC 9899:2011, International Standard - Programming Languages - C (The 2011 C Standard), International Organization for Standardization

ISO/IEC 14882-2014, International Standard - Programming Languages - C++ (The 2014 C++ Standard), International Organization for Standardization

The C Programming Language (second edition), by Brian W. Kernighan and Dennis M. Ritchie, published by Prentice-Hall, Englewood Cliffs, New Jersey, 1988

The Annotated C++ Reference Manual, Margaret A. Ellis and Bjarne Stroustrup, published by Addison-Wesley Publishing Company, Reading, Massachusetts, 1990

C: A Reference Manual (fourth edition), by Samuel P. Harbison, and Guy L. Steele Jr., published by Prentice Hall, Englewood Cliffs, New Jersey

Programming Embedded Systems in C and C++, by Michael Barr, Andy Oram (Editor), published by O'Reilly & Associates; ISBN: 1565923545, February 1999

Programming in C, Steve G. Kochan, Hayden Book Company

The C++ Programming Language (second edition), Bjarne Stroustrup, published by Addison-Wesley Publishing Company, Reading, Massachusetts, 1990

DWARF Debugging Information Format Version 3, DWARF Debugging Information Format Workgroup, Free Standards Group, 2005 (<http://dwarfstd.org>)

DWARF Debugging Information Format Version 4, DWARF Debugging Information Format Workgroup, Free Standards Group, 2010 (<http://dwarfstd.org>)

System V ABI specification (<http://www.sco.com/developers/gabi/>)

OpenCL™ Specification version 1.2 (<https://www.khronos.org/opencl/>)

Related Documentation From Texas Instruments

See the following resources for further information about the TI Code Generation Tools:

- Texas Instruments Wiki: [Compiler topics](#)
- Texas Instruments E2E Community: [Compiler forum](#)

You can use the following documents to supplement this user's guide:

SPRUIG5 —C6000-to-C7000 Migration Users Guide

SPRUIG4 —C7000 Embedded Application Binary Interface (EABI) Users Guide

SPRUIG3 —C7000 VCOP Kernel-C Translation Functional Specification

SPRUIG6 —C7000 Host Emulation Users Guide

SPRAAB5 — *The Impact of DWARF on TI Object Files.*

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Introduction to the Software Development Tools

The C7000™ is supported by a set of software development tools, which includes an optimizing C/C++ compiler, a linker, and assorted utilities.

This chapter provides an overview of these tools and introduces the features of the optimizing C/C++ compiler.

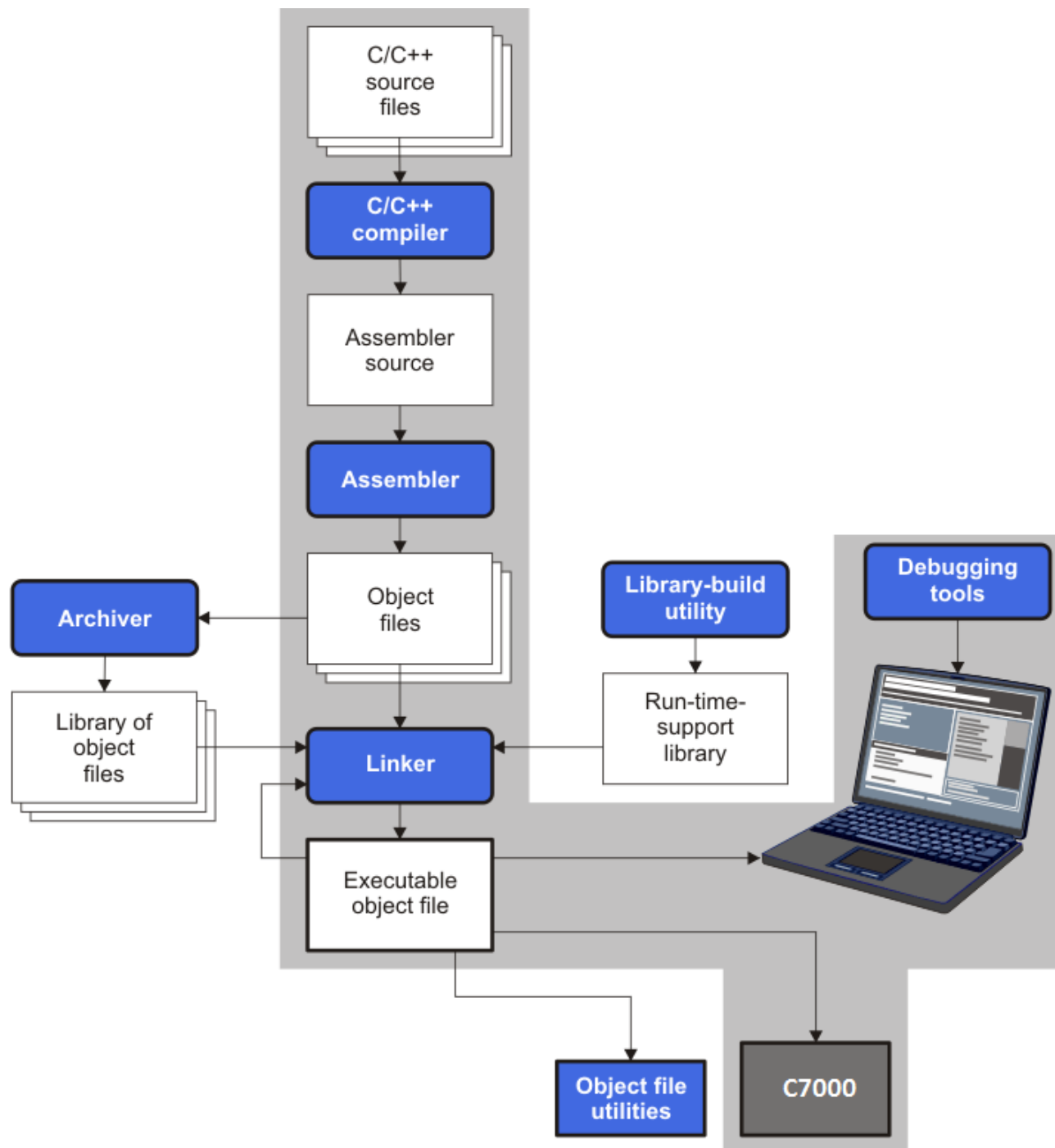
The C7000™ Code Generation Tools are similar to those provided for the TMS320C6000™. See the *C6000-to-C7000 Migration Users Guide* ([SPRUIG5](#)) for information about differences and migration.

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1.1 Software Development Tools Overview

Figure 1-1 illustrates the software development flow. The shaded portion of the figure highlights the most common path of software development for C language programs. The other portions are peripheral functions that enhance the development process.

Figure 1-1. C7000 Software Development Flow



The following list describes the tools that are shown in Figure 1-1:

- The **compiler** accepts C/C++ source code and produces C7000 assembly language source code, which it automatically translates into machine language relocatable object files. See [Chapter 3](#).
- The **linker** combines relocatable object files into a single absolute executable object file. As it creates

the executable file, it performs relocation and resolves external references. The linker accepts relocatable object files and object libraries as input. See [Chapter 11](#) for an overview of the linker.

- The **archiver** allows you to collect a group of files into a single archive file, called a *library*. The archiver allows you to modify such libraries by deleting, replacing, extracting, or adding members. One of the most useful applications of the archiver is building a library of object files.
- The **run-time-support libraries** contain the standard ISO C and C++ library functions, compiler-utility functions, floating-point arithmetic functions, and C I/O functions that are supported by the compiler. See [Chapter 7](#).

The **library-build utility** automatically builds the run-time-support library if compiler and linker options require a custom version of the library. See [Section 7.4](#). Source code for the standard run-time-support library functions for C and C++ is provided in the lib\src subdirectory of the directory where the compiler is installed.

- The **C++ name demangler** is a debugging aid that converts names mangled by the compiler back to their original names as declared in the C++ source code. As shown in [Figure 1-1](#), you can use the C++ name demangler on the assembly file that is output by the compiler; you can also use this utility on the assembler listing file and the linker map file. See [Chapter 14](#).
- The main product of this development process is an executable object file that can be executed on a C7000 CPU that is part of a larger device.

In addition, the following utilities are provided to help examine or manage the content of a given object file:

- The **object file display utility** prints the contents of object files and object libraries in either human readable or XML formats. See [Section 13.1](#).
- The **disassembler** decodes the machine code from object modules to show the assembly instructions that it represents. See [Section 13.2](#).
- The **name utility** prints a list of symbol names for objects and functions defined or referenced in an object file or object archive. See [Section 13.3](#).
- The **strip utility** removes symbol table and debugging information from object files and object libraries. See [Section 13.4](#).

1.2 Compiler Interface

The compiler is a command-line program named cl7x. This program can compile, optimize, assemble, and link programs in a single step. Within Code Composer Studio™, the compiler is run automatically to perform the steps needed to build a project.

For more information about compiling a program, see [Section 3.1](#)

The compiler has straightforward calling conventions, so you can write C functions that call each other. For more information about calling conventions, see [Chapter 6](#).

1.3 ANSI/ISO Standard

The compiler supports the 1989, 1999, and 2011 versions of the C language and the 2014 version of the C++ language. The C and C++ language features in the compiler are implemented in conformance with the following ISO standards:

- **ISO-standard C**

The C compiler supports the 1989, 1999, and 2011 versions of the C language.

- **C89.** Compiling with the `--c89` option causes the compiler to conform to the ISO/IEC 9899:1990 C standard, which was previously ratified as ANSI X3.159-1989. The names "C89" and "C90" refer to the same programming language. "C89" is used in this document.
- **C99.** Compiling with the `--c99` option causes the compiler to conform to the ISO/IEC 9899:1999 C standard.
- **C11.** Compiling with the `--c11` option causes the compiler to conform to the ISO/IEC 9899:2011 C standard.

The C language is also described in the second edition of Kernighan and Ritchie's *The C Programming Language* (K&R).

- **ISO-standard C++**

The compiler uses the C++14 version of the C++ standard. See the C++ Standard ISO/IEC 14882:2014. For a description of *unsupported C++* features, see [Section 5.2](#).

- **ISO-standard run-time support**

The compiler tools come with an extensive run-time library. Library functions conform to the ISO C/C++ library standard unless otherwise stated. The library includes functions for standard input and output, string manipulation, dynamic memory allocation, data conversion, timekeeping, trigonometry, and exponential and hyperbolic functions. Functions for signal handling are not included, because these are target-system specific. For more information, see [Chapter 7](#).

See [Section 5.13](#) for command line options to select the C or C++ standard your code uses.

1.4 Output Files

The following type of output file is created by the compiler:

- **ELF object files.** Executable and Linking Format (ELF) enables supporting modern language features like early template instantiation and exporting inline functions. ELF is part of the [System V Application Binary Interface \(ABI\)](#). The ELF format used for C7000 is extended by the C7000 Embedded Application Binary Interface (EABI), which is documented in [SPRUIG4](#).

Getting Started with the Code Generation Tools

This chapter provides an overview of the procedure for creating a Code Composer Studio project that uses the Code Generation Tools. In addition, it provides an introduction to the command-line for the compiler and linker.

2.1 How Code Composer Studio Projects Use the Compiler

If you use Code Composer Studio (CCS) as your development environment, the compiler and linker options are automatically set for you when you create a project. The project settings you make determine which compiler and linker command line options are used to build the project. Follow these steps to create and build a project in CCS v6.0. The exact steps may vary somewhat in other versions of CCS.

Table 2-1. Steps for Creating a CCS Project

Step	Effects on Use of the Compiler
1. Choose File > New > CCS Project from the menus.	
2. In the New CCS Project wizard, first select the Target . You can use the drop-down on the left to filter the list of specific targets on the right.	Sets the <code>--silicon_version</code> (<code>-mv</code>) compiler option. See Section 3.3.5 . In addition, a preprocessor symbol matching the target is defined using the <code>--define</code> compiler option. See Section 3.3.2 .
3. In the Connection field, select the method you will use to connect to the device.	Generates a target configuration file for use when running the project.
4. In the Project name field, type a name for the project.	Determines the folder where the project is stored.
5. Expand the Advanced settings area.	
6. Make sure the Compiler version you want to use is selected.	Sets the <code>--include_path</code> compiler option to the include directory for that version of the Code Generation Tools. See Section 3.5.2.1 .
7. By default, C7000 applications are compiled to be little-endian. In the Device endianness field, you can choose big-endian if needed.	Sets the <code>--big_endian</code> compiler option if the default is not used. See Section 3.3.4 .
8. The linker command file and runtime support library are selected automatically based on your choices in the other fields.	
9. Expand the Project templates and examples area.	
10. Select a template for your project. The project templates you can choose from include a completely empty project with no source files, a project containing only <code>main.c</code> , and a Hello World example. Other examples that use plug-in software components you have installed are available in the TI Resource Explorer window.	
11. Click Finish .	

After you have created a CCS project, you can use the Properties dialog for the project to see how the compiler and linker will be used and modify the command-line options used when compiling and linking. To open this dialog, select the project in the Project Explorer and choose **Project > Properties** from the menus. Expand the category tree to select **Build > C7000 Compiler** and **Build > C7000 Linker**. You can learn more about any command-line options you see in this dialog in [Chapter 3](#).

2.2 Compiling from the Command Line

If you are developing your project outside of an IDE such as Code Composer Studio, you will need to use the command-line interface to the compiler and linker.

The compiler and linker are run using the same executable. This executable is the **cl7x.exe** file, which is located in the **bin** subdirectory of your TI Code Generation Tools installation.

You can use a single command line to both compile your code to create object files and link the object files to create an executable. All the command-line options that occur before the `--run_linker` (or `-z` for short) option apply to the compiler. All the command-line options that occur after the `--run_linker` (`-z`) option apply to the linker. In the following command-line, the `-mv7100`, `--c99`, `--opt_level`, `--define`, and `--include_path` options are compiler options. The `--library`, `--heap_size`, and `--output_file` options are linker options.

```
cl7x -mv7100 --c99 --opt_level=1 --define=c7000 --include_path="C:/ti/ti-cgt-c7000/include"
    hello.c objects.cpp
    --run_linker --library=lnk.cmd --heap_size=0x800 --output_file=myprogram.out
```

Using the C/C++ Compiler

The compiler translates your source program into machine language object code that the C7000 can execute. Source code must be compiled, assembled, and linked to create an executable file. All of these steps are executed at once by using the compiler.

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3.1 About the Compiler

The compiler lets you compile, optimize, assemble, and optionally link in one step. The compiler performs the following steps on one or more source modules:

- The **compiler** accepts C/C++ source code. It produces object code.
You can compile C and C++ files in a single command. The compiler uses the filename extensions to distinguish between different file types. See [Section 3.3.10](#) for more information.
- The **linker** combines object files to create a static executable file. The link step is optional, so you can compile many modules independently and link them later. See [Chapter 11](#) for information about linking the files.

Invoking the Linker

NOTE: By default, the compiler does not invoke the linker. You can invoke the linker by using the `--run_linker (-z)` compiler option. See [Section 11.1.1](#) for details.

3.2 Invoking the C/C++ Compiler

To invoke the compiler, enter:

```
cl7x [options] [filenames] [--run_linker [link_options] object files]
```

cl7x	Command that runs the compiler.
<i>options</i>	Options that affect the way the compiler processes input files. The options are listed in Table 3-6 through Table 3-28 .
<i>filenames</i>	One or more C/C++ source files.
--run_linker (-z)	Option that invokes the linker. The <code>--run_linker</code> option's short form is <code>-z</code> . See Chapter 11 for more information.
<i>link_options</i>	Options that control the linking process.
<i>object files</i>	Names of the object files for the linking process.

The arguments to the compiler are of three types:

- Compiler options
- Link options
- Filenames

The `--run_linker` option indicates linking is to be performed. If the `--run_linker` option is used, any compiler options must precede the `--run_linker` option, and all link options must follow the `--run_linker` option.

Source code filenames must be placed before the `--run_linker` option. Additional object file filenames can be placed after the `--run_linker` option.

For example, if you want to compile two files named `syntab.c` and `file.c`, and link to create an executable program called `myprogram.out`, you will enter:

```
cl7x syntab.c file.c --run_linker --library=lnk.cmd
    --output_file=myprogram.out
```

3.3 Changing the Compiler's Behavior with Options

Options control the operation of the compiler. This section provides a description of option conventions and an option summary table. It also provides detailed descriptions of the most frequently used options, including options used for type-checking.

For a help screen summary of the options, enter **cl7x** with no parameters on the command line.

The following apply to the compiler options:

- There are typically two ways of specifying a given option. The "long form" uses a two hyphen prefix and is usually a more descriptive name. The "short form" uses a single hyphen prefix and a combination of letters and numbers that are not always intuitive.
- Options are usually case sensitive.
- Individual options cannot be combined.
- An option with a parameter should be specified with an equal sign before the parameter to clearly associate the parameter with the option. For example, the option to undefine a constant can be expressed as `--undefine=name`. Likewise, the option to specify the maximum amount of optimization can be expressed as `-O=3`. You can also specify a parameter directly after certain options, for example `-O3` is the same as `-O=3`. No space is allowed between the option and the optional parameter, so `-O 3` is not accepted.
- Files and options except the `--run_linker` option can occur in any order. The `--run_linker` option must follow all compiler options and precede any linker options.

You can define default options for the compiler by using the `C7X_C_OPTION` environment variable. For a detailed description of the environment variable, see [Section 3.4.1](#).

[Table 3-6](#) through [Table 3-28](#) summarize all options (including link options). Use the references in the tables for more complete descriptions of the options.

Table 3-1. Processor Options

Option	Alias	Effect	Section
<code>--silicon_version=id</code>	<code>-mv</code>	Selects target version. Defaults to 7100.	Section 3.3.5
<code>--big_endian</code>	<code>-me</code>	Produces object code in big-endian format. The default format is little-endian.	Section 3.3.4

Table 3-2. Optimization Options⁽¹⁾

Option	Alias	Effect	Section
<code>--opt_level=off</code>		Disables all optimization (default if option not used and <code>--vectypes=off</code>).	Section 4.1
<code>--opt_level=n</code>	<code>-On</code>	Level 0 (<code>-O0</code>) optimizes register usage only (default if option not used and <code>--vectypes=on</code>). Level 1 (<code>-O1</code>) uses Level 0 optimizations and optimizes locally. Level 2 (<code>-O2</code>) uses Level 1 optimizations and optimizes globally (default if option used with no setting). Level 3 (<code>-O3</code>) uses Level 2 optimizations and optimizes the file. Level 4 (<code>-O4</code>) uses Level 3 optimizations and performs link-time optimization.	Section 4.1 , Section 4.3
<code>--opt_for_speed[=n]</code>	<code>-mf</code>	Controls the tradeoff between size and speed (0-5 range). If this option is not specified or is specified without <i>n</i> , the default value is 4.	Section 4.2

⁽¹⁾ **Note:** Machine-specific options (see [Table 3-12](#)) can also affect optimization.

Table 3-3. Advanced Optimization Options⁽¹⁾

Option	Alias	Effect	Section
<code>--auto_inline=[size]</code>	<code>-oi</code>	Sets automatic inlining size (<code>--opt_level=3</code> only). If <i>size</i> is not specified, the default is 1.	Section 4.5

⁽¹⁾ **Note:** Machine-specific options (see [Table 3-12](#)) can also affect optimization.

Table 3-3. Advanced Optimization Options⁽¹⁾ (continued)

Option	Alias	Effect	Section
--call_assumptions= <i>n</i>	-op <i>n</i>	Level 0 (-op0) specifies that the module contains functions and variables that are called or modified from outside the source code provided to the compiler. Level 1 (-op1) specifies that the module contains variables modified from outside the source code provided to the compiler but does not use functions called from outside the source code. Level 2 (-op2) specifies that the module contains no functions or variables that are called or modified from outside the source code provided to the compiler (default). Level 3 (-op3) specifies that the module contains functions that are called from outside the source code provided to the compiler but does not use variables modified from outside the source code.	Section 4.4.1
--disable_inlining		Prevents any inlining from occurring.	Section 3.10
--fp_mode={relaxed strict}		Enables or disables relaxed floating-point mode.	Section 3.3.3
--fp_reassoc={on off}		Enables or disables the reassociation of floating-point arithmetic.	Section 3.3.3
--gen_opt_info= <i>n</i>	-on <i>n</i>	Level 0 (-on0) disables the optimization information file. Level 1 (-on1) produces an optimization information file. Level 2 (-on2) produces a verbose optimization information file.	Section 4.3.1
--optimizer_interlist	-os	Interlists optimizer comments with assembly statements.	Section 4.11
--program_level_compile	-pm	Combines source files to perform program-level optimization.	Section 4.4
--src_interlist	-s	Interlists optimizer comments (if available) and assembly source statements; otherwise interlists C and assembly source statements.	Section 3.3.2
--aliased_variables	-ma	Notifies the compiler that addresses passed to functions may be modified by an alias in the called function.	Section 4.9.1

Table 3-4. Debug Options

Option	Alias	Effect	Section
--symdebug:dwarf	-g	Default behavior. Enables symbolic debugging. The generation of debug information does not impact optimization. Therefore, generating debug information is enabled by default.	Section 3.3.6 Section 4.12
--symdebug:dwarf_version=3 4		Specifies the DWARF format version. The default version is 4.	Section 3.3.6
--symdebug:none		Disables all symbolic debugging.	Section 3.3.6 Section 4.12

Table 3-5. Include Options

Option	Alias	Effect	Section
--include_path= <i>directory</i>	-I	Adds the specified directory to the #include search path.	Section 3.5.2.1
--preinclude= <i>filename</i>		Includes <i>filename</i> at the beginning of compilation.	Section 3.3.3

Table 3-6. Control Options

Option	Alias	Effect	Section
--compile_only	-c	Disables linking (negates --run_linker).	Section 11.1.3
--help	-h	Prints (on the standard output device) a description of the options understood by the compiler.	Section 3.3.2
--run_linker	-z	Causes the linker to be invoked from the compiler command line.	Section 3.3.2
--skip_assembler	-n	Compiles C/C++ source file, producing an assembly language output file. The assembler is not run and no object file is produced.	Section 3.3.2
--keep_asm	-k	Keeps the assembly language (.asm) file.	

Table 3-7. Language Options

Option	Alias	Effect	Section
--c89		Processes C files according to the ISO C89 standard.	Section 5.13
--c99		Processes C files according to the ISO C99 standard.	Section 5.13
--c11		Processes C files according to the ISO C11 standard.	Section 5.13
--c++14		Processes C++ files according to the ISO C++14 standard.	Section 5.13
--cpp_default	-fg	Processes all source files with a C extension as C++ source files.	Section 3.3.8
--exceptions		Enables C++ exception handling.	Section 5.7
--extern_c_can_throw		Allow extern C functions to propagate exceptions.	--
--float_operations_allowed ={none all 32 64}		Restricts the types of floating point operations allowed.	Section 3.3.3
--pending_instantiations=#		Specify the number of template instantiations that may be in progress at any given time. Use 0 to specify an unlimited number.	Section 3.3.4
--printf_support={nofloat full minimal}		Enables support for smaller, limited versions of the printf function family (sprintf, fprintf, etc.) and the scanf function family (sscanf, fscanf, etc.) run-time-support functions.	Section 3.3.3
--relaxed_ansi	-pr	Enables relaxed mode; ignores strict ISO violations. This is on by default. To disable this mode, use the --strict_ansi option.	Section 5.13.3
--rtti	-rtti	Enables C++ run-time type information (RTTI).	--
--strict_ansi	-ps	Enables strict ANSI/ISO mode (for C/C++, not for K&R C). In this mode, language extensions that conflict with ANSI/ISO C/C++ are disabled. In strict ANSI/ISO mode, most ANSI/ISO violations are reported as errors. Violations that are considered discretionary may be reported as warnings instead.	Section 5.13.3
--vectypes={on off}		Enable support for native vector data types. On by default.	Section 5.4.2

Table 3-8. Parser Preprocessing Options

Option	Alias	Effect	Section
--preproc_dependency[= <i>filename</i>]	-ppd	Performs preprocessing only, but instead of writing preprocessed output, writes a list of dependency lines suitable for input to a standard make utility.	Section 3.5.8
--preproc_includes[= <i>filename</i>]	-ppi	Performs preprocessing only, but instead of writing preprocessed output, writes a list of files included with the #include directive.	Section 3.5.9
--preproc_macros[= <i>filename</i>]	-ppm	Performs preprocessing only. Writes list of predefined and user-defined macros to a file with the same name as the input but with a .pp extension.	Section 3.5.10
--preproc_only	-ppo	Performs preprocessing only. Writes preprocessed output to a file with the same name as the input but with a .pp extension.	Section 3.5.4
--preproc_with_comment	-ppc	Performs preprocessing only. Writes preprocessed output, keeping the comments, to a file with the same name as the input but with a .pp extension.	Section 3.5.6
--preproc_with_compile	-ppa	Continues compilation after preprocessing with any of the -pp<x> options that normally disable compilation.	Section 3.5.5
--preproc_with_line	-ppl	Performs preprocessing only. Writes preprocessed output with line-control information (#line directives) to a file with the same name as the input but with a .pp extension.	Section 3.5.7

Table 3-9. Predefined Macro Options

Option	Alias	Effect	Section
--define= <i>name</i> [= <i>def</i>]	-D	Predefines <i>name</i> .	Section 3.3.2
--undefine= <i>name</i>	-U	Undefines <i>name</i> .	Section 3.3.2

Table 3-10. Diagnostic Message Options

Option	Alias	Effect	Section
--compiler_revision		Prints out the compiler release revision and exits.	--
--diag_error=num	-pdse	Categorizes the diagnostic identified by <i>num</i> as an error.	Section 3.7.1
--diag_remark=num	-pdsr	Categorizes the diagnostic identified by <i>num</i> as a remark.	Section 3.7.1
--diag_suppress=num	-pds	Suppresses the diagnostic identified by <i>num</i> .	Section 3.7.1
--diag_warning=num	-pdsd	Categorizes the diagnostic identified by <i>num</i> as a warning.	Section 3.7.1
--diag_wrap={on off}		Wrap diagnostic messages (default is on). Note that this command-line option cannot be used within the Code Composer Studio IDE.	
--display_error_number	-pden	Displays a diagnostic's identifiers along with its text. Note that this command-line option cannot be used within the Code Composer Studio IDE.	Section 3.7.1
--emit_warnings_as_errors	-pdew	Treat warnings as errors.	Section 3.7.1
--issue_remarks	-pdr	Issues remarks (non-serious warnings).	Section 3.7.1
--no_warnings	-pdw	Suppresses diagnostic warnings (errors are still issued).	Section 3.7.1
--quiet	-q	Suppresses progress messages (quiet).	--
--set_error_limit=num	-pdel	Sets the error limit to <i>num</i> . The compiler abandons compiling after this number of errors. (The default is 100.)	Section 3.7.1
--super_quiet	-qq	Super quiet mode.	--
--tool_version	-version	Displays version number for each tool.	--
--verbose		Display banner and function progress information.	--
--verbose_diagnostics	-pdv	Provides verbose diagnostic messages that display the original source with line-wrap. Note that this command-line option cannot be used within the Code Composer Studio IDE.	Section 3.7.1
--write_diagnostics_file	-pdf	Generates a diagnostic message information file. Compiler only option. Note that this command-line option cannot be used within the Code Composer Studio IDE.	Section 3.7.1

Table 3-11. Supplemental Information Options

Option	Alias	Effect	Section
--gen_preprocessor_listing	-pl	Generates a raw listing file (.rl).	Section 3.9
--section_sizes={on off}		Generates section size information, including sizes for sections containing executable code and constants, constant or initialized data (global and static variables), and uninitialized data. (Default is off if this option is not included on the command line. Default is on if this option is used with no value specified.)	Section 3.7.1

Table 3-12. Run-Time Model Options

Option	Alias	Effect	Section
--common={on off}		On by default. When on, uninitialized file scope variables are emitted as common symbols. When off, common symbols are not created.	Section 3.3.4
--debug_software_pipeline	-mw	Produce verbose software pipelining report.	Section 4.7.2
--disable_software_pipeline	-mu	Turns off software pipelining.	Section 4.7.1
--fp_not_associative	-mc	Prevents reordering of associative floating-point operations.	Section 4.10
--gen_data_subsections={on off}		Place all aggregate data (arrays, structs, and unions) into subsections. This gives the linker more control over removing unused data during the final link step. The default is on.	Section 11.2.3
--gen_func_subsections={on off}	-mo	Puts each function in a separate subsection in the object file.	Section 11.2.2
--ramfunc={on off}		If set to on, indicates that each function will be run from RAM. Functions will be placed in RAM and optimized for RAM execution. Equivalent to specifying <code>__attribute__((ram_func))</code> on all functions in the translation unit.	Section 3.3.4

Table 3-13. Entry/Exit Hook Options

Option	Alias	Effect	Section
--entry_hook[= <i>name</i>]		Enables entry hooks.	Section 3.14
--entry_parm={ <i>none</i> <i>name</i> <i>address</i> }		Specifies the parameters to the function to the --entry_hook option.	Section 3.14
--exit_hook[= <i>name</i>]		Enables exit hooks.	Section 3.14
--exit_parm={ <i>none</i> <i>name</i> <i>address</i> }		Specifies the parameters to the function to the --exit_hook option.	Section 3.14
--remove_hooks_when_inlining		Removes entry/exit hooks for auto-inlined functions.	Section 3.14

Table 3-14. Assembly Options

Option	Alias	Effect	Section
--c_src_interlist	-ss	Interlists C source and assembly statements.	Section 3.11 Section 4.11

Table 3-15. File Type Specifier Options

Option	Alias	Effect	Section
--asm_file= <i>filename</i>	-fa	Identifies <i>filename</i> as an assembly source file regardless of its extension. By default, the compiler and assembler treat .asm files as assembly source files.	Section 3.3.8
--c_file= <i>filename</i>	-fc	Identifies <i>filename</i> as a C source file regardless of its extension. By default, the compiler treats .c files as C source files.	Section 3.3.8
--cpp_file= <i>filename</i>	-fp	Identifies <i>filename</i> as a C++ file, regardless of its extension. By default, the compiler treats .C, .cpp, .cc and .cxx files as a C++ files.	Section 3.3.8
--obj_file= <i>filename</i>	-fo	Identifies <i>filename</i> as an object code file regardless of its extension. By default, the compiler and linker treat .obj files as object code files, including both *.c.obj and *.cpp.obj files.	Section 3.3.8

Table 3-16. Directory Specifier Options

Option	Alias	Effect	Section
--asm_directory= <i>directory</i>	-fs	Specifies an assembly file directory. By default, the compiler uses the current directory.	Section 3.3.11
--obj_directory= <i>directory</i>	-fr	Specifies an object file directory. By default, the compiler uses the current directory.	Section 3.3.11
--output_file= <i>filename</i>	-fe	Specifies a compilation output file name; can override --obj_directory.	Section 3.3.11
--pp_directory= <i>dir</i>		Specifies a preprocessor file directory. By default, the compiler uses the current directory.	Section 3.3.11
--temp_directory= <i>directory</i>	-ft	Specifies a temporary file directory. By default, the compiler uses the current directory.	Section 3.3.11

Table 3-17. Default File Extensions Options

Option	Alias	Effect	Section
--asm_extension=[.] <i>extension</i>	-ea	Sets a default extension for assembly source files.	Section 3.3.10
--c_extension=[.] <i>extension</i>	-ec	Sets a default extension for C source files.	Section 3.3.10
--cpp_extension=[.] <i>extension</i>	-ep	Sets a default extension for C++ source files.	Section 3.3.10
--listing_extension=[.] <i>extension</i>	-es	Sets a default extension for listing files.	Section 3.3.10
--obj_extension=[.] <i>extension</i>	-eo	Sets a default extension for object files.	Section 3.3.10

Table 3-18. Command Files Options

Option	Alias	Effect	Section
--cmd_file= <i>filename</i>	-@	Interprets contents of a file as an extension to the command line. Multiple -@ instances can be used.	Section 3.3.2

Table 3-19. MISRA-C 2004 Options

Option	Alias	Effect	Section
--check_misra[={all required advisory none rulespec}]		Enables checking of the specified MISRA-C:2004 rules. Default is all.	Section 3.3.3
--misra_advisory={error warning remark suppress}		Sets the diagnostic severity for advisory MISRA-C:2004 rules.	Section 3.3.3
--misra_required={error warning remark suppress}		Sets the diagnostic severity for required MISRA-C:2004 rules.	Section 3.3.3

Table 3-20. Performance Advisor Options

Option	Alias	Effect	Section
--advice:performance[={all none}]		Generates compiler optimization advice. Default is all.	Section 3.12
--advice:performance_file={stdout stderr user_specified_filename}		Specifies that advice be written to stdout, stderr, or a file.	Section 3.12
--advice:performance_dir={user_specified_directory_name}		Specifies that advice file be created in the named directory.	Section 3.12

3.3.1 Linker Options

The following tables list the linker options. See [Chapter 11](#) of this document and [Chapter 12](#) for details on these options.

Table 3-21. Linker Basic Options

Option	Alias	Description
--run_linker	-z	Enables linking.
--output_file= <i>file</i>	-o	Names the executable output file. The default filename is a .out file.
--map_file= <i>file</i>	-m	Produces a map or listing of the input and output sections, including holes, and places the listing in <i>file</i> .
--stack_size= <i>size</i>	[-]-stack	Sets C system stack size to <i>size</i> bytes and defines a global symbol that specifies the stack size. Default = 1K bytes.
--heap_size= <i>size</i>	[-]-heap	Sets heap size (for the dynamic memory allocation in C) to <i>size</i> bytes and defines a global symbol that specifies the heap size. Default = 1K bytes.

Table 3-22. File Search Path Options

Option	Alias	Description
--library= <i>file</i>	-l	Names an archive library or link command <i>file</i> as linker input.
--disable_auto_rts		Disables the automatic selection of a run-time-support library. See Section 11.3.1.1 .
--priority	-priority	Satisfies unresolved references by the first library that contains a definition for that symbol.
--reread_libs	-x	Forces rereading of libraries, which resolves back references.
--search_path= <i>pathname</i>	-I	Alters library-search algorithms to look in a directory named with <i>pathname</i> before looking in the default location. This option must appear before the --library option.

Table 3-23. Command File Preprocessing Options

Option	Alias	Description
--define= <i>name=value</i>		Predefines <i>name</i> as a preprocessor macro.
--undefine= <i>name</i>		Removes the preprocessor macro <i>name</i> .
--disable_pp		Disables preprocessing for command files.

Table 3-24. Diagnostic Message Options

Option	Alias	Description
--diag_error= <i>num</i>		Categorizes the diagnostic identified by <i>num</i> as an error.
--diag_remark= <i>num</i>		Categorizes the diagnostic identified by <i>num</i> as a remark.
--diag_suppress= <i>num</i>		Suppresses the diagnostic identified by <i>num</i> .
--diag_warning= <i>num</i>		Categorizes the diagnostic identified by <i>num</i> as a warning.
--display_error_number		Displays a diagnostic's identifiers along with its text.
--emit_references:file[= <i>file</i>]		Emits a file containing section information. The information includes section size, symbols defined, and references to symbols.
--emit_warnings_as_errors	-pdew	Treat warnings as errors.
--issue_remarks		Issues remarks (non-serious warnings).
--no_demangle		Disables demangling of symbol names in diagnostic messages.
--no_warnings		Suppresses diagnostic warnings (errors are still issued).
--set_error_limit= <i>count</i>		Sets the error limit to <i>count</i> . The linker abandons linking after this number of errors. (The default is 100.)
--verbose_diagnostics		Provides verbose diagnostic messages that display the original source with line-wrap.

Table 3-25. Linker Output Options

Option	Alias	Description
--absolute_exe	-a	Produces an absolute, executable object file. This is the default; if neither --absolute_exe nor --relocatable is specified, the linker acts as if --absolute_exe were specified.
--mapfile_contents= <i>attribute</i>		Controls the information that appears in the map file.
--relocatable	-r	Produces a nonexecutable, relocatable output object file.
--rom		Creates a ROM object.
--xml_link_info= <i>file</i>		Generates a well-formed XML <i>file</i> containing detailed information about the result of a link.

Table 3-26. Symbol Management Options

Option	Alias	Description
--entry_point= <i>symbol</i>	-e	Defines a global symbol that specifies the primary entry point for the executable object file.
--globalize= <i>pattern</i>		Changes the symbol linkage to global for symbols that match <i>pattern</i> .
--hide= <i>pattern</i>		Hides symbols that match the specified <i>pattern</i> .
--localize= <i>pattern</i>		Make the symbols that match the specified <i>pattern</i> local.
--make_global= <i>symbol</i>	-g	Makes <i>symbol</i> global (overrides -h).
--make_static	-h	Makes all global symbols static.
--no_symtable	-s	Strips symbol table information and line number entries from the executable object file.
--retain={ <i>symbol</i> section specification}		Specifies a symbol or section to be retained by the linker.
--scan_libraries	-scanlibs	Scans all libraries for duplicate symbol definitions.
--symbol_map= <i>refname=defname</i>		Specifies a symbol mapping; references to the <i>refname</i> symbol are replaced with references to the <i>defname</i> symbol.
--undef_sym= <i>symbol</i>	-u	Adds <i>symbol</i> to the symbol table as an unresolved symbol.
--unhide= <i>pattern</i>		Excludes symbols that match the specified <i>pattern</i> from being hidden.

Table 3-27. Run-Time Environment Options

Option	Alias	Description
--arg_size=size	--args	Reserve size bytes for the argc/argv memory area.
--cinit_compression[=type]		Specifies the type of compression to apply to the C auto initialization data. The default if this option is specified with no type is lzss for Lempel-Ziv-Storer-Szymanski compression.
--copy_compression[=type]		Compresses data copied by linker copy tables. The default if this option is specified with no type is lzss for Lempel-Ziv-Storer-Szymanski compression.
--fill_value=value	-f	Sets default fill value for holes within output sections
--ram_model	-cr	Initializes variables at load time.
--rom_model	-c	Autoinitializes variables at run time.
--trampolines[=off on]		Generates far call trampolines. Default is on.

Table 3-28. Miscellaneous Options

Option	Alias	Description
--compress_dwarf[=off on]		Aggressively reduces the size of DWARF information from input object files. Default is on.
--linker_help	[-]help	Displays information about syntax and available options.
--minimize_trampolines[=off postorder]		Places sections to minimize number of far trampolines required. Default is postorder.
--preferred_order=function		Prioritizes placement of functions.
--strict_compatibility[=off on]		Performs more conservative and rigorous compatibility checking of input object files. Default is on.
--zero_init=[off on]		Controls preinitialization of uninitialized variables. Default is on.

3.3.2 Frequently Used Options

Following are detailed descriptions of options that you will probably use frequently:

--c_src_interlist	Invokes the interlist feature, which interweaves original C/C++ source with compiler-generated assembly language. The interlisted C statements may appear to be out of sequence. You can use the interlist feature with the optimizer by combining the --optimizer_interlist and --c_src_interlist options. See Section 4.11 . The --c_src_interlist option can have a negative performance and/or code size impact.
--cmd_file=filename	<p>Appends the contents of a file to the option set. You can use this option to avoid limitations on command line length or C style comments imposed by the host operating system. Use a # or ; at the beginning of a line in the command file to include comments. You can also include comments by delimiting them with /* and */. To specify options, surround hyphens with quotation marks. For example, "--quiet.</p> <p>You can use the --cmd_file option multiple times to specify multiple files. For instance, the following indicates that file3 should be compiled as source and file1 and file2 are --cmd_file files:</p> <pre>c17x --cmd_file=file1 --cmd_file=file2 file3</pre>
--compile_only	Suppresses the linker and overrides the --run_linker option, which specifies linking. The --compile_only option's short form is -c. Use this option when you have --run_linker specified in the C7X_C_OPTION environment variable and you do not want to link. See Section 11.1.3 .

--define=name[=def]	<p>Predefines the constant <i>name</i> for the preprocessor. This is equivalent to inserting <code>#define name def</code> at the top of each C source file. If the optional <code>[=def]</code> is omitted, the <i>name</i> is set to 1. The <code>--define</code> option's short form is <code>-D</code>.</p> <p>If you want to define a quoted string and keep the quotation marks, do one of the following:</p> <ul style="list-style-type: none"> For Windows, use <code>--define=name=\"string def\"</code>. For example, <code>--define=car=\"sedan\"</code> For UNIX, use <code>--define=name='string def'</code>. For example, <code>--define=car='sedan'</code> For Code Composer Studio, enter the definition in a file and include that file with the <code>--cmd_file</code> option.
--help	<p>Displays the syntax for invoking the compiler and lists available options. If the <code>--help</code> option is followed by another option or phrase, detailed information about the option or phrase is displayed. For example, to see information about debugging options use <code>--help debug</code>.</p>
--include_path=directory	<p>Adds <i>directory</i> to the list of directories that the compiler searches for <code>#include</code> files. The <code>--include_path</code> option's short form is <code>-I</code>. You can use this option several times to define several directories; be sure to separate the <code>--include_path</code> options with spaces. If you do not specify a directory name, the preprocessor ignores the <code>--include_path</code> option. See Section 3.5.2.1.</p>
--keep_asm	<p>Retains the assembly language output from the compiler or assembly optimizer. Normally, the compiler deletes the output assembly language file after assembly is complete. The <code>--keep_asm</code> option's short form is <code>-k</code>.</p>
--quiet	<p>Suppresses banners and progress information from all the tools. Only source filenames and error messages are output. The <code>--quiet</code> option's short form is <code>-q</code>.</p>
--run_linker	<p>Runs the linker on the specified object files. The <code>--run_linker</code> option and its parameters follow all other options on the command line. All arguments that follow <code>--run_linker</code> are passed to the linker. The <code>--run_linker</code> option's short form is <code>-z</code>. See Section 11.1.</p>
--skip_assembler	<p>Compiles only. The specified source files are compiled but not assembled or linked. The <code>--skip_assembler</code> option's short form is <code>-n</code>. This option overrides <code>--run_linker</code>. The output is assembly language output from the compiler.</p>
--src_interlist	<p>Invokes the interlist feature, which interweaves optimizer comments or C/C++ source with assembly source. If the optimizer is invoked (<code>--opt_level=n</code> option), optimizer comments are interlisted with the assembly language output of the compiler, which may rearrange code significantly. If the optimizer is not invoked, C/C++ source statements are interlisted with the assembly language output of the compiler, which allows you to inspect the code generated for each C/C++ statement. The <code>--src_interlist</code> option implies the <code>--keep_asm</code> option. The <code>--src_interlist</code> option's short form is <code>-s</code>.</p>
--tool_version	<p>Prints the version number for each tool in the compiler. No compiling occurs.</p>
--undefine=name	<p>Undefines the predefined constant <i>name</i>. This option overrides any <code>--define</code> options for the specified constant. The <code>--undefine</code> option's short form is <code>-U</code>.</p>
--verbose	<p>Displays progress information and toolset version while compiling. Resets the <code>--quiet</code> option.</p>

3.3.3 Miscellaneous Useful Options

Following are detailed descriptions of miscellaneous options:

--check_misra={all|required|
advisory|none|rulespec}

Displays the specified amount or type of MISRA-C documentation. This option must be used if you want to enable use of the CHECK_MISRA and RESET_MISRA pragmas within the source code. The *rulespec* parameter is a comma-separated list of specifiers. See [Section 5.3](#) for details.

--float_operations_allowed=
{none|all|32|64}

Restricts the type of floating point operations allowed in the application. The default is all. If set to none, 32, or 64, the application is checked for operations that will be performed at runtime. For example, if --float_operations_allowed=32 is specified on the command line, the compiler issues an error if a double precision operation will be generated. This can be used to ensure that double precision operations are not accidentally introduced into an application. The checks are performed after relaxed mode optimizations have been performed, so illegal operations that are completely removed result in no diagnostic messages.

--fp_mode={relaxed|strict}

The default floating-point mode is strict. To enable relaxed floating-point mode use the --fp_mode=relaxed option. Relaxed floating-point mode causes double-precision floating-point computations and storage to be converted to integers where possible. This behavior does not conform with ISO, but it results in faster code, with some loss in accuracy. The following specific changes occur in relaxed mode:

- If the result of a double-precision floating-point expression is assigned to a single-precision floating-point or an integer or immediately used in a single-precision context, the computations in the expression are converted to single-precision computations. Double-precision constants in the expression are also converted to single-precision if they can be correctly represented as single-precision constants.
- Calls to double-precision functions in math.h are converted to their single-precision counterparts if all arguments are single-precision and the result is used in a single-precision context. The math.h header file must be included for this optimization to work.
- Division by a constant is converted to inverse multiplication.

In the following examples, iN=integer variable, fN=float variable, and dN=double variable:

```
i1 = f1 + f2 * 5.0 -> +, * are float, 5.0 is converted to 5.0f
i1 = d1 + d2 * d3 -> +, * are float
f1 = f2 + f3 * 1.1; -> +, * are float, 1.1 is converted to 1.1f
```

To enable relaxed floating-point mode use the --fp_mode=relaxed option, which also sets --fp_reassoc=on. To disable relaxed floating-point mode use the --fp_mode=strict option, which also sets --fp_reassoc=off.

If --strict_ansi is specified, --fp_mode=strict is set automatically. You can enable the relaxed floating-point mode with strict ANSI mode by specifying --fp_mode=relaxed after --strict_ansi.

--fp_reassoc ={on off}	<p>Enables or disables the reassociation of floating-point arithmetic. If <code>--strict_ansi</code> is set, <code>--fp_reassoc=off</code> is set since reassociation of floating-point arithmetic is an ANSI violation.</p> <p>Because floating-point values are of limited precision, and because floating-point operations round, floating-point arithmetic is neither associative nor distributive. For instance, $(1 + 3e100) - 3e100$ is not equal to $1 + (3e100 - 3e100)$. If strictly following IEEE 754, the compiler cannot, in general, reassociate floating-point operations. Using <code>--fp_reassoc=on</code> allows the compiler to perform the algebraic reassociation, at the cost of a small amount of precision for some operations.</p>
--misra_advisory ={error warning remark suppress}	Sets the diagnostic severity for advisory MISRA-C:2004 rules.
--misra_required ={error warning remark suppress}	Sets the diagnostic severity for required MISRA-C:2004 rules.
--preinclude =filename	Includes the source code of <i>filename</i> at the beginning of the compilation. This can be used to establish standard macro definitions. The filename is searched for in the directories on the include search list. The files are processed in the order in which they were specified.
--printf_support ={full nofloat minimal}	<p>Enables support for smaller, limited versions of the printf function family (sprintf, fprintf, etc.) and the scanf function family (sscanf, fscanf, etc.) run-time-support functions. The valid values are:</p> <ul style="list-style-type: none"> • full: Supports all format specifiers. This is the default. • nofloat: Excludes support for printing and scanning floating-point values. Supports all format specifiers except %a, %A, %f, %F, %g, %G, %e, and %E. • minimal: Supports the printing and scanning of integer, char, or string values without width or precision flags. Specifically, only the %, %d, %o, %c, %s, and %x format specifiers are supported <p>There is no run-time error checking to detect if a format specifier is used for which support is not included. The <code>--printf_support</code> option precedes the <code>--run_linker</code> option, and must be used when performing the final link.</p>

3.3.4 Run-Time Model Options

These options are specific to the C7000 toolset. See the referenced sections for more information.

--big_endian	Produces code in big-endian format. By default, little-endian code is produced.
--advice:performance	Generates compile-time optimization advice. See Section 3.12 .
--common ={on off}	When on (the default), uninitialized file scope variables are emitted as common symbols. When off, common symbols are not created. The benefit of allowing common symbols to be created is that generated code can remove unused variables that would otherwise increase the size of the .bss section. (Uninitialized variables of a size larger than 32 bytes are separately optimized through placement in separate subsections that can be omitted from a link.) Variables cannot be common symbols if they are assigned to a section other than .bss or have a specified memory bank.
--debug_software_pipeline	Produces verbose software pipelining report. See Section 4.7.2 .
--disable_software_pipeline	Turns off software pipelining. See Section 4.7.1 .
--fp_not_associative	Compiler does not reorder floating-point operations. See Section 4.10 .

--pending_instantiations=#	Specify the number of template instantiations that may be in progress at any given time. Use 0 to specify an unlimited number.
--ramfunc={on off}	If set to on, indicates that each function will be run from RAM. Functions will be placed in RAM and optimized for RAM execution. Equivalent to specifying <code>__attribute__((ram_func))</code> on all functions in the translation unit. If set to off, only functions with the <code>ramfunc</code> function attribute are treated this way. See Section 5.14.2 .
--silicon_version=num	Selects the target CPU version. See Section 3.3.5 .

3.3.5 Selecting Target CPU Version (--silicon_version Option)

The `--silicon_version` option controls the use of target-specific instructions and alignment. The alias for this option is `-mv`. If this option is not used, the compiler generates code for the C7100 parts by default.

Currently, the only setting for this option is `--silicon_version=7100` (or its alias, `-mv7100`).

3.3.6 Symbolic Debugging and Profiling Options

The following options are used to select symbolic debugging:

--symdebug:dwarf	(Default) Generates directives that are used by the C/C++ source-level debugger. The <code>--symdebug:dwarf</code> option's short form is <code>-g</code> . See Section 4.12 . For more information on the DWARF debug format, see <i>The DWARF Debugging Standard</i> .
--symdebug:dwarf_version={3 4}	Specifies the DWARF debugging format version (3 or 4) to be generated when <code>--symdebug:dwarf</code> (the default) is specified. By default, the compiler generates DWARF version 4 debug information. For more information on TI extensions to the DWARF language, see <i>The Impact of DWARF on TI Object Files</i> (SPRAAB5).
--symdebug:none	Disables all symbolic debugging output. This option is not recommended; it prevents debugging and most performance analysis capabilities.

3.3.7 Specifying Filenames

The input files that you specify on the command line can be C source files, C++ source files, or object files. The compiler uses filename extensions to determine the file type.

Extension	File Type
.c	C source
.C	Depends on operating system
.cpp, .cxx, .cc	C++ source
.obj .c.obj .cpp.obj .o* .dll .so	Object

NOTE: Case Sensitivity in Filename Extensions

Case sensitivity in filename extensions is determined by your operating system. If your operating system is not case sensitive, a file with a `.C` extension is interpreted as a C file. If your operating system is case sensitive, a file with a `.C` extension is interpreted as a C++ file.

For information about how you can alter the way that the compiler interprets individual filenames, see [Section 3.3.8](#). For information about how you can alter the way that the compiler interprets and names the extensions of files, see [Section 3.3.11](#).

You can use wildcard characters to compile multiple files. Wildcard specifications vary by system; use the appropriate form listed in your operating system manual. For example, to compile all of the files in a directory with the extension `.cpp`, enter the following:

```
c17x *.cpp
```

NOTE: No Default Extension for Source Files is Assumed

If you list a filename called `example` on the command line, the compiler assumes that the entire filename is `example` not `example.c`. No default extensions are added onto files that do not contain an extension.

3.3.8 Changing How the Compiler Interprets Filenames

You can use options to change how the compiler interprets your filenames. If the extensions that you use are different from those recognized by the compiler, you can use the filename options to specify the type of file. You can insert an optional space between the option and the filename. Select the appropriate option for the type of file you want to specify:

<code>--asm_file=filename</code>	for an assembly language source file
<code>--c_file=filename</code>	for a C source file
<code>--cpp_file=filename</code>	for a C++ source file
<code>--obj_file=filename</code>	for an object file

For example, if you have a C source file called `file.s` and a C++ file called `objects.cp`, use the `--cpp_file` and `--c_file` options to force the correct interpretation:

```
c17x --c_file=file.s --cpp_file=objects.cp
```

You cannot use the filename options with wildcard specifications.

NOTE: The default file extensions for object files created by the compiler have been changed in order to prevent conflicts when C and C++ files have the same names. Object files generated from C source files have the `.c.obj` extension. Object files generated from C++ source files have the `.cpp.obj` extension.

3.3.9 Changing How the Compiler Processes C Files

The `--cpp_default` option causes the compiler to process C files as C++ files. By default, the compiler treats files with a `.c` extension as C files. See [Section 3.3.10](#) for more information about filename extension conventions.

3.3.10 Changing How the Compiler Interprets and Names Extensions

You can use options to change how the compiler program interprets filename extensions and names the extensions of the files that it creates. The filename extension options must precede the filenames they apply to on the command line. You can use wildcard specifications with these options. An extension can be up to nine characters in length. Select the appropriate option for the type of extension you want to specify:

<code>--asm_extension=new extension</code>	for an assembly language file
<code>--c_extension=new extension</code>	for a C source file
<code>--cpp_extension=new extension</code>	for a C++ source file
<code>--listing_extension=new extension</code>	sets default extension for listing files
<code>--obj_extension=new extension</code>	for an object file

The following example compiles the file `fit.rrr` and creates an object file named `fit.o`:

```
cl7x --cpp_extension=.rrr --obj_extension=.o fit.rrr
```

The period (.) in the extension is optional. You can also write the example above as:

```
cl7x --cpp_extension=rrr --obj_extension=o fit.rrr
```

3.3.11 Specifying Directories

By default, the compiler program places the object and temporary files that it creates into the current directory. If you want the compiler program to place these files in different directories, use the following options:

--asm_directory=directory	Specifies a directory for assembly files. For example: <code>cl7x --asm_directory=d:\assembly</code>
--obj_directory=directory	Specifies a directory for object files. For example: <code>cl7x --obj_directory=d:\object</code>
--output_file=filename	Specifies a compilation output file name; can override <code>--obj_directory</code> . For example: <code>cl7x --output_file=transfer</code>
--pp_directory=directory	Specifies a preprocessor file directory for object files (default is .). For example: <code>cl7x --pp_directory=d:\preproc</code>
--temp_directory=directory	Specifies a directory for temporary intermediate files. For example: <code>cl7x --temp_directory=d:\temp</code>

3.4 Controlling the Compiler Through Environment Variables

An environment variable is a system symbol that you define and assign a string to. Setting environment variables is useful when you want to run the compiler repeatedly without re-entering options, input filenames, or pathnames.

NOTE: **C_OPTION** and **C_DIR** -- The **C_OPTION** and **C_DIR** environment variables are deprecated. Use device-specific environment variables instead.

3.4.1 Setting Default Compiler Options (C7X_C_OPTION)

You might find it useful to set the compiler and linker default options using the **C7X_C_OPTION** environment variable. If you do this, the compiler uses the default options and/or input filenames that you name **C7X_C_OPTION** every time you run the compiler.

Setting the default options with these environment variables is useful when you want to run the compiler repeatedly with the same set of options and/or input files. After the compiler reads the command line and the input filenames, it looks for the **C7X_C_OPTION** environment variable and processes it.

The table below shows how to set the **C7X_C_OPTION** environment variable. Select the command for your operating system:

Operating System	Enter
UNIX (Bourne shell)	C7X_C_OPTION=" option₁ [option₂ . . .]"; export C7X_C_OPTION
Windows	set C7X_C_OPTION= option₁ [option₂ . . .]

Environment variable options are specified in the same way and have the same meaning as they do on the command line. For example, if you want to always run quietly (the `--quiet` option), enable C/C++ source interlisting (the `--src_interlist` option), and link (the `--run_linker` option) for Windows, set up the **C7X_C_OPTION** environment variable as follows:

```
set C7X_C_OPTION=--quiet --src_interlist --run_linker
```

In the following examples, each time you run the compiler, it runs the linker. Any options following `--run_linker` on the command line or in `C7X_C_OPTION` are passed to the linker. Thus, you can use the `C7X_C_OPTION` environment variable to specify default compiler and linker options and then specify additional compiler and linker options on the command line. If you have set `--run_linker` in the environment variable and want to compile only, use the compiler `--compile_only` option. These additional examples assume `C7X_C_OPTION` is set as shown above:

```
cl7x *c                ; compiles and links
cl7x --compile_only *.c ; only compiles
cl7x *.c --run_linker lnk.cmd ; compiles and links using a command file
cl7x --compile_only *.c --run_linker lnk.cmd
                        ; only compiles (--compile_only overrides --run_linker)
```

For details on compiler options, see [Section 3.3](#). For details on linker options, see [Section 12.4](#).

3.4.2 Naming One or More Alternate Directories (C7X_C_DIR)

The linker uses the `C7X_C_DIR` environment variable to name alternate directories that contain object libraries. The command syntaxes for assigning the environment variable are:

Operating System	Enter
UNIX (Bourne shell)	<code>C7X_C_DIR=" pathname₁ ; pathname₂ ;..."; export C7X_C_DIR</code>
Windows	<code>set C7X_C_DIR= pathname₁ ; pathname₂ ;...</code>

The *pathnames* are directories that contain input files. The pathnames must follow these constraints:

- Pathnames must be separated with a semicolon.
- Spaces or tabs at the beginning or end of a path are ignored. For example, the space before and after the semicolon in the following is ignored:

```
set C7X_C_DIR=c:\path\one\to\tools ; c:\path\two\to\tools
```

- Spaces and tabs are allowed within paths to accommodate Windows directories that contain spaces. For example, the pathnames in the following are valid:

```
set C7X_C_DIR=c:\first path\to\tools;d:\second path\to\tools
```

The environment variable remains set until you reboot the system or reset the variable by entering:

Operating System	Enter
UNIX (Bourne shell)	<code>unset C7X_C_DIR</code>
Windows	<code>set C7X_C_DIR=</code>

3.5 Controlling the Preprocessor

This section describes features that control the preprocessor, which is part of the parser. A general description of C preprocessing is in section A12 of K&R. The C/C++ compiler includes standard C/C++ preprocessing functions, which are built into the first pass of the compiler. The preprocessor handles:

- Macro definitions and expansions
- `#include` files
- Conditional compilation
- Various preprocessor directives, specified in the source file as lines beginning with the `#` character

The preprocessor produces self-explanatory error messages. The line number and the filename where the error occurred are printed along with a diagnostic message.

3.5.1 Predefined Macro Names

The compiler maintains and recognizes the predefined macro names listed in [Table 12-9](#).

Table 3-29. Predefined C7000 Macro Names

Macro Name	Description
<code>__C7000__</code>	Defined to 1 for all C7000 subtargets.
<code>__C7100__</code>	Defined to 1 for the C7100 subtarget.
<code>__DATE__</code> ⁽¹⁾	Expands to the compilation date in the form <i>mmm dd yyyy</i>
<code>__FILE__</code> ⁽¹⁾	Expands to the current source filename
<code>__LINE__</code> ⁽¹⁾	Expands to the current line number
<code>__STDC__</code> ⁽¹⁾	Defined to 1 to indicate that compiler conforms to ISO C Standard. See Section 5.1 for exceptions to ISO C conformance.
<code>__STDC_VERSION__</code>	C standard macro.
<code>__STDC_HOSTED__</code>	C standard macro. Always defined to 1.
<code>__STDC_NO_THREADS__</code>	C standard macro. Always defined to 1.
<code>__TI_C99_COMPLEX_ENABLED__</code>	Defined to 1 if complex data types are enabled. This is always the case, though math operations are available only if <code>complex.h</code> is included.
<code>__TI_COMPILER_VERSION__</code>	Defined to a 7-9 digit integer, depending on if X has 1, 2, or 3 digits. The number does not contain a decimal. For example, version 3.2.1 is represented as 3002001. The leading zeros are dropped to prevent the number being interpreted as an octal.
<code>__TI_EABI__</code>	Always defined to 1.
<code>__TI_GNU_ATTRIBUTE_SUPPORT__</code>	Defined to 1 if GCC extensions are enabled (which is the default)
<code>__TI_STRICT_ANSI_MODE__</code>	Defined to 1 if strict ANSI/ISO mode is enabled (the <code>--strict_ansi</code> option is used); otherwise, it is defined as 0.
<code>__TI_STRICT_FP_MODE__</code>	Defined to 1 if <code>--fp_mode=strict</code> is used (default); otherwise, it is defined as 0.
<code>__TIME__</code> ⁽¹⁾	Expands to the compilation time in the form <i>"hh:mm:ss"</i>
<code>__big_endian__</code>	Defined to 1 if big-endian mode is selected (the <code>--endian=big</code> option is used); otherwise, it is undefined.
<code>__INLINE</code>	Expands to 1 if optimization is used (<code>--opt_level</code> or <code>-O</code> option); undefined otherwise.
<code>__little_endian__</code>	Defined to 1 if little-endian mode is selected (the <code>--big_endian</code> option is not used); otherwise, it is undefined.

⁽¹⁾ Specified by the ISO standard

You can use the names listed in [Table 12-9](#) in the same manner as any other defined name. For example,

```
printf ( "%s %s" , __TIME__ , __DATE__ );
```

translates to a line such as:

```
printf ( "%s %s" , "13:58:17" , "Jan 14 1997" );
```


3.5.2 The Search Path for #include Files

The #include preprocessor directive tells the compiler to read source statements from another file. When specifying the file, you can enclose the filename in double quotes or in angle brackets. The filename can be a complete pathname, partial path information, or a filename with no path information.

- If you enclose the filename in double quotes (" "), the compiler searches for the file in the following directories in this order:
 1. The directory of the file that contains the #include directive and in the directories of any files that contain that file.
 2. Directories named with the --include_path option.
 3. Directories set with the C7X_C_DIR environment variable.
- If you enclose the filename in angle brackets (< >), the compiler searches for the file in the following directories in this order:
 1. Directories named with the --include_path option.
 2. Directories set with the C7X_C_DIR environment variable.

See [Section 3.5.2.1](#) for information on using the --include_path option. See [Section 3.4.2](#) for more information on input file directories.

3.5.2.1 Adding a Directory to the #include File Search Path (--include_path Option)

The --include_path option names an alternate directory that contains #include files. The --include_path option's short form is -I. The format of the --include_path option is:

--include_path=directory1 [--include_path= directory2 ...]

There is no limit to the number of --include_path options per invocation of the compiler; each --include_path option names one *directory*. In C source, you can use the #include directive without specifying any directory information for the file; instead, you can specify the directory information with the --include_path option.

For example, assume that a file called source.c is in the current directory. The file source.c contains the following directive statement:

```
#include "alt.h"
```

Assume that the complete pathname for alt.h is:

UNIX	/tools/files/alt.h
Windows	c:\tools\files\alt.h

The table below shows how to invoke the compiler. Select the command for your operating system:

Operating System	Enter
UNIX	<code>cl7x --include_path=/tools/files source.c</code>
Windows	<code>cl7x --include_path=c:\tools\files source.c</code>

NOTE: Specifying Path Information in Angle Brackets

If you specify the path information in angle brackets, the compiler applies that information relative to the path information specified with `--include_path` options and the `C7X_C_DIR` environment variable.

For example, if you set up `C7X_C_DIR` with the following command:

```
C7X_C_DIR "/usr/include:/usr/ucb"; export C7X_C_DIR
```

or invoke the compiler with the following command:

```
cl7x --include_path=/usr/include file.c
```

and `file.c` contains this line:

```
#include <sys/proc.h>
```

the result is that the included file is in the following path:

```
/usr/include/sys/proc.h
```

3.5.3 Support for the `#warning` and `#warn` Directives

In strict ANSI mode, the TI preprocessor allows you to use the `#warn` directive to cause the preprocessor to issue a warning and continue preprocessing. The `#warn` directive is equivalent to the `#warning` directive supported by GCC, IAR, and other compilers.

If you use the `--relaxed_ansi` option (on by default), both the `#warn` and `#warning` preprocessor directives are supported.

3.5.4 Generating a Preprocessed Listing File (`--preproc_only` Option)

The `--preproc_only` option allows you to generate a preprocessed version of your source file with an extension of `.pp`. The compiler's preprocessing functions perform the following operations on the source file:

- Each source line ending in a backslash (`\`) is joined with the following line.
- Trigraph sequences are expanded.
- Comments are removed.
- `#include` files are copied into the file.
- Macro definitions are processed.
- All macros are expanded.
- All other preprocessing directives, including `#line` directives and conditional compilation, are expanded.

The `--preproc_only` option is useful when creating a source file for a technical support case or to ask a question about your code. It allows you to reduce the test case to a single source file, because `#include` files are incorporated when the preprocessor runs.

3.5.5 Continuing Compilation After Preprocessing (`--preproc_with_compile` Option)

If you are preprocessing, the preprocessor performs preprocessing only; it does not compile your source code. To override this feature and continue to compile after your source code is preprocessed, use the `--preproc_with_compile` option along with the other preprocessing options. For example, use `--preproc_with_compile` with `--preproc_only` to perform preprocessing, write preprocessed output to a file with a `.pp` extension, and compile your source code.

3.5.6 Generating a Preprocessed Listing File with Comments (`--preproc_with_comment` Option)

The `--preproc_with_comment` option performs all of the preprocessing functions except removing comments and generates a preprocessed version of your source file with a `.pp` extension. Use the `--preproc_with_comment` option instead of the `--preproc_only` option if you want to keep the comments.

3.5.7 Generating Preprocessed Listing with Line-Control Details (`--preproc_with_line` Option)

By default, the preprocessed output file contains no preprocessor directives. To include the `#line` directives, use the `--preproc_with_line` option. The `--preproc_with_line` option performs preprocessing only and writes preprocessed output with line-control information (`#line` directives) to a file named as the source file but with a `.pp` extension.

3.5.8 Generating Preprocessed Output for a Make Utility (`--preproc_dependency` Option)

The `--preproc_dependency` option performs preprocessing only. Instead of writing preprocessed output, it writes a list of dependency lines suitable for input to a standard make utility. If you do not supply an optional filename, the list is written to a file with the same name as the source file but a `.pp` extension.

3.5.9 Generating a List of Files Included with `#include` (`--preproc_includes` Option)

The `--preproc_includes` option performs preprocessing only, but instead of writing preprocessed output, writes a list of files included with the `#include` directive. If you do not supply an optional filename, the list is written to a file with the same name as the source file but with a `.pp` extension.

3.5.10 Generating a List of Macros in a File (`--preproc_macros` Option)

The `--preproc_macros` option generates a list of all predefined and user-defined macros. If you do not supply an optional filename, the list is written to a file with the same name as the source file but with a `.pp` extension.

The output includes only those files directly included by the source file. Predefined macros are listed first and indicated by the comment `/* Predefined */`. User-defined macros are listed next and indicated by the source filename.

3.6 Passing Arguments to `main()`

Some programs pass arguments to `main()` via `argc` and `argv`. This presents special challenges in an embedded program that is not run from the command line. In general, `argc` and `argv` are made available to your program through the `.args` section. There are various ways to populate the contents of this section for use by your program.

To cause the linker to allocate an `.args` section of the appropriate size, use the `--arg_size=size` linker option. This option tells the linker to allocate an uninitialized section named `.args`, which can be used by the loader to pass arguments from the command line of the loader to the program. The `size` is the number of bytes to be allocated. When you use the `--arg_size` option, the linker defines the `__c_args__` symbol to contain the address of the `.args` section.

It is the responsibility of the loader to populate the `.args` section. The loader and the target boot code can use the `.args` section and the `__c_args__` symbol to determine whether and how to pass arguments from the host to the target program. The format of the arguments is an array of pointers to `char` on the target. Due to variations in loaders, it is not specified how the loader determines which arguments to pass to the target.

If you are using Code Composer Studio to run your application, you can use the Scripting Console tool to populate the `.args` section. To open this tool, choose **View > Scripting Console** from the CCS menus. You can use the `loadProg` command to load an object file and its associated symbol table into memory and pass an array of arguments to `main()`. These arguments are automatically written to the allocated `.args` section.

The `loadProg` syntax is as follows, where `file` is an executable file and `args` is an object array of arguments. Use JavaScript to declare the array of arguments before using this command.

```
loadProg(file, args)
```

The .args section is loaded with the following data for non-SYS/BIOS-based executables, where each element in the argv[] array contains a string corresponding to that argument:

```
Int argc;
Char * argv[0];
Char * argv[1];
...
Char * argv[n];
```

For SYS/BIOS-based executables, the elements in the .args section are as follows:

```
Int argc;
Char ** argv; /* points to argv[0] */
Char * envp; /* ignored by loadProg command */
Char * argv[0];
Char * argv[1];
...
Char * argv[n];
```

For more details, see the "[Scripting Console](#)" topic in the TI Processors Wiki.

3.7 Understanding Diagnostic Messages

One of the primary functions of the compiler and linker is to report diagnostic messages for the source program. A diagnostic message indicates that something may be wrong with the program. When the compiler or linker detects a suspect condition, it displays a message in the following format:

"file.c", line n : diagnostic severity : diagnostic message

<i>"file.c"</i>	The name of the file involved
line n :	The line number where the diagnostic applies
<i>diagnostic severity</i>	The diagnostic message severity (severity category descriptions follow)
<i>diagnostic message</i>	The text that describes the problem

Diagnostic messages have a severity, as follows:

- A **fatal error** indicates a problem so severe that the compilation cannot continue. Examples of such problems include command-line errors, internal errors, and missing include files. If multiple source files are being compiled, any source files after the current one will not be compiled.
- An **error** indicates a violation of the syntax or semantic rules of the C/C++ language. Compilation may continue, but object code is not generated.
- A **warning** indicates something that is likely to be a problem, but cannot be proven to be an error. For example, the compiler emits a warning for an unused variable. An unused variable does not affect program execution, but its existence suggests that you might have meant to use it. Compilation continues and object code is generated (if no errors are detected).
- A **remark** is less serious than a warning. It may indicate something that is a potential problem in rare cases, or the remark may be strictly informational. Compilation continues and object code is generated (if no errors are detected). By default, remarks are not issued. Use the --issue_remarks compiler option to enable remarks.

Diagnostic messages are written to standard error with a form like the following example:

```
"test.c", line 5: error: a break statement may only be used within a loop or switch
    break;
    ^
```

By default, the source code line is not printed. Use the --verbose_diagnostics compiler option to display the source line and the error position. The above example makes use of this option.

The message identifies the file and line involved in the diagnostic, and the source line itself (with the position indicated by the ^ character) follows the message. If several diagnostic messages apply to one source line, each diagnostic has the form shown; the text of the source line is displayed several times, with an appropriate position indicated each time.

Long messages are wrapped to additional lines, when necessary.

You can use the `--display_error_number` command-line option to request that the diagnostic's numeric identifier be included in the diagnostic message. When displayed, the diagnostic identifier also indicates whether the diagnostic can have its severity overridden on the command line. If the severity can be overridden, the diagnostic identifier includes the suffix `-D` (for *discretionary*); otherwise, no suffix is present. For example:

```
"Test_name.c", line 7: error #64-D: declaration does not declare anything
    struct {};
    ^
"Test_name.c", line 9: error #77: this declaration has no storage class or type specifier
    xxxxx;
    ^
```

Because errors are determined to be discretionary based on the severity in a specific context, an error can be discretionary in some cases and not in others. All warnings and remarks are discretionary.

For some messages, a list of entities (functions, local variables, source files, etc.) is useful; the entities are listed following the initial error message:

```
"test.c", line 4: error: more than one instance of overloaded function "f"
    matches the argument list:
        function "f(int)"
        function "f(float)"
    argument types are: (double)
    f(1.5);
    ^
```

In some cases, additional context information is provided. Specifically, the context information is useful when the front end issues a diagnostic while doing a template instantiation or while generating a constructor, destructor, or assignment operator function. For example:

```
"test.c", line 7: error: "A::A()" is inaccessible
    B x;
    ^
    detected during implicit generation of "B::B()" at line 7
```

Without the context information, it is difficult to determine to what the error refers.

3.7.1 Controlling Diagnostic Messages

The C/C++ compiler provides diagnostic options to control compiler- and linker-generated diagnostic messages. The diagnostic options must be specified before the `--run_linker` option.

<code>--diag_error=num</code>	Categorizes the diagnostic identified by <i>num</i> as an error. To determine the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate compile. Then use <code>--diag_error=num</code> to recategorize the diagnostic as an error. You can only alter the severity of discretionary diagnostic messages.
<code>--diag_remark=num</code>	Categorizes the diagnostic identified by <i>num</i> as a remark. To determine the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate compile. Then use <code>--diag_remark=num</code> to recategorize the diagnostic as a remark. You can only alter the severity of discretionary diagnostic messages.
<code>--diag_suppress=num</code>	Suppresses the diagnostic identified by <i>num</i> . To determine the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate compile. Then use <code>--diag_suppress=num</code> to suppress the diagnostic. You can only suppress discretionary diagnostic messages.
<code>--diag_warning=num</code>	Categorizes the diagnostic identified by <i>num</i> as a warning. To determine the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate compile. Then use <code>--diag_warning=num</code> to recategorize the diagnostic as a warning. You can only alter the severity of discretionary diagnostic messages.

--display_error_number	Displays a diagnostic's numeric identifier along with its text. Use this option in determining which arguments you need to supply to the diagnostic suppression options (<code>--diag_suppress</code> , <code>--diag_error</code> , <code>--diag_remark</code> , and <code>--diag_warning</code>). This option also indicates whether a diagnostic is discretionary. A discretionary diagnostic is one whose severity can be overridden. A discretionary diagnostic includes the suffix <code>-D</code> ; otherwise, no suffix is present. See Section 3.7 .
--emit_warnings_as_errors	Treats all warnings as errors. This option cannot be used with the <code>--no_warnings</code> option. The <code>--diag_remark</code> option takes precedence over this option. This option takes precedence over the <code>--diag_warning</code> option.
--issue_remarks	Issues remarks (non-serious warnings), which are suppressed by default.
--no_warnings	Suppresses diagnostic warnings (errors are still issued).
--section_sizes={on off}	Generates section size information, including sizes for sections containing executable code and constants, constant or initialized data (global and static variables), and uninitialized data. Section size information is output during the linking phase. This option should be placed on the command line with the compiler options (that is, before the <code>--run_linker</code> or <code>--z</code> option).
--set_error_limit=num	Sets the error limit to <i>num</i> , which can be any decimal value. The compiler abandons compiling after this number of errors. (The default is 100.)
--verbose_diagnostics	Provides verbose diagnostic messages that display the original source with line-wrap and indicate the position of the error in the source line. Note that this command-line option cannot be used within the Code Composer Studio IDE.
--write_diagnostics_file	Produces a diagnostic message information file with the same source file name with an <code>.err</code> extension. (The <code>--write_diagnostics_file</code> option is not supported by the linker.) Note that this command-line option cannot be used within the Code Composer Studio IDE.

3.7.2 How You Can Use Diagnostic Suppression Options

The following example demonstrates how you can control diagnostic messages issued by the compiler. You control the linker diagnostic messages in a similar manner.

```
int one();
int I;
int main()
{
    switch (I){
        case 1;
            return one ();
            break;
        default:
            return 0;
            break;
    }
}
```

If you invoke the compiler with the `--quiet` option, this is the result:

```
"err.c", line 9: warning: statement is unreachable
"err.c", line 12: warning: statement is unreachable
```

Because it is standard programming practice to include `break` statements at the end of each case arm to avoid the fall-through condition, these warnings can be ignored. Using the `--display_error_number` option, you can find out the diagnostic identifier for these warnings. Here is the result:

```
[err.c]
"err.c", line 9: warning #111-D: statement is unreachable
"err.c", line 12: warning #111-D: statement is unreachable
```

Next, you can use the diagnostic identifier of 111 as the argument to the `--diag_remark` option to treat this warning as a remark. This compilation produces no diagnostic messages (because remarks are disabled by default).

NOTE: You can suppress any non-fatal errors, but be careful to make sure you only suppress diagnostic messages that you understand and are known not to affect the correctness of your program.

3.8 Other Messages

Other error messages that are unrelated to the source, such as incorrect command-line syntax or inability to find specified files, are usually fatal. They are identified by the symbol >> preceding the message.

3.9 Generating a Raw Listing File (--gen_preprocessor_listing Option)

The `--gen_preprocessor_listing` option generates a raw listing file that can help you understand how the compiler is preprocessing your source file. Whereas the preprocessed listing file (generated with the `--preproc_only`, `--preproc_with_comment`, `--preproc_with_line`, and `--preproc_dependency` preprocessor options) shows a preprocessed version of your source file, a raw listing file provides a comparison between the original source line and the preprocessed output. The raw listing file has the same name as the corresponding source file with an `.rl` extension.

The raw listing file contains the following information:

- Each original source line
- Transitions into and out of include files
- Diagnostic messages
- Preprocessed source line if nontrivial processing was performed (comment removal is considered trivial; other preprocessing is nontrivial)

Each source line in the raw listing file begins with one of the identifiers listed in [Table 3-30](#).

Table 3-30. Raw Listing File Identifiers

Identifier	Definition
N	Normal line of source
X	Expanded line of source. It appears immediately following the normal line of source if nontrivial preprocessing occurs.
S	Skipped source line (false <code>#if</code> clause)
L	Change in source position, given in the following format: L <i>line number filename key</i> Where <i>line number</i> is the line number in the source file. The <i>key</i> is present only when the change is due to entry/exit of an include file. Possible values of <i>key</i> are: 1 = entry into an include file 2 = exit from an include file

The `--gen_preprocessor_listing` option also includes diagnostic identifiers as defined in [Table 3-31](#).

Table 3-31. Raw Listing File Diagnostic Identifiers

Diagnostic Identifier	Definition
E	Error
F	Fatal
R	Remark
W	Warning

Diagnostic raw listing information is displayed in the following format:

S filename line number column number diagnostic

S	One of the identifiers in Table 3-31 that indicates the severity of the diagnostic
<i>filename</i>	The source file
<i>line number</i>	The line number in the source file
<i>column number</i>	The column number in the source file
<i>diagnostic</i>	The message text for the diagnostic

Diagnostic messages after the end of file are indicated as the last line of the file with a column number of 0. When diagnostic message text requires more than one line, each subsequent line contains the same file, line, and column information but uses a lowercase version of the diagnostic identifier. For more information about diagnostic messages, see [Section 3.7](#).

3.10 Using Inline Function Expansion

When an inline function is called, a copy of the C/C++ source code for the function is inserted at the point of the call. This is known as inline function expansion, commonly called *function inlining* or just *inlining*. Inline function expansion can speed up execution by eliminating function call overhead. This is particularly beneficial for very small functions that are called frequently. Function inlining involves a tradeoff between execution speed and code size, because the code is duplicated at each function call site. Large functions that are called in many places are poor candidates for inlining.

NOTE: Excessive Inlining Can Degrade Performance

Excessive inlining can make the compiler dramatically slower and degrade the performance of generated code.

Function inlining is triggered by the following situations:

- The use of built-in intrinsic operations. Intrinsic operations look like function calls, and are inlined automatically, even though no function body exists.
- Use of the `inline` keyword or the equivalent `__inline` keyword. Functions declared with the `inline` keyword may be inlined by the compiler if you set `--opt_level=0` or greater. The `inline` keyword is a suggestion from the programmer to the compiler. Even if your optimization level is high, inlining is still optional for the compiler. The compiler decides whether to inline a function based on the length of the function, the number of times it is called, your `--opt_for_speed` setting, and any contents of the function that disqualify it from inlining (see [Section 3.10.2](#)). Functions can be inlined at `--opt_level=0` or above if the function body is visible in the same module or if `-pm` is also used and the function is visible in one of the modules being compiled. Functions may be inlined at link time if the file containing the definition and the call site were both compiled with `--opt_level=4`. Functions defined as both static and inline are more likely to be inlined.
- When `--opt_level=3` or greater is used, the compiler may automatically inline eligible functions even if they are not declared as inline functions. The same list of decision factors listed for functions explicitly defined with the `inline` keyword is used. For more about automatic function inlining, see [Section 4.5](#).
- The pragma `FUNC_ALWAYS_INLINE` ([Section 5.9.13](#)) and the equivalent `always_inline` attribute ([Section 5.14.2](#)) force a function to be inlined (where it is legal to do so) unless `--opt_level=off`. That is, the pragma `FUNC_ALWAYS_INLINE` forces function inlining even if the function is not declared as inline and the `--opt_level=0` or `--opt_level=1`.
- The `FORCEINLINE` pragma ([Section 5.9.11](#)) forces functions to be inlined in the annotated statement. That is, it has no effect on those functions in general, only on function calls in a single statement. The `FORCEINLINE_RECURSIVE` pragma forces inlining not only of calls visible in the statement, but also in the inlined bodies of calls from that statement.
- The `--disable_inlining` option prevents any inlining. The pragma `FUNC_CANNOT_INLINE` prevents a function from being inlined. The `NOINLINE` pragma prevents calls within a single statement from being

inlined. (NOINLINE is the inverse of the FORCEINLINE pragma.)

NOTE: Function Inlining Can Greatly Increase Code Size

Function inlining increases code size, especially inlining a function that is called in a number of places. Function inlining is optimal for functions that are called only from a small number of places and for small functions.

The semantics of the `inline` keyword in C code follow the C99 standard. The semantics of the `inline` keyword in C++ code follow the C++ standard.

The `inline` keyword is supported in all C++ modes, in relaxed ANSI mode for all C standards, and in strict ANSI mode for C99. It is disabled in strict ANSI mode for C89, because it is a language extension that could conflict with a strictly conforming program. If you want to define inline functions while in strict ANSI C89 mode, use the alternate keyword `__inline`.

Compiler options that affect inlining are: `--opt_level`, `--auto_inline`, `--remove_hooks_when_inlining`, `--opt_for_speed`, and `--disable_inlining`.

3.10.1 Inlining Intrinsic Operators

The compiler has a number of built-in function-like operations called intrinsics. The implementation of an intrinsic function is handled by the compiler, which substitutes a sequence of instructions for the function call. This is similar to the way inline functions are handled; however, because the compiler knows the code of the intrinsic function, it can perform better optimization.

Intrinsics are inlined whether or not you use the optimizer.

For details about intrinsics, and a list of the intrinsics, see [Section 5.16](#). In addition to those listed, `abs` and `memcpy` are implemented as intrinsics.

3.10.2 Inlining Restrictions

The compiler makes decisions about which functions to inline based on the factors mentioned in [Section 3.10](#). In addition, there are several restrictions that can disqualify a function from being inlined by automatic inlining or inline keyword-based inlining.

The compiler will leave calls as they are if the function:

- Has a different number of arguments than the call site
- Has an argument whose type is incompatible with the corresponding call site argument
- Is not declared inline and returns void but its return value is needed

The compiler will also not inline a call if the function has features that create difficult situations for the compiler:

- Has a variable-length argument list
- Never returns
- Is a recursive or non-leaf function that exceeds the depth limit
- Is not declared inline and contains an `asm()` statement that is not a comment
- Is an interrupt function
- Is the `main()` function
- Is not declared inline and will require too much stack space for local array or structure variables
- Contains a volatile local variable or argument
- Is a C++ function that contains a `catch`
- Is not defined in the current compilation unit and `-O4` optimization is not used

A call in a statement that is annotated with a `NOINLINE` pragma will not be inlined, regardless of other indications (including a `FUNC_ALWAYS_INLINE` pragma or `always_inline` attribute on the called function).

A call in a statement that is annotated with a **FORCEINLINE** pragma will always be inlined, if it is not disqualified for one of the reasons above, even if the called function has a **FUNC_CANNOT_INLINE** pragma or **cannot_inline** attribute.

In other words, a statement-level pragma overrides a function-level pragma or attribute. If both **NOINLINE** and **FORCEINLINE** apply to the same statement, then the one that appears first will be used and the rest will be ignored.

3.10.3 Unguarded Definition-Controlled Inlining

The **inline** keyword specifies that a function is expanded inline at the point at which it is called rather than by using standard calling procedures. The compiler performs inline expansion of functions declared with the **inline** keyword.

You must invoke the optimizer with any **--opt_level** option to turn on definition-controlled inlining. Automatic inlining is also turned on when using **--opt_level=3**.

[Example 3-1](#) shows usage of the **inline** keyword, where the function call is replaced by the code in the called function.

Example 3-1. Using the Inline Keyword

```
inline float volume_sphere(float r)
{
    return 4.0/3.0 * PI * r * r * r;
}
int foo(...)
{
    ...
    volume = volume_sphere(radius);
    ...
}
```

3.10.4 Guarded Inlining and the **_INLINE** Preprocessor Symbol

When declaring a function in a header file as static inline, you must follow additional procedures to avoid a potential code size increase the optimizer is not run.

To prevent a static inline function in a header file from causing an increase in code size when inlining gets turned off, use the following procedure. This allows external-linkage when inlining is turned off; thus, only one function definition will exist throughout the object files.

- Prototype a static inline version of the function. Then, prototype an alternative, nonstatic, externally-linked version of the function. Conditionally preprocess these two prototypes with the **_INLINE** preprocessor symbol, as shown in [Example 3-2](#).
- Create an identical version of the function definition in a **.c** or **.cpp** file, as shown in [Example 3-3](#).

In the following examples there are two definitions of the strlen function. The first ([Example 3-2](#)), in the header file, is an inline definition. This definition is enabled and the prototype is declared as static inline only if `_INLINE` is true (`_INLINE` is automatically defined for you when the optimizer is used).

The second definition (see [Example 3-3](#)) for the library, ensures that the callable version of strlen exists when inlining is disabled. Since this is not an inline function, the `_INLINE` preprocessor symbol is undefined (`#undef`) before `string.h` is included to generate a non-inline version of strlen's prototype.

Example 3-2. Header File `string.h`

```

/*****
/* string.h vx.xx (Excerpted)
/*****
#ifdef _INLINE
#define _IDECL static inline
#else
#define _IDECL extern _CODE_ACCESS
#endif

_IDECL size_t strlen(const char *_string);

#ifdef _INLINE

/*****
/* strlen
/*****
static inline size_t strlen(const char *string)
{
    size_t    n = (size_t)-1;
    const char *s = string - 1;

    do n++; while (*++s);
    return n
}

#endif

```

Example 3-3. Library Definition File

```

/*****
/* strlen
/*****
#undef _INLINE

#include <string.h>
{
_CODE_ACCESS size_t strlen(cont char * string)
    size_t    n = (size_t)-1;
    const char *s = string - 1;

    do n++; while (*++s);
    return n;
}

```

3.11 Using Interlist

The compiler tools include a feature that interlists C/C++ source statements into the assembly language output of the compiler. The interlist feature enables you to inspect the assembly code generated for each C statement. The interlist behaves differently, depending on whether or not the optimizer is used, and depending on which options you specify.

The easiest way to invoke the interlist feature is to use the `--c_src_interlist` option. To compile and run the interlist on a program called `function.c`, enter:

```
cl7x --c_src_interlist function
```

The `--c_src_interlist` option prevents the compiler from deleting the interlisted assembly language output file. The output assembly file, `function.asm`, is assembled normally.

When you invoke the interlist feature without the optimizer, the interlist runs as a separate pass between the code generator and the assembler. It reads both the assembly and C/C++ source files, merges them, and writes the C/C++ statements into the assembly file as comments.

Using the `--c_src_interlist` option can cause performance and/or code size degradation.

For more information about using the interlist feature with the optimizer, see [Section 4.11](#).

Example 3-4. An Interlisted Assembly Language File

The C code for the `foo()` function in `foo.c`:

```
int foo(int a, int b, int c)
{
    int d = a + b;
    int e = d - c;
    return e;
}
```

Is compiled with the following command:

```
cl7x foo.c --c_src_interlist --symdebug:none
```

Generates an assembly file, `foo.asm`, that contains in part:

```

;-----
; 1 | int foo(int a, int b, int c)
;-----
;*****
;* FUNCTION NAME: foo                                     *
;*                                                         *
;*   Regs Modified   : A4,A8,D0,SP                         *
;*   Regs Used       : A4,A5,A6,A8,D0,SP                   *
;*   Local Frame Size : 0 Args + 0 Auto + 8 Save = 8 byte  *
;*****
||foo||:
;*****-----*

                MVC     .S1      RP,A8                    ; [A_S1]
||              STD     .D1      A8,*SP(8)                ; [A_D1]

                ADDD     .D1      SP,0xffffffff8,SP        ; [A_D1]
;-----
; 3 | int d = a + b;
;-----
                ADDW     .D1      A5,A4,D0                 ; [A_D1] |3|
;-----
; 4 | int e = d - c;
;-----
                SUBW     .D1      D0,A6,A4                 ; [A_D1] |4|
;-----
```

Example 3-4. An Interlisted Assembly Language File (continued)

```

; 5 | return e;
;-----
MVC    .S1    A8,RP          ; [A_S1] BARRIER
LDD     .D1    *SP(16),A8     ; [A_D1]

RET     .B1    ; [A_B]
|| ADDD    .D1    SP,0x8,SP     ; [A_D1]

; RETURN OCCURS {RP}          ; []

```

3.12 Generating and Using Performance Advice

The compiler can do better optimization in some cases, if the user aids the compiler by providing additional information in the code. The compiler can prompt you to take certain actions to improve performance, by emitting "Advice". To get this Advice, use the `--advice:performance` option:

```
cl7x --advice:performance -o3 filename.c
```

This Performance Advice is of 3 different types :

- Advice to use correct compiler options
- Advice to prevent software pipeline disqualification
- Advice to improve loop performance

3.13 About the Application Binary Interface

An Application Binary Interface (ABI) defines the low level interface between object files, and between an executable and its execution environment. An ABI allows ABI-compliant object files to be linked together, regardless of their origin, and allows the resulting executable to run on any system that supports that ABI.

The C7000 compiler supports only the Embedded Application Binary Interface (EABI) ABI, which works only with object files that use the ELF object file format and the DWARF debug format.

3.14 Enabling Entry Hook and Exit Hook Functions

An entry hook is a routine that is called upon entry to each function in the program. An exit hook is a routine that is called upon exit of each function. Applications for hooks include debugging, trace, profiling, and stack overflow checking.

Entry and exit hooks are enabled using the following options:

--entry_hook[=<i>name</i>]	Enables entry hooks. If specified, the hook function is called <i>name</i> . Otherwise, the default entry hook function name is <code>__entry_hook</code> .
--entry_parm{=<i>name</i> address none}	Specify the parameters to the hook function. The name parameter specifies that the name of the calling function is passed to the hook function as an argument. In this case the signature for the hook function is: <code>void hook(const char *name);</code> The address parameter specifies that the address of the calling function is passed to the hook function. In this case the signature for the hook function is: <code>void hook(void (*addr)());</code> The none parameter specifies that the hook is called with no parameters. This is the default. In this case the signature for the hook function is: <code>void hook(void);</code>
--exit_hook[=<i>name</i>]	Enables exit hooks. If specified, the hook function is called <i>name</i> . Otherwise, the default exit hook function name is <code>__exit_hook</code> .
--exit_parm{=<i>name</i> address none}	Specify the parameters to the hook function. The name parameter specifies that the name of the calling function is passed to the hook function as an argument. In this case the signature for the hook function is: <code>void hook(const char *name);</code> The address parameter specifies that the address of the calling function is passed to the hook function. In this case the signature for the hook function is: <code>void hook(void (*addr)());</code> The none parameter specifies that the hook is called with no parameters. This is the default. In this case the signature for the hook function is: <code>void hook(void);</code>

The presence of the hook options creates an implicit declaration of the hook function with the given signature. If a declaration or definition of the hook function appears in the compilation unit compiled with the options, it must agree with the signatures listed above.

In C++, the hooks are declared extern "C". Thus you can define them in C without being concerned with name mangling.

Hooks can be declared inline, in which case the compiler tries to inline them using the same criteria as other inline functions.

Entry hooks and exit hooks are independent. You can enable one but not the other, or both. The same function can be used as both the entry and exit hook.

You must take care to avoid recursive calls to hook functions. The hook function should not call any function which itself has hook calls inserted. To help prevent this, hooks are not generated for inline functions, or for the hook functions themselves.

You can use the `--remove_hooks_when_inlining` option to remove entry/exit hooks for functions that are auto-inlined by the optimizer.

See [Section 5.9.28](#) for information about the `NO_HOOKS` pragma.

Optimizing Your Code

The compiler tools can perform many optimizations to improve the execution speed and reduce the size of C and C++ programs by simplifying loops, software pipelining, rearranging statements and expressions, and allocating variables into registers.

This chapter describes how to invoke different levels of optimization and describes which optimizations are performed at each level. This chapter also describes how you can use the Interlist feature when performing optimization and how you can debug optimized code.

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4.1 Invoking Optimization

The C/C++ compiler is able to perform various optimizations. High-level optimizations are performed in the optimizer and low-level, target-specific optimizations occur in the code generator. Use higher optimization levels, such as `--opt_level=2` and `--opt_level=3`, to achieve optimal code.

The easiest way to invoke optimization is to use the compiler program, specifying the `--opt_level=n` option on the compiler command line. You can use `-On` to alias the `--opt_level` option. The *n* denotes the level of optimization (0, 1, 2, 3), which controls the type and degree of optimization.

- **`--opt_level=off` or `-Ooff`** (default if `--opt_level` option not used and `--vectypes=off`)
 - Performs no optimization
- **`--opt_level=0` or `-O0`** (default if `--opt_level` option not used and `--vectypes=on`)
 - Performs control-flow-graph simplification
 - Allocates variables to registers
 - Performs loop rotation
 - Eliminates unused code
 - Simplifies expressions and statements
 - Expands calls to functions declared inline
- **`--opt_level=1` or `-O1`**
 Performs all `--opt_level=0` (`-O0`) optimizations, plus:
 - Performs local copy/constant propagation
 - Removes unused assignments
 - Eliminates local common expressions
- **`--opt_level=2` or `-O2`** (default if `--opt_level` option used with no setting)
 Performs all `--opt_level=1` (`-O1`) optimizations, plus:
 - Performs software pipelining (see [Section 4.7](#))
 - Performs loop optimizations
 - Eliminates global common subexpressions
 - Eliminates global unused assignments
 - Converts array references in loops to incremented pointer form
 - Performs loop unrolling
- **`--opt_level=3` or `-O3`**
 Performs all `--opt_level=2` (`-O2`) optimizations, plus:
 - Removes all functions that are never called
 - Simplifies functions with return values that are never used
 - Inlines calls to small functions
 - Reorders function declarations; the called functions attributes are known when the caller is optimized
 - Propagates arguments into function bodies when all calls pass the same value in the same argument position
 - Identifies file-level variable characteristics
 If you use `--opt_level=3` (`-O3`), see [Section 4.3](#) and [Section 4.4](#) for more information.
- **`--opt_level=4` or `-O4`**
 Performs link-time optimization. See [Section 4.6](#) for details.

For information about how the `--opt_level` option along with the `--opt_for_speed` option and various pragmas affect inlining, see [Section 3.10](#).

By default, debugging is enabled and the default optimization level is unaffected by the generation of debug information.

The levels of optimizations are performed by the stand-alone optimization pass. The code generator performs several additional optimizations, particularly processor-specific optimizations. It does so regardless of whether you invoke the optimizer. These optimizations are always enabled, although they are more effective when the optimizer is used.

Do Not Lower the Optimization Level to Control Code Size

NOTE: To reduce code size, do not lower the `--opt_level` optimization level. Instead, use the `--opt_for_speed` option to control the code size/performance tradeoff. Higher optimization levels (`--opt_level` or `-O`) combined with low `--opt_for_speed` levels (0, 1 or 2) result in smaller code sizes.

4.2 Controlling Code Size Versus Speed

To balance the tradeoff between code size and speed, use the `--opt_for_speed` option. The level of optimization (0-5) controls the type and degree of code size or code speed optimization:

- `--opt_for_speed=0`
Optimizes code size with a *high* risk of worsening or impacting performance.
- `--opt_for_speed=1`
Optimizes code size with a *medium* risk of worsening or impacting performance.
- `--opt_for_speed=2`
Optimizes code size with a *low* risk of worsening or impacting performance.
- `--opt_for_speed=3`
Optimizes code performance/speed with a *low* risk of worsening or impacting code size.
- `--opt_for_speed=4`
Optimizes code performance/speed with a *medium* risk of worsening or impacting code size.
- `--opt_for_speed=5`
Optimizes code performance/speed with a *high* risk of worsening or impacting code size.

If you specify the `--opt_for_speed` option without a parameter, the default setting is `--opt_for_speed=4`. If you do not specify the `--opt_for_speed` option, the default setting is 4

4.3 Performing File-Level Optimization (`--opt_level=3` option)

The `--opt_level=3` option (aliased as the `-O3` option) instructs the compiler to perform file-level optimization. You can use the `--opt_level=3` option alone to perform general file-level optimization, or you can combine it with other options to perform more specific optimizations. The options listed in [Table 4-1](#) work with `--opt_level=3` to perform the indicated optimization:

Table 4-1. Options That You Can Use With `--opt_level=3`

If You ...	Use this Option	See
Want to create an optimization information file	<code>--gen_opt_level=n</code>	Section 4.3.1
Want to compile multiple source files	<code>--program_level_compile</code>	Section 4.4

Do Not Lower the Optimization Level to Control Code Size

NOTE: When trying to reduce code size, do not lower the level of optimization, as you might see an increase in code size. Instead, set the `--opt_for_speed` option to 0, 1, or 2 to reduce the code size.

4.3.1 Creating an Optimization Information File (--gen_opt_info Option)

When you invoke the compiler with the --opt_level=3 option, you can use the --gen_opt_info option to create an optimization information file that you can read. The number following the option denotes the level (0, 1, or 2). The resulting file has an .nfo extension. Use [Table 4-2](#) to select the appropriate level to append to the option.

Table 4-2. Selecting a Level for the --gen_opt_info Option

If you...	Use this option
Do not want to produce an information file, but you used the --gen_opt_level=1 or --gen_opt_level=2 option in a command file or an environment variable. The --gen_opt_level=0 option restores the default behavior of the optimizer.	--gen_opt_info=0
Want to produce an optimization information file	--gen_opt_info=1
Want to produce a verbose optimization information file	--gen_opt_info=2

4.4 Program-Level Optimization (--program_level_compile and --opt_level=3 options)

You can specify program-level optimization by using the --program_level_compile option with the --opt_level=3 option (aliased as -O3). (If you use --opt_level=4 (-O4), the --program_level_compile option cannot be used, because link-time optimization provides the same optimization opportunities as program level optimization.)

With program-level optimization, all of your source files are compiled into one intermediate file called a *module*. The module moves to the optimization and code generation passes of the compiler. Because the compiler can see the entire program, it performs several optimizations that are rarely applied during file-level optimization:

- If a particular argument in a function always has the same value, the compiler replaces the argument with the value and passes the value instead of the argument.
- If a return value of a function is never used, the compiler deletes the return code in the function.
- If a function is not called directly or indirectly by main(), the compiler removes the function.

The --program_level_compile option requires use of --opt_level=3 in order to perform these optimizations.

To see which program-level optimizations the compiler is applying, use the --gen_opt_level=2 option to generate an information file. See [Section 4.3.1](#) for more information.

In Code Composer Studio, when the --program_level_compile option is used, C and C++ files that have the same options are compiled together. However, if any file has a file-specific option that is not selected as a project-wide option, that file is compiled separately. For example, if every C and C++ file in your project has a different set of file-specific options, each is compiled separately, even though program-level optimization has been specified. To compile all C and C++ files together, make sure the files do not have file-specific options. Be aware that compiling C and C++ files together may not be safe if previously you used a file-specific option.

Compiling Files With the --program_level_compile and --keep_asm Options

NOTE: If you compile all files with the --program_level_compile and --keep_asm options, the compiler produces only one .asm file, not one for each corresponding source file.

4.4.1 Controlling Program-Level Optimization (--call_assumptions Option)

You can control program-level optimization, which you invoke with --program_level_compile --opt_level=3, by using the --call_assumptions option. Specifically, the --call_assumptions option indicates if functions in other modules can call a module's external functions or modify a module's external variables. The number following --call_assumptions indicates the level you set for the module that you are allowing to be called or modified. The --opt_level=3 option combines this information with its own file-level analysis to decide whether to treat this module's external function and variable declarations as if they had been declared static. Use [Table 4-3](#) to select the appropriate level to append to the --call_assumptions option.

Table 4-3. Selecting a Level for the --call_assumptions Option

If Your Module ...	Use this Option
Has functions that are called from other modules and global variables that are modified in other modules	--call_assumptions=0
Does not have functions that are called by other modules but has global variables that are modified in other modules	--call_assumptions=1
Does not have functions that are called by other modules or global variables that are modified in other modules	--call_assumptions=2
Has functions that are called from other modules but does not have global variables that are modified in other modules	--call_assumptions=3

In certain circumstances, the compiler reverts to a different --call_assumptions level from the one you specified, or it might disable program-level optimization altogether. [Table 4-4](#) lists the combinations of --call_assumptions levels and conditions that cause the compiler to revert to other --call_assumptions levels.

Table 4-4. Special Considerations When Using the --call_assumptions Option

If --call_assumptions is...	Under these Conditions...	Then the --call_assumptions Level...
Not specified	The --opt_level=3 optimization level was specified	Defaults to --call_assumptions=2
Not specified	The compiler sees calls to outside functions under the --opt_level=3 optimization level	Reverts to --call_assumptions=0
Not specified	Main is not defined	Reverts to --call_assumptions=0
--call_assumptions=1 or --call_assumptions=2	No function has main defined as an entry point, <i>and</i> no interrupt functions are defined, <i>and</i> no functions are identified by the FUNC_EXT_CALLED pragma	Reverts to --call_assumptions=0
--call_assumptions=1 or --call_assumptions=2	A main function is defined, <i>or</i> , an interrupt function is defined, <i>or</i> a function is identified by the FUNC_EXT_CALLED pragma	Remains --call_assumptions=1 or --call_assumptions=2
--call_assumptions=3	Any condition	Remains --call_assumptions=3

In some situations when you use --program_level_compile and --opt_level=3, you *must* use a --call_assumptions option or the FUNC_EXT_CALLED pragma.

4.5 Automatic Inline Expansion (--auto_inline Option)

When optimizing with the --opt_level=3 option (aliased as -O3), the compiler automatically inlines small functions. A command-line option, --auto_inline=size, specifies the size threshold for automatic inlining. This option controls only the inlining of functions that are not explicitly declared as inline.

When the --auto_inline option is not used, the compiler sets the size limit based on the optimization level and the optimization goal (performance versus code size). If the -auto_inline size parameter is set to 0, automatic inline expansion is disabled. If the --auto_inline size parameter is set to a non-zero integer, the compiler automatically inlines any function smaller than size. (This is a change from previous releases, which inlined functions for which the product of the function size and the number of calls to it was less than size. The new scheme is simpler, but will usually lead to more inlining for a given value of size.)

The compiler measures the size of a function in arbitrary units; however the optimizer information file (created with the --gen_opt_info=1 or --gen_opt_info=2 option) reports the size of each function in the same units that the --auto_inline option uses. When --auto_inline is used, the compiler does not attempt to prevent inlining that causes excessive growth in compile time or size; use with care.

When --auto_inline option is not used, the decision to inline a function at a particular call-site is based on an algorithm that attempts to optimize benefit and cost. The compiler inlines eligible functions at call-sites until a limit on size or compilation time is reached.

Inlining behavior varies, depending on which compile-time options are specified:

- The code size limit is smaller when compiling for code size rather than performance. The --auto_inline option overrides this size limit.
- At --opt_level=3, the compiler automatically inlines small functions.

For information about interactions between command-line options, pragmas, and keywords that affect inlining, see [Section 3.10](#).

Some Functions Cannot Be Inlined

NOTE: For a call-site to be considered for inlining, it must be legal to inline the function and inlining must not be disabled in some way. See the inlining restrictions in [Section 3.10.2](#).

Optimization Level 3 and Inlining

NOTE: In order to turn on automatic inlining, you must use the --opt_level=3 option. If you desire the --opt_level=3 optimizations, but not automatic inlining, use --auto_inline=0 with the --opt_level=3 option.

Inlining and Code Size

NOTE: Expanding functions inline increases code size, especially inlining a function that is called in a number of places. Function inlining is optimal for functions that are called only from a small number of places and for small functions. To prevent increases in code size because of inlining, use the --auto_inline=0 option. This option causes the compiler to inline intrinsics only.

4.6 Link-Time Optimization (--opt_level=4 Option)

Link-time optimization is an optimization mode that allows the compiler to have visibility of the entire program. The optimization occurs at link-time instead of compile-time like other optimization levels.

Link-time optimization is invoked by using the --opt_level=4 option. This option must be used in both the compilation and linking steps. At compile time, the compiler embeds an intermediate representation of the file being compiled into the resulting object file. At link-time this representation is extracted from every object file which contains it, and is used to optimize the entire program.

If you use --opt_level=4 (-O4), the --program_level_compile option cannot also be used, because link-time optimization provides the same optimization opportunities as program level optimization ([Section 4.4](#)). Link-time optimization provides the following benefits:

- Each source file can be compiled separately. One issue with program-level compilation is that it requires all source files to be passed to the compiler at one time. This often requires significant modification of a customer's build process. With link-time optimization, all files can be compiled separately.
- Third party object files can participate in optimization. If a third party vendor provides object files that were compiled with the --opt_level=4 option, those files participate in optimization along with user-generated files. This includes object files supplied as part of the TI run-time support. Object files that were not compiled with --opt_level=4 can still be used in a link that is performing link-time optimization. Those files that were not compiled with --opt_level=4 do not participate in the optimization.
- Source files can be compiled with different option sets. With program-level compilation, all source files must be compiled with the same option set. With link-time optimization files can be compiled with different options. If the compiler determines that two options are incompatible, it issues an error.

4.6.1 Option Handling

When performing link-time optimization, source files can be compiled with different options. When possible, the options that were used during compilation are used during link-time optimization. For options which apply at the program level, --auto_inline for instance, the options used to compile the main function are used. If main is not included in link-time optimization, the option set used for the first object file specified on the command line is used. Some options, --opt_for_speed for instance, can affect a wide range of optimizations. For these options, the program-level behavior is derived from main, and the local optimizations are obtained from the original option set.

Some options are incompatible when performing link-time optimization. These are usually options which conflict on the command line as well, but can also be options that cannot be handled during link-time optimization.

4.6.2 Incompatible Types

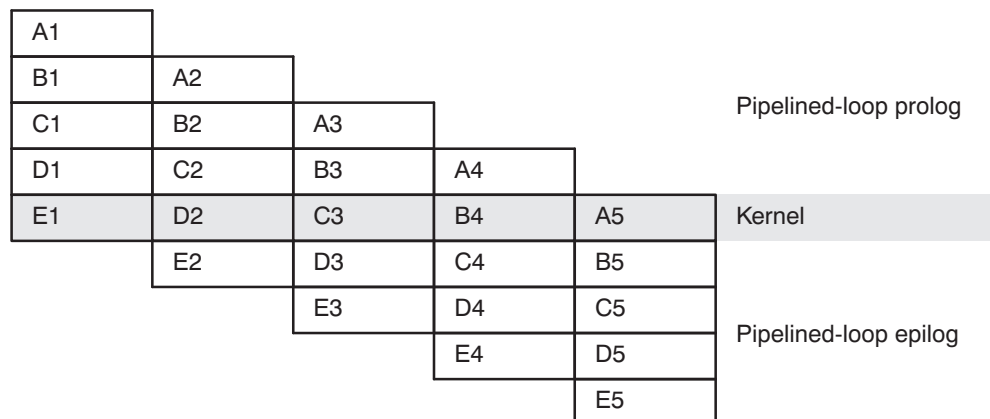
During a normal link, the linker does not check to make sure that each symbol was declared with the same type in different files. This is not necessary during a normal link. When performing link-time optimization, however, the linker must ensure that all symbols are declared with compatible types in different source files. If a symbol is found which has incompatible types, an error is issued. The rules for compatible types are derived from the C and C++ standards.

4.7 Optimizing Software Pipelining

Software pipelining schedules instructions from a loop so that multiple iterations of the loop execute in parallel. At optimization levels --opt_level=2 (or -O2) and --opt_level=3 (or -O3), the compiler usually attempts to software pipeline your loops. The --opt_for_speed option also affects the compiler's decision to attempt to software pipeline loops. In general, code size and performance are better when you use the --opt_level=2 or --opt_level=3 options. (See [Section 4.1](#).)

[Figure 4-1](#) illustrates a software-pipelined loop. The stages of the loop are represented by A, B, C, D, and E. In this figure, a maximum of five iterations of the loop can execute at one time. The shaded area represents the loop *kernel*. In the loop kernel, all five stages execute in parallel. The area above the kernel is known as the *pipelined loop prolog*, and the area below the kernel is known as the *pipelined loop epilog*.

Figure 4-1. Software-Pipelined Loop



4.7.1 Turn Off Software Pipelining (--disable_software_pipeline Option)

At optimization levels --opt_level=2 (or -O2) and -O3, the compiler attempts to software pipeline your loops. You might not want your loops to be software pipelined for debugging reasons. Software-pipelined loops are sometimes difficult to debug because the code is not presented serially.

4.7.2 Software Pipelining Information

The compiler embeds software pipelined loop information in the .asm file. This information is used to optimize C/C++ code.

The software pipelining information appears as a comment in the .asm file before a loop and for the assembly optimizer the information is displayed as the tool is running. [Example 4-1](#) illustrates the information that is generated for each loop.

The --debug_software_pipeline option adds additional information displaying the register usage at each cycle of the loop kernel and displays the instruction ordering of a single iteration of the software pipelined loop.

Example 4-1. Software Pipelining Information

```

;*  SOFTWARE PIPELINE INFORMATION
;*
;*      Loop found in file           : file_name.c
;*      Loop source line            : 68
;*      Loop opening brace source line : 69
;*      Loop closing brace source line : 79
;*      Loop Unroll Multiple         : 2x
;*      Known Minimum Trip Count     : 2
;*      Known Max Trip Count Factor   : 2
;*      Loop Carried Dependency Bound(^) : 2
;*      Unpartitioned Resource Bound  : 3
;*      Partitioned Resource Bound    : 3 (pre-sched)
;*
;*      Searching for software pipeline schedule at ...
;*      ii = 3  Did not find schedule
;*      ii = 4  Schedule found with 3 iterations in parallel
;*
;*      Partitioned Resource Bound(*) : 4 (post-sched)
;*
;*      Constant Extension #0 Used [C0] : 1
;*      Constant Extension #1 Used [C1] : 1
;*
;*      Resource Partition (may include "post-sched" split/spill moves):
;*
;*
;*      A-side  B-side
;*      .L units      2      2
;*      .S units      0      0
;*      .M units      0      0
;*      .N units      0      0
;*      .D units      6      -
;*      .B units      1      -
;*      .C units      -      0
;*      .P units      -      0
;*
;*      .M/.N units    0      0
;*      .L/.S units    2      2
;*      .L/.S/.C units 0      0
;*      .L/.S/.C/.M units 2      2
;*      .L/.S/.C/.M/.D units 3      2
;*
;*      .X cross paths      2      2
;*
;*      Bound(.D1 .D2)      3      -
;*      Bound(.M .N .MN)    0      0
;*      Bound(.L .S .LS)    2      2
;*      Bound(.L .S .C .LS .LSC) 2      2
;*      Bound(.L .S .C .M .LS .LSC .LSCM) 2      2
;*      Bound(.L .S .C .M .D .LS .LSC .LSCM .LSCMD) 3      2
;*
;*      Done
;*
;*      Epilog not entirely removed
;*      Collapsed epilog stages      : 1
;*      Prolog not removed
;*      Collapsed prolog stages      : 0
;*      Max amt of load speculation   : 6 bytes
;*      Minimum safe trip count      : 2 (after unrolling)
;*      Mem bank conflicts/iter(est.) : { min 0.000, est 0.000, max 0.000 }
;*      Mem bank perf. penalty (est.) : 0.0%
;*
;*      Total cycles (est.)          : 8 + trip_cnt * 4
;*-----*

```

The terms defined below appear in the software pipelining information.

- **Loop unroll factor.** The number of times the loop was unrolled specifically to increase performance.
- **Known minimum trip count.** The minimum number of times the loop will be executed.
- **Known maximum trip count.** The maximum number of times the loop will be executed.
- **Known max trip count factor.** Factor that would always evenly divide the loops trip count. This information can be used to possibly unroll the loop.
- **Loop carried dependency bound.** The distance of the largest loop carry path. A loop carry path occurs when one iteration of a loop writes a value that must be read in a future iteration. Instructions that are part of the loop carry bound are marked with the ^ symbol.
- **Initiation interval (ii).** The number of cycles between the initiation of successive iterations of the loop. The smaller the initiation interval, the fewer cycles it takes to execute a loop.
- **Resource bound.** The most used resource constrains the minimum initiation interval. If four instructions require a .D unit, they require at least two cycles to execute (4 instructions/2 parallel .D units).
- **Unpartitioned resource bound.** The best possible resource bound values before the instructions in the loop are partitioned to a particular side.
- **Partitioned resource bound (*).** The resource bound values after the instructions are partitioned.
- **Resource partition.** This table summarizes how the instructions have been partitioned. This information can be used to help assign functional units when writing linear assembly. Each table entry has values for the A-side and B-side functional units. An asterisk is used to mark those entries that determine the resource bound value. The table entries represent the following terms:
 - **.L units** is the total number of instructions that require .L units only.
 - **.S units** is the total number of instructions that require .S units only.
 - **.M units** is the total number of instructions that require .M units only.
 - **.N units** is the total number of instructions that require .N units only.
 - **.D units** is the total number of instructions that require .D units only.
 - **.B units** is the total number of instructions that require the .B unit only.
 - **.C units** is the total number of instructions that require the .C unit only.
 - **.P units** is the total number of instructions that require the .P unit only.
 - **.M/.N units** is the total number of instructions that can use either the .M or .N unit.
 - **.L/.S units** is the total number of instructions that can use either the .L or .S unit.
 - **.L/.S/.C units** is the total number of instructions that can use either the .L, .S, or .C unit.
 - **.L/.S/.C/.M units** is the total number of instructions that can use either the .L, .S, .C, or .M unit.
 - **.L/.S/.C/.M/.D units** is the total number of instructions that can use the .L, .S, .C, .M, or .D unit.
 - **.X cross paths** is the total number of cross paths needed.
- **Bound(.D1 .D2 .D).** The resource bound as determined by the number of instructions that can use the .D1 and .D2 units.
- **Bound(.M .N .MN).** The resource bound as determined by the number of instructions that can use the .M and .N units.
- **Bound(.L .S .LS).** The resource bound as determined by the number of instructions that can use the .L and .S units.
- **Bound(.L .S .C .LS .LSC).** The resource bound as determined by the number of instructions that can use the .L, .S, and .C units.
- **Bound(.L .S .C .M .LS .LSC .LSCM).** The resource bound as determined by the number of instructions that can use the .L, .S, .C, and .M units.
- **Bound(.L .S .C .M .D .LS .LSC .LSCM .LSCMD).** The resource bound as determined by the number of instructions that can use the .L, .S, .C, .M, and .D units.
- **Max amt of load speculation.** The maximum number of bytes that loads in this loop will speculate beyond the end of an array (behind or ahead). No user action is required here as the compiler will use load instructions that are safe to speculate.

4.7.2.1 Loop Disqualified for Software Pipelining Messages

The following messages appear if the loop is completely disqualified for software pipelining:

- **Bad loop structure.** This error is very rare and can stem from the following:
 - An asm statement inserted in the C code inner loop
 - Complex control flow such as GOTO statements and breaks
- **Loop contains a call.** Sometimes the compiler may not be able to inline a function call that is in a loop. Because the compiler could not inline the function call, the loop could not be software pipelined.
- **Too many instructions.** There are too many instructions in the loop to software pipeline.
- **Software pipelining disabled.** Software pipelining has been disabled by a command-line option, such as when using the `--disable_software_pipeline` option, not using the `--opt_level=2` (or `-O2`) or `--opt_level=3` (or `-O3`) option, or using the `--opt_for_speed=0` or `--opt_for_speed=1` option.
- **Uninitialized trip counter.** The trip counter may not have been set to an initial value.
- **Suppressed to prevent code expansion.** Software pipelining may be suppressed because of the `--opt_for_speed=2` option. When the `--opt_for_speed=2` option is used, software pipelining is disabled in less promising cases to reduce code size. To enable pipelining, use `--opt_for_speed=4` or `--opt_for_speed=5`.
- **Cannot identify trip counter.** The loop trip counter could not be identified or was used incorrectly in the loop body.

4.7.2.2 Pipeline Failure Messages

The following messages can appear when the compiler or assembly optimizer is processing a software pipeline and it fails:

- **Address increment is too large.** An address register's offset must be adjusted because the offset is out of range of the offset addressing mode. You must minimize address register offsets.
- **Cannot allocate machine registers.** A software pipeline schedule was found, but it cannot allocate machine registers for the schedule. Simplification of the loop may help.
The register usage for the schedule found at the given ii is displayed.
 - **Regs Live Always.** The number of values that must be assigned a register for the duration of the whole loop body. This means that these values must always be allocated registers for any given schedule found for the loop.
 - **Max Regs Live.** Maximum number of values live at any given cycle in the loop that must be allocated to a register. This indicates the maximum number of registers required by the schedule found.
 - **Max Cond Regs Live.** Maximum number of registers live at any given cycle in the loop kernel that must be allocated to a condition register.
- **Cycle count too high. Never profitable.** With the schedule that the compiler found for the loop, it is more efficient to use a non-software-pipelined version.
- **Did not find schedule.** The compiler was unable to find a schedule for the software pipeline at the given ii (iteration interval). You should simplify the loop and/or eliminate loop carried dependencies.
- **Iterations in parallel > minimum or maximum trip count.** A software pipeline schedule was found, but the schedule has more iterations in parallel than the minimum or maximum loop trip count. You must enable redundant loops or communicate the trip information.
- **Register is live too long.** A register must have a value that exists (is live) for more than ii cycles. The compiler tries to insert move instructions to split register lifetimes that are longer than ii cycles, but may not always be successful.
- **Too many predicates live on one side.** The C7000 has predicate, or conditional, registers available for use with conditional instructions. There are six predicate registers. There are three on the A side and three on the B side. Sometimes the particular partition and schedule combination requires more than these available registers.
- **Schedule found with N iterations in parallel.** (This is not a failure message.) A software pipeline schedule was found with N iterations executing in parallel.

- **Trip variable used in loop - Cannot adjust trip count.** The loop trip counter has a use in the loop other than as a loop trip counter.
- **Unsafe schedule for irregular loop.** "Irregular" loops are non-downcounting loops with a known number of iterations, such as a while loop. Irregular loops may require transformations that execute instructions more times than called for by the loop. This error means the compiler was unable to find a schedule with instructions that are safe to over-execute, are guarded with a predicate, or have their effects undone after the loop. Try to rewrite the loop as a down-counting loop.

4.7.2.3 Register Usage Table Generated by the --debug_software_pipeline Option

The --debug_software_pipeline option places additional software pipeline feedback in the generated assembly file. This information includes a single scheduled iteration view of the software pipelined loop.

If software pipelining succeeds for a given loop, and the --debug_software_pipeline option was used during the compilation process, a register usage table is added to the software pipelining information comment block in the generated assembly code.

The numbers on each row represent the cycle number within the loop kernel.

Each column represents one register on the C7000. The registers are labeled in the first three rows of the register usage table and should be read columnwise.

An * in a table entry indicates that the register indicated by the column header is live on the kernel execute packet indicated by the cycle number labeling each row.

An example of the register usage table follows:

```

;*      Register Usage Tables:
;*
;*      +-----+-----+-----+-----+-----+-----+
;*      |               ASIDE               |               BSIDE               |
;*      +-----+-----+-----+-----+-----+-----+
;*      | "Axx" | "ALx" | "AMx" | "VBxx" | "VBLx" | "VBMx" |
;*      +-----+-----+-----+-----+-----+-----+
;*      | 0000000000111111 | 00000000 | 00000000 | 0000000000111111 | 00000000 | 00000000 |
;*      | 0123456789012345 | 01234567 | 01234567 | 0123456789012345 | 01234567 | 01234567 |
;*      +-----+-----+-----+-----+-----+-----+
;*      0: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      1: | *   *   *   | **  | *   *   | *   | *   *   | *   *   *   *   |
;*      2: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      3: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      4: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      5: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      6: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      7: | *   *   *   | *   | *   *   | *   | *   *   | *   *   *   *   |
;*      +-----+-----+-----+-----+-----+-----+
;*
;*      +-----+-----+-----+
;*      | "Dxx" | | "Px" | | "CUCRx" |
;*      +-----+-----+-----+
;*      | 0000000000111111 | | 00000000 | | 0000 |
;*      | 0123456789012345 | | 01234567 | | 0123 |
;*      +-----+-----+-----+
;*      0: | *   | | |
;*      1: | *   | | |
;*      2: | *   | | |
;*      3: | *   | | |
;*      4: | *   | | |
;*      5: | *   | | |
;*      6: | *   | | |
;*      7: | *   | | |
;*      +-----+-----+-----+

```

This example shows that on cycle 0 (the first execute packet) of the loop kernel, registers A0, A3, A4, A5, A6, AL0, AM0, AM1, AM2, VB5, VBL0, VBL1, VBL2, VBM0, VBM1, VBM2, VBM3, VBM4, VBM5, VBM6, and D0 are all live during this cycle.

4.7.3 Collapsing Prologs and Epilogs for Improved Performance and Code Size

When a loop is software pipelined, a prolog and epilog are generally required. The prolog is used to pipe up the loop and epilog is used to pipe down the loop.

In general, a loop must execute a minimum number of iterations before the software-pipelined version can be safely executed. If the minimum known trip count is too small, either a redundant loop is added or software pipelining is disabled. Collapsing the prolog and epilog of a loop can reduce the minimum trip count necessary to safely execute the pipelined loop.

Collapsing can also substantially reduce code size. Some of this code size growth is due to the redundant loop. The remainder is due to the prolog and epilog.

The prolog and epilog of a software-pipelined loop consists of up to $p-1$ stages of length ii , where p is the number of iterations that are executed in parallel during the steady state and ii is the cycle time for the pipelined loop body. During prolog and epilog collapsing the compiler tries to collapse as many stages as possible. However, over-collapsing can have a negative performance impact. Thus, by default, the compiler attempts to collapse as many stages as possible without sacrificing performance. When the `--opt_for_speed=2` or `--opt_for_speed=1` options are invoked, the compiler increasingly favors code size over performance.

4.7.3.1 Speculative Execution

Collapsing of the prolog and epilog can usually reduce the minimum safe trip count. If the minimum known trip count is less than the minimum safe trip count, a redundant loop is required. Otherwise, pipelining must be suppressed. Both these values can be found in the comment block preceding a software pipelined loop.

```

; *           Known Minimum Trip Count       : 1
....
; *           Minimum safe trip count       : 7

```

4.8 Redundant Loops

A loop iterates some number of times before the loop terminates. The number of iterations is called the *trip count*. The variable that counts iterations is the *trip counter*. When the trip counter reaches a limit equal to the trip count, the loop terminates. The Code Generation Tools use the trip count to determine whether or not a loop can be pipelined. The structure of a software pipelined loop requires the execution of a minimum number of loop iterations (a minimum trip count) in order to fill or prime the pipeline.

The minimum trip count for a software pipelined loop is set by the number of iterations executing in parallel. In [Figure 4-1](#), the minimum trip count is five. In the following example A, B, and C are instructions in a software pipeline, so the minimum trip count for this single-cycle software pipelined loop is three.

```

A
B   A
C   B   A   ← Three iterations in parallel = minimum trip count
      C   B
          C

```

When the Code Generation Tools cannot determine the trip count for a loop, then by default two loops and control logic are generated. The first loop is not pipelined, and it executes if the run-time trip count is less than the loop's minimum safe trip count. The second loop is the software pipelined loop, and it executes when the run-time trip count is greater than or equal to the minimum trip count. At any given time, one of the loops is a *redundant loop*. For example:

```

foo(N) /* N is the trip count */
{
    for (I=0; I < N; I++) /* I is the trip counter */
}

```

After finding a software pipeline for the loop, the compiler transforms `foo()` as below, assuming the minimum trip count for the loop is 3. Two versions of the loop would be generated and the following comparison would be used to determine which version should be executed:

```
foo(N)
{
    if (N < 3)
    {
        for (I=0; I < N; I++)    /* Unpipelined version */
        {
        }
    }
    else
    {
        for (I=0; I < N; I++)    /* Pipelined version    */
        {
        }
    }
}
foo(50); /* Execute software pipelined loop          */
foo(2);  /* Execute loop (unpipelined)*/
```

You may be able to help the compiler avoid producing redundant loops with the use of `--program_level_compile --opt_level=3` (see [Section 4.4](#)) or the use of the `MUST_ITERATE` pragma (see [Section 5.9.24](#)).

4.9 Indicating Whether Certain Aliasing Techniques Are Used

Aliasing occurs when you can access a single object in more than one way, such as when two pointers point to the same object or when a pointer points to a named object. Aliasing can disrupt optimization, because any indirect reference can refer to another object. The compiler analyzes the code to determine where aliasing can and cannot occur, then optimizes as much as possible while preserving the correctness of the program. The compiler behaves conservatively.

The following sections describe some aliasing techniques that may be used in your code. These techniques are valid according to the ISO C standard and are accepted by the C7000 compiler; however, they prevent the optimizer from fully optimizing your code.

4.9.1 Use the `--aliased_variables` Option When Certain Aliases are Used

The compiler, when invoked with optimization, assumes that if the address of a local variable is passed to a function, the function changes the local variable by writing through the pointer. This makes the local variable's address unavailable for use elsewhere after returning. For example, the called function cannot assign the local variable's address to a global variable or return the local variable's address.

If your code uses aliases in this way and uses optimization, you must use the `--aliased_variables` option. For example, suppose your code is similar to the following, in which the address of the local variable `x` is passed to the function `f()`, which aliases `glob_ptr` to that address and returns the address. If this example were to be compiled with optimization, the `--aliased_variables` option would be needed in order for the function `f()` to be able to successfully perform its actions.

```
int *glob_ptr;

g()
{
    int x = 1;
    int *p = f(&x);

    *p      = 5;    /* p aliases x */
    *glob_ptr = 10; /* glob_ptr aliases x */

    h(x);
}

int *f(int *arg)
{
    glob_ptr = arg;
    return arg;
}
```

4.10 Prevent Reordering of Associative Floating-Point Operations

The compiler freely reorders associative floating-point operations. If you do not wish to have the compiler reorder associative floating point operations, use the `--fp_not_associative` option. Specifying the `--fp_not_associative` option may decrease performance.

4.11 Using the Interlist Feature With Optimization

You control the output of the interlist feature when compiling with optimization (the `--opt_level=n` or `-On` option) with the `--optimizer_interlist` and `--c_src_interlist` options.

- The `--optimizer_interlist` option interlists compiler comments with assembly source statements.
- The `--c_src_interlist` and `--optimizer_interlist` options together interlist the compiler comments and the original C/C++ source with the assembly code.

When you use the `--optimizer_interlist` option with optimization, the interlist feature does *not* run as a separate pass. Instead, the compiler inserts comments into the code, indicating how the compiler has rearranged and optimized the code. These comments appear in the assembly language file as comments starting with `;**`. The C/C++ source code is not interlisted, unless you use the `--c_src_interlist` option also.

The interlist feature can affect optimized code because it might prevent some optimization from crossing C/C++ statement boundaries. Optimization makes normal source interlisting impractical, because the compiler extensively rearranges your program. Therefore, when you use the `--optimizer_interlist` option, the compiler writes reconstructed C/C++ statements.

Impact on Performance and Code Size

NOTE: The `--c_src_interlist` option can have a negative effect on performance and code size.

When you use the `--c_src_interlist` and `--optimizer_interlist` options with optimization, the compiler inserts its comments and the interlist feature runs before the assembler, merging the original C/C++ source into the assembly file.

4.12 Debugging and Profiling Optimized Code

The compiler generates symbolic debugging information by default at all optimization levels. Generating debug information does not affect compiler optimization or generated code. However, higher levels of optimization negatively impact the debugging experience due to the code transformations that are done. For the best debugging experience use `--opt_level=off`.

The default optimization level is off.

Debug information increases the size of object files, but it does not affect the size of code or data on the target. If object file size is a concern and debugging is not needed, use `--symdebug:none` to disable the generation of debug information.

If you are having trouble debugging loops in your code, you can use the `--disable_software_pipeline` option to turn off software pipelining. See [Section 4.7.1](#) for more information.

4.12.1 Profiling Optimized Code

To profile optimized code, use optimization (`--opt_level=0` through `--opt_level=3`).

4.13 What Kind of Optimization Is Being Performed?

The C7000 C/C++ compiler uses a variety of optimization techniques to improve the execution speed of your C/C++ programs and to reduce their size.

Following are some of the optimizations performed by the compiler:

Optimization	See
Cost-based register allocation	Section 4.13.1
Alias disambiguation	Section 4.13.1
Branch optimizations and control-flow simplification	Section 4.13.3
Data flow optimizations <ul style="list-style-type: none"> • Copy propagation • Common subexpression elimination • Redundant assignment elimination 	Section 4.13.4
Expression simplification	Section 4.13.5
Inline expansion of functions	Section 4.13.6
Function Symbol Aliasing	Section 4.13.7
Induction variable optimizations and strength reduction	Section 4.13.8
Loop-invariant code motion	Section 4.13.9
Loop rotation	Section 4.13.10
Instruction scheduling	Section 4.13.13

C7000-Specific Optimization	See
Register variables	Section 4.13.14
Register tracking/targeting	Section 4.13.15
Software pipelining	Section 4.13.16

4.13.1 Cost-Based Register Allocation

The compiler, when optimization is enabled, allocates registers to user variables and compiler temporary values according to their type, use, and frequency. Variables used within loops are weighted to have priority over others, and those variables whose uses do not overlap can be allocated to the same register.

Induction variable elimination and loop test replacement allow the compiler to recognize the loop as a simple counting loop and software pipeline, unroll or eliminate the loop. Strength reduction turns the array references into efficient pointer references with autoincrements.

4.13.2 Alias Disambiguation

C and C++ programs generally use many pointer variables. Frequently, compilers are unable to determine whether or not two or more l values (lowercase L: symbols, pointer references, or structure references) refer to the same memory location. This aliasing of memory locations often prevents the compiler from retaining values in registers because it cannot be sure that the register and memory continue to hold the same values over time.

Alias disambiguation is a technique that determines when two pointer expressions cannot point to the same location, allowing the compiler to freely optimize such expressions.

4.13.3 Branch Optimizations and Control-Flow Simplification

The compiler analyzes the branching behavior of a program and rearranges the linear sequences of operations (basic blocks) to remove branches or redundant conditions. Unreachable code is deleted, branches to branches are bypassed, and conditional branches over unconditional branches are simplified to a single conditional branch.

When the value of a condition is determined at compile time (through copy propagation or other data flow analysis), the compiler can delete a conditional branch. Switch case lists are analyzed in the same way as conditional branches and are sometimes eliminated entirely. Some simple control flow constructs are reduced to conditional instructions, totally eliminating the need for branches.

4.13.4 Data Flow Optimizations

Collectively, the following data flow optimizations replace expressions with less costly ones, detect and remove unnecessary assignments, and avoid operations that produce values that are already computed. The compiler with optimization enabled performs these data flow optimizations both locally (within basic blocks) and globally (across entire functions).

- **Copy propagation.** Following an assignment to a variable, the compiler replaces references to the variable with its value. The value can be another variable, a constant, or a common subexpression. This can result in increased opportunities for constant folding, common subexpression elimination, or even total elimination of the variable.
- **Common subexpression elimination.** When two or more expressions produce the same value, the compiler computes the value once, saves it, and reuses it.
- **Redundant assignment elimination.** Often, copy propagation and common subexpression elimination optimizations result in unnecessary assignments to variables (variables with no subsequent reference before another assignment or before the end of the function). The compiler removes these dead assignments.

4.13.5 Expression Simplification

For optimal evaluation, the compiler simplifies expressions into equivalent forms, requiring fewer instructions or registers. Operations between constants are folded into single constants. For example, $a = (b + 4) - (c + 1)$ becomes $a = b - c + 3$.

4.13.6 Inline Expansion of Functions

The compiler replaces calls to small functions with inline code, saving the overhead associated with a function call as well as providing increased opportunities to apply other optimizations.

For information about interactions between command-line options, pragmas, and keywords that affect inlining, see [Section 3.10](#).

4.13.7 Function Symbol Aliasing

The compiler recognizes a function whose definition contains only a call to another function. If the two functions have the same signature (same return value and same number of parameters with the same type, in the same order), then the compiler can make the calling function an alias of the called function.

For example, consider the following:

```
int bbb(int arg1, char *arg2);

int aaa(int n, char *str)
{
    return bbb(n, str);
}
```

For this example, the compiler makes `aaa` an alias of `bbb`, so that at link time all calls to function `aaa` should be redirected to `bbb`. If the linker can successfully redirect all references to `aaa`, then the body of function `aaa` can be removed and the symbol `aaa` is defined at the same address as `bbb`.

For information about using the GCC function attribute syntax to declare function aliases, see [Section 5.14.2](#).

4.13.8 Induction Variables and Strength Reduction

Induction variables are variables whose value within a loop is directly related to the number of executions of the loop. Array indices and control variables for loops are often induction variables.

Strength reduction is the process of replacing inefficient expressions involving induction variables with more efficient expressions. For example, code that indexes into a sequence of array elements is replaced with code that increments a pointer through the array.

Induction variable analysis and strength reduction together often remove all references to your loop-control variable, allowing its elimination.

4.13.9 Loop-Invariant Code Motion

This optimization identifies expressions within loops that always compute to the same value. The computation is moved in front of the loop, and each occurrence of the expression in the loop is replaced by a reference to the precomputed value.

4.13.10 Loop Rotation

The compiler evaluates loop conditionals at the bottom of loops, saving an extra branch out of the loop. In many cases, the initial entry conditional check and the branch are optimized out.

4.13.11 Loop Collapsing and Loop Coalescing

Under certain circumstances, the compiler combines a loop nest (for example, a "for" loop inside a "for" loop) when the compiler thinks this will lead to faster performance.

4.13.12 Vectorization (SIMD)

The compiler may convert a loop such that it uses instructions that operate on more than one piece of data at a time, increasing the performance dramatically.

4.13.13 Instruction Scheduling

The compiler performs instruction scheduling, which is the rearranging of machine instructions in such a way that improves performance while maintaining the semantics of the original order. Instruction scheduling is used to improve instruction parallelism and hide latencies. It can also be used to reduce code size.

4.13.14 Register Variables

The compiler helps maximize the use of registers for storing local variables, parameters, and temporary values. Accessing variables stored in registers is more efficient than accessing variables in memory. Register variables are particularly effective for pointers.

4.13.15 Register Tracking/Targeting

The compiler tracks the contents of registers to avoid reloading values if they are used again soon. Variables, constants, and structure references such as (a.b) are tracked through straight-line code. Register targeting also computes expressions directly into specific registers when required, as in the case of assigning to register variables or returning values from functions.

4.13.16 Software Pipelining

Software pipelining is a technique used to schedule from a loop so that multiple iterations of a loop execute in parallel. See [Section 4.7](#) for more information.

4.14 Streaming Engine and Stream Address Generator

The Streaming Engine (SE) and Stream Address Generator (SA) intrinsic interface is defined in `c7x_strm.h`, which is included as part of the C7000 runtime support.

As described in the subsections that follow, basic utilization of the SE and SA relies on a common parameter template that must be pre-configured before the SE or SA can be opened and used. Additionally, there is a unique set of flags that must be configured.

For both the SE and the SA, the vector length is configured as part of the setup flags. The advancement mechanism is based on this as well as the dimensions and counts that are configured as part of the parameter template.

For the SE, the element size is also configured directly into the setup flags and is then used in the SE address calculation. However, the SA does not work this way. For the SA, the advancement mechanism is abstracted based on its configuration, but the actual hardware offset is calculated and scaled based on the element size, which is derived not from the flags but from the load or store instruction being used with the SA. This allows the same SA to be effectively used by different load or store instructions that have different element sizes.

4.14.1 Parameter Template Configuration

A parameter template is a variable of the type `__STRM_TEMPLATE`, which is effectively simply a vector of 64-bit values. It is the same for both the SE and SA. The configuration of the parameter template, which consists of iteration counters (ICNT) and dimension sizes (DIM) for up to six levels of nesting, is accomplished using the following API:

- Set Iteration Counter for Level 0 (Dimension is always implied to be the element width)
`__STRM_TEMPLATE __set_ICNT0 (__STRM_TEMPLATE p, uint32_t ICNT);`
- Set Iteration Counter and Dimension Size for Level 1
`__STRM_TEMPLATE __set_ICNT1_DIM1 (__STRM_TEMPLATE p, uint32_t ICNT, int32_t DIM);`
- Set Iteration Counter and Dimension Size for Level 2
`__STRM_TEMPLATE __set_ICNT2_DIM2 (__STRM_TEMPLATE p, uint32_t ICNT, int32_t DIM);`
- Set Iteration Counter and Dimension Size for Level 3
`__STRM_TEMPLATE __set_ICNT3_DIM3 (__STRM_TEMPLATE p, uint32_t ICNT, int32_t DIM);`
- Set Iteration Counter and Dimension Size for Level 4
`__STRM_TEMPLATE __set_ICNT4_DIM4 (__STRM_TEMPLATE p, uint32_t ICNT, int32_t DIM);`
- Set Iteration Counter and Dimension Size for Level 5
`__STRM_TEMPLATE __set_ICNT5_DIM5 (__STRM_TEMPLATE p, uint32_t ICNT, int32_t DIM);`
- Set DECDIM1 width
`__STRM_TEMPLATE __set_DECDIM1_WIDTH (__STRM_TEMPLATE p, uint32_t DECDIM_WIDTH);`
- Set DECDIM2 width
`__STRM_TEMPLATE __set_DECDIM2_WIDTH (__STRM_TEMPLATE p, uint32_t DECDIM_WIDTH);`
- Set LEZR Count
`__STRM_TEMPLATE __set_LEZR_CNT (__STRM_TEMPLATE p, uint8_t LEZR_CNT);`

For example, to configure a parameter vector for an SE or SA with four dimensions:

```
// Setup Template Vector Based on Settings and Open the Stream
// Based on Iteration Counters and Dimensions (in Terms of # of Elms)
__STRM_TEMPLATE params = (0);
params                = __set_ICNT0(params, 4);
params                = __set_ICNT1_DIM1(params, 2, 4);
params                = __set_ICNT2_DIM2(params, 2, 8);
params                = __set_ICNT3_DIM3(params, 4, -16);
```

The counters and dimension sizes for the unused dimensions do not need to be pre-configured as long as the `DIMFMT` flag is set to the proper format flag (see next section). This tells the hardware to ignore the (uninitialized) data in these unused fields.

4.14.2 Functional Flag Configuration

In addition to the iteration counters and dimension sizes, the functional flags have to also be configured by way of a C struct, named `__SE_FLAGS` and `__SA_FLAGS` for the SE and SA, respectively. These flags vary between the SE and SA and are documented in `c7x_strm.h`.

- `__SE_FLAGS`

```
typedef struct __SE_FLAGS_t
{
    uint8_t ELETTYPE;
    uint8_t TRANSPPOSE;
    uint8_t PROMOTE;
    uint8_t GRPDUP;
    uint8_t VECLLEN;
    uint8_t ELDUP;
    uint8_t DECIM;
    uint8_t DIR;
    uint8_t DIMFMT;
    uint8_t DECDIM1;
    uint8_t DECDIM2;
    uint8_t LEZR;
} __SE_FLAGS;
```

- `__SA_FLAGS`

```
typedef struct __SA_FLAGS_t
{
    uint8_t VECLLEN;
    uint8_t DIMFMT;
    uint8_t DECDIM1;
    uint8_t DECDIM1SD;
    uint8_t DECDIM2;
    uint8_t DECDIM2SD;
} __SA_FLAGS;
```

Each struct member must be set to a value, even if it is not used.

To make default flag initialization easier, the following APIs are provided to return each functional flags struct with all of the fields pre-initialized with default values:

- Default Streaming Engine Flags:

```
__SE_FLAGS __SE_FLAGS_default();
```

- Default Circular Streaming Engine Flags:

```
__SE_CIRC_FLAGS __SE_CIRC_FLAGS_default();
```

- Default Stream Address Generator Flags:

```
__SA_FLAGS __SA_FLAGS_default();
```

Most importantly, the `DIMFMT` flag and `VECLLEN` flag must be set to valid values for the SE or SA to be function correctly. Once set, the flags are then configured into the parameter vector using the following API:

- Set Streaming Engine Flags:

```
__STRM_TEMPLATE __set_SE_FLAGS(__STRM_TEMPLATE param, __SE_FLAGS *pFlags,
                                __SE_CIRC_FLAGS *pCFlags);
```

- Set Stream Address Generator Flags:

```
__STRM_TEMPLATE __set_SA_FLAGS(__STRM_TEMPLATE param, __SA_FLAGS *pFlags);
```

An example of a flag configuration for an SE with four dimensions:

```
__STRM_TEMPLATE params = (0); // SE PARAMETER VECTOR
__SE_FLAGS      flags;      // SE FLAGS STRUCTURE

flags.DIMFMT    = __SE_DIMFMT_4D;

flags.DIR       = __SE_DIR_INC;
flags.TRANSPOSE = __SE_TRANSPOSE_OFF;
flags.DECIM     = __SE_DECIM_OFF;

flags.ELETYPE   = __SE_ELETYPE_32BIT;
flags.PROMOTE   = __SE_PROMOTE_OFF;
flags.GRPDUP    = __SE_GRPDUP_OFF;
flags.ELDUP     = __SE_ELEDUP_OFF;
flags.DECDIM1   = __SE_DECDIM0;
flags.DECDIM2   = __SE_DECDIM0;
flags.LEZR      = __SE_LEZR_OFF;

flags.VECLLEN   = __SE_VECLLEN_4ELEMS; // 4 ELEMENTS

params          = __set_SE_FLAGS(params, &flags, NULL);
```

An example of a flag configuration for an SE with four dimensions using the SE flags default initialization routine:

```
__STRM_TEMPLATE params = (0);
__SE_FLAGS      flags = __SE_FLAGS_default();

flags.DIMFMT    = __SE_DIMFMT_4D;
flags.ELETYPE   = __SE_ELETYPE_32BIT;
flags.VECLLEN   = __SE_VECLLEN_4ELEMS;

params          = __set_SE_FLAGS(params, &flags, NULL);
```

An example of a flag configuration for an SA with four dimensions:

```
__STRM_TEMPLATE params = (0); // SA PARAMETER VECTOR
__SA_FLAGS      flags;      // SA FLAGS STRUCTURE

flags.DIMFMT    = __SA_DIMFMT_4D;
flags.DECDIM1   = __SA_DECDIM0;
flags.DECDIM2   = __SA_DECDIM0;
flags.VECLLEN   = __SA_VECLLEN_4ELEMS; // 4 ELEMENTS

params          = __set_SA_FLAGS(params, &flags);
```

4.14.3 Using the Streaming Engine

Once the streaming engine has been configured, a corresponding stream can be opened and used. The following API is provided to facilitate this, which take the parameter template as well as the starting memory address from which the hardware should fetch the stream data:

- Open Streaming Engine 0: `__SE0_OPEN(void *addr, __STRM_TEMPLATE param);`
- Open Streaming Engine 1: `__SE1_OPEN(void *addr, __STRM_TEMPLATE param);`

The streaming engines are accessed using the following API, which will return a vector of data according to the given type, which is used to cast the type of the data being fetched by the stream:

- Read Streaming Engine 0 (and advance): `__SE0(type), __SE0ADV(type)`
- Read Streaming Engine 1 (and advance): `__SE1(type), __SE1ADV(type)`

Streaming Engines are closed using the corresponding close API:

- Close Streaming Engine 0: `__SE0_CLOSE();`
- Close Streaming Engine 1: `__SE1_CLOSE();`

Example for a stream with four dimensions:

```
// OPEN STREAMING ENGINE 1 AT startaddr WITH PARAMETER TEMPLATE params
__SE1_OPEN((void*)startaddr, params);

// READ THE STREAM AND ADVANCE THE COUNTERS
for (I0 = 0; I0 < 8; I0++)
{
    uint8 Vout;
    Vout.lo = __SE1ADV(uint4);
    Vout.hi = __SE1ADV(uint4);

    Vresult += Vout;
}

// CLOSE THE STREAM
__SE1_CLOSE();
```

NOTE: Streaming from the provided memory address implies a contract in which the program promises never or modify the data in any area of memory that can be reached by that streaming engine during its lifetime.

4.14.4 Using the Streaming Engine with Hard-Coded Intrinsic Operands

A small handful of C7000 instructions, specifically some VFIR and VMATMPY instructions, can *only* accept streaming engine operands because they are hard-wired to the SE. This includes accesses of a single SE (e.g. SE0) as well as accesses of a pair of SE streams together (e.g. SE1:SE0). These instructions have a special intrinsic interface that is defined using an enumeration called `SE_REG` or `SE_REG_PAIR` that must be used with the intrinsic. Because of this special interface, these instructions can only be accessed using direct-mapped, low-level intrinsics.

- `SE_REG`

```
/*-----*/
/* Use the following for SE_REG operands. */
/*-----*/
enum SE_REG
{
    SE_REG_0      = 0, // READ SE0
    SE_REG_0_ADV  = 1, // READ SE0 AND ADVANCE
    SE_REG_1      = 2, // READ SE1
    SE_REG_1_ADV  = 3  // READ SE1 AND ADVANCE
};
```

- `SE_REG_PAIR`

```
/*-----*/
/* Use the following for SE_REG_PAIR operands. */
/*-----*/
enum SE_REG_PAIR
{
    SE_REG_PAIR_0      = 0, // READ SE0 AND SE1
    SE_REG_PAIR_0_ADV  = 1  // READ SE0 AND SE1 AND ADVANCE BOTH STREAMS
};
```

4.14.5 Using the Stream Address Generator

Similar to the SE, once the stream address generator (SA) has been configured, a corresponding SA can be opened and used. The following API is provided to facilitate this, which takes the parameter template as input:

- Open Stream Address Generator 0: `__SA0_OPEN(__STRM_TEMPLATE param);`
- Open Stream Address Generator 1: `__SA1_OPEN(__STRM_TEMPLATE param);`
- Open Stream Address Generator 2: `__SA2_OPEN(__STRM_TEMPLATE param);`
- Open Stream Address Generator 3: `__SA3_OPEN(__STRM_TEMPLATE param);`

The Stream Address Generators are accessed using the following API. Note that for Stream Address Generators, the base address is given as an input to the read operation, and the return value is a pointer to the location that is then used by a memory load or memory store operation. This is because, unlike the SE, an SA simply provides an offset added to the given base address. The given type is used to cast the type of the data loaded or stored through the SA.

- Read Stream Address Generator 0 (and advance):
`__SA0(type, baseptr), __SA0ADV(type, baseptr)`
- Read Stream Address Generator 1 (and advance):
`__SA1(type, baseptr), __SA1ADV(type, baseptr)`
- Read Stream Address Generator 2 (and advance):
`__SA2(type, baseptr), __SA2ADV(type, baseptr)`
- Read Stream Address Generator 3 (and advance):
`__SA3(type, baseptr), __SA3ADV(type, baseptr)`

Stream Address Generators are closed using the corresponding close API:

- Close Stream Address Generator 0: `__SA0_CLOSE()` ;
- Close Stream Address Generator 1: `__SA1_CLOSE()` ;
- Close Stream Address Generator 2: `__SA2_CLOSE()` ;
- Close Stream Address Generator 3: `__SA3_CLOSE()` ;

When the accessor APIs shown above are used by themselves, the compiler will match a basic load or store operation for them, depending on whether they are on the left-hand-side (LHS) or right-hand-side (RHS) of an assignment operator.

The following is an example of an SA-returned pointer dereferenced by itself on both the LHS and RHS to copy data from one location to another. Because the SA returns a pointer, dereferencing it on the RHS generates a load, and dereferencing it on the LHS generates a store.

```
// OPEN THE STREAMS, SA0 AND SA1
__SA0_OPEN(params);
__SA1_OPEN(params);

// COPY DATA FROM *(src_addr+SA1) TO *(dst_addr+SA0)
for (i0 = 0; i0 < 8; i0++)
{
    // COMPILER MATCHES VECTOR LOAD AND STORE FOR FOUR WORD DATA

    *__SA0ADV(uint8, dst_addr) = *__SA1ADV(uint8, src_addr);
}

// CLOSE THE STREAMS
__SA0_CLOSE();
__SA1_CLOSE();
```

However, the SA accessor APIs can also be given as input to a load or store intrinsic, as in the following example. In this case, since the SA simply returns a pointer that is not dereferenced, the compiler will not attempt to match a corresponding basic vector load or store and will instead use the load or store indicated by the intrinsic.

```
// OPEN THE STREAMS, SA0 AND SA1
__SA0_OPEN(params);
__SA1_OPEN(params);

// COPY DATA (WITH UNPACK + PACK) FROM *(src_addr+SA1) TO *(dst_addr+SA0)

for (i0 = 0; i0 < 8; i0++)
{
    ulong8 data = __vload_unpack_long(__SA1ADV(uint8, src_addr));

    __vstore_packl(__SA0ADV(uint8, dst_addr), data);
}

// CLOSE THE STREAMS
__SA0_CLOSE();
__SA1_CLOSE();
```

NOTE: If the Stream Address Generator is used with a base pointer that is flagged as `restrict`, then derivations based on that pointer (base + offset), as calculated by the SA, are also assumed to be `restrict`. This means that SA-generated pointers, and all loads and stores that use them, are not assumed to alias other memory pointers.

Therefore, using the SA based on `restrict` base pointers implies a contract in which the program promises never to modify the data in any area of memory that can be reached by that stream address generator during its lifetime.

4.14.6 Leveraging Stream Address Generator Store Lane Masking

Each Stream Address Generator has an implicit store predicate that is set when storing to memory based on the number of valid vector elements. However, expressing this behavior using C semantics is not possible, because the compiler does not see or track how or when the hardware does the predication, since the predication is based upon the SA configuration and may vary for each invocation of the store.

In order to express this functionality in C, the compiler provides an explicit semantic framework that you can leverage. The framework explicitly predicates a store operation with a predicate value extracted from the corresponding SA. If the compiler detects that the extracted predicate type matches the SA accessor (and corresponding memory operation), the compiler then attempts to collapse this down in order to leverage the SA's implicit predication capability.

The API to extract the predicate value into a value of type `__vpred` includes the following:

- Extract VPRED from SA0 and scale according to specified type: `__SA0_VPRED(type)`
- Extract VPRED from SA0 and scale according to specified type: `__SA1_VPRED(type)`
- Extract VPRED from SA0 and scale according to specified type: `__SA2_VPRED(type)`
- Extract VPRED from SA0 and scale according to specified type: `__SA3_VPRED(type)`

The following is an example of this use:

```
__SA0_OPEN(params);

for (I = 0; I < ((ROW * COL) / SIMD); I++)
{
    vpred sa0_vp = __SA0_VPRED(int16);           // EXTRACT SA0 PREDICATE
    int16 *addr  = __SA0ADV(int16, (int16 *)data); // EXTRACT SA0 ADDRESS

    __vstore_pred(sa0_vp, addr, data);           // USE PREDICATED INTRINSIC
}
__SA0_CLOSE();
```

NOTE: As indicated in the example, extracts of the vector predicate associated with a particular stream address generator must be done outside of the call to the store intrinsic. If this weren't the case, according to C rules, the order in which parameters of a call are evaluated would be unspecified. Therefore doing this:

```
__vstore_pred(__SA0_VPRED(int16), __SA0ADV(int16, (int16 *)data);
```

results in undefined behavior because `SA0ADV` modifies the value returned by `SA0_VPRED()`.

NOTE: Regardless of the type used in the predicate extraction API or the SA access, an SA advance will always increment based on its preconfigured state. The given typename does not impact how an SA advance is done.

4.15 Nested Loop Controller (NLC)

In order to better facilitate nested loop *coalescing*, in which an outer loop level containing instructions is merged into an inner loop level, the C7000 architecture provides a feature known as the Nested Loop Controller (NLC). This feature implements hardware loop control for no more than one level of loop nesting. This allows the compiler to coalesce loop levels while predicating the execution of outer loop instructions in the inner loop. This reduces loop control overhead and provides for better function unit resource utilization for software pipelined loops. Loop coalescing is something that the compiler attempts to do automatically if the operation is both legal and profitable. Profitability is determined by a heuristic.

There are two pragmas that allow you to explicitly enable or disable coalescing of specific nested loops. These pragmas can only be applied to loops and must appear immediately before a loop construct in C/C++:

```
#pragma COALESCE_LOOP
#pragma NO_COALESCE_LOOP
```

4.15.1 Obstacles That May Inhibit Use of NLC

As stated above, the compiler must check for legality before attempting to coalesce the loop. If the compiler cannot guarantee that an inner loop is executed at least one time, then it will not coalesce the loop, even if you have disabled the profitability heuristic.

To inform the compiler that a loop will always be executed, use a `MUST_ITERATE` pragma just prior to the loop body:

```
#pragma MUST_ITERATE(1,65535,)
```

This pragma tells the compiler that the loop executes at least once and no more than 65,535 times.

C/C++ Language Implementation

The C language supported by the C7000 was developed by a committee of the American National Standards Institute (ANSI) and subsequently adopted by the International Standards Organization (ISO).

The C++ language supported by the C7000 is defined by the ANSI/ISO/IEC 14882:2014 standard with certain exceptions.

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5.1 Characteristics of C7000 C

The C compiler supports the 1989, 1999, and 2011 versions of the C language:

- **C89.** Compiling with the `--c89` option causes the compiler to conform to the ISO/IEC 9899:1990 C standard, which was previously ratified as ANSI X3.159-1989. The names "C89" and "C90" refer to the same programming language. "C89" is used in this document.
- **C99.** Compiling with the `--c99` option causes the compiler to conform to the ISO/IEC 9899:1999 C standard.
- **C11.** Compiling with the `--c11` option causes the compiler to conform to the ISO/IEC 9899:2011 C standard.

The C language is also described in the second edition of Kernighan and Ritchie's *The C Programming Language* (K&R). The compiler can also accept many of the language extensions found in the GNU C compiler (see [Section 5.14](#)).

The compiler supports some features of C99 in the default relaxed ANSI mode with C89 support. It supports all language features of C99 in C99 mode. See [Section 5.13](#).

The ANSI/ISO standard identifies some features of the C language that may be affected by characteristics of the target processor, run-time environment, or host environment. This set of features can differ among standard compilers.

Unsupported features of the C library are:

- The run-time library has minimal support for wide characters. The type `wchar_t` is implemented as unsigned int (32 bits). The wide character set is equivalent to the set of values of type `char`. The library includes the header files `<wchar.h>` and `<wctype.h>`, but does not include all the functions specified in the standard. See [Section 5.5](#) for information about extended and multibyte character sets.
- The run-time library includes the header file `<locale.h>`, but with a minimal implementation. The only supported locale is the C locale. That is, library behavior that is specified to vary by locale is hard-coded to the behavior of the C locale, and attempting to install a different locale by way of a call to `setlocale()` will return `NULL`.
- Some run-time functions and features in the C99 specification are not supported. See [Section 5.13](#).

5.1.1 Implementation-Defined Behavior

The C standard requires that conforming implementations provide documentation on how the compiler handles instances of implementation-defined behavior.

The TI compiler officially supports a freestanding environment. The C standard does not require a freestanding environment to supply every C feature; in particular the library need not be complete. However, the TI compiler strives to provide most features of a hosted environment.

The section numbers in the lists that follow correspond to section numbers in Appendix J of the C99 standard. The numbers in parentheses at the end of each item are sections in the C99 standard that discuss the topic. Certain items listed in Appendix J of the C99 standard have been omitted from this list.

J.3.1 Translation

- The compiler and related tools emit diagnostic messages with several distinct formats. Diagnostic messages are emitted to `stderr`; any text on `stderr` may be assumed to be a diagnostic. If any errors are present, the tool will exit with an exit status indicating failure (non-zero). (3.10, 5.1.1.3)
- Nonempty sequences of white-space characters are preserved and are not replaced by a single space character in translation phase 3. (5.1.1.2)

J.3.2 Environment

- The compiler does not support multibyte characters in identifiers, string literals, or character constants. There is no mapping from multibyte characters to the source character set. However, the compiler accepts multibyte characters in comments. See [Section 5.5](#) for details. (5.1.1.2)
- The name of the function called at program startup is "main" (5.1.2.1)
- Program termination does not affect the environment; there is no way to return an exit code to the environment. By default, the program is known to have halted when execution reaches the special `C$_EXIT` label. (5.1.2.1)

- In relaxed ANSI mode, the compiler accepts "void main(void)" and "void main(int argc, char *argv[])" as alternate definitions of main. The alternate definitions are rejected in strict ANSI mode. (5.1.2.2.1)
- If space is provided for program arguments at link time with the --args option and the program is run under a system that can populate the .args section (such as CCS), argv[0] will contain the filename of the executable, argv[1] through argv[argc-1] will contain the command-line arguments to the program, and argv[argc] will be NULL. Otherwise, the value of argv and argc are undefined. (5.1.2.2.1)
- Interactive devices include stdin, stdout, and stderr (when attached to a system that honors CIO requests). Interactive devices are not limited to those output locations; the program may access hardware peripherals that interact with the external state. (5.1.2.3)
- Signals are not supported. The function signal is not supported. (7.14) (7.14.1.1)
- The library function getenv is implemented through the CIO interface. If the program is run under a system that supports CIO, the system performs getenv calls on the host system and passes the result back to the program. Otherwise the operation of getenv is undefined. No method of changing the environment from inside the target program is provided. (7.20.4.5)
- The system function is not supported. (7.20.4.6).

J.3.3. Identifiers

- The compiler does not support multibyte characters in identifiers. See [Section 5.5](#) for details. (6.4.2)
- The number of significant initial characters in an identifier is unlimited. (5.2.4.1, 6.4.2)

J.3.4 Characters

- The number of bits in a byte (CHAR_BIT) is 8. See [Section 5.4](#) for details about data types. (3.6)
- The execution character set is the same as the basic execution character set: plain ASCII. (5.2.1)
- The values produced for the standard alphabetic escape sequences are as follows: (5.2.2)

Escape Sequence	ASCII Meaning	Integer Value
\a	BEL (bell)	7
\b	BS (backspace)	8
\f	FF (form feed)	12
\n	LF (line feed)	10
\r	CR (carriage return)	13
\t	HT (horizontal tab)	9
\v	VT (vertical tab)	11

- The value of a char object into which any character other than a member of the basic execution character set has been stored is the ASCII value of that character. (6.2.5)
- Plain char is identical to signed char. (6.2.5, 6.3.1.1)
- The source character set and execution character set are both plain ASCII, so the mapping between them is one-to-one. The compiler accepts multibyte characters in comments. See [Section 5.5](#) for details. (6.4.4.4, 5.1.1.2)
- The compiler currently supports only one locale, "C". (6.4.4.4).
- The compiler currently supports only one locale, "C". (6.4.5).

J.3.5 Integers

- No extended integer types are provided. (6.2.5)
- Negative values for signed integer types are represented as two's complement, and there are no trap representations. (6.2.6.2)
- No extended integer types are provided, so there is no change to the integer ranks. (6.3.1.1)
- When an integer is converted to a signed integer type which cannot represent the value, the value is truncated (without raising a signal) by discarding the bits which cannot be stored in the destination type; the lowest bits are not modified. (6.3.1.3)
- Right shift of a signed integer value performs an arithmetic (signed) shift. The bitwise operations other than right shift operate on the bits in exactly the same way as on an unsigned value. That is, after the

usual arithmetic conversions, the bitwise operation is performed without regard to the format of the integer type, in particular the sign bit. (6.5)

J.3.6 Floating point

- The accuracy of floating-point operations (+ - * /) is bit-exact. The accuracy of library functions that return floating-point results is not specified. (5.2.4.2.2)
- The compiler does not provide non-standard values for FLT_ROUNDS (5.2.4.2.2)
- The compiler does not provide non-standard negative values of FLT_EVAL_METHOD (5.2.4.2.2)
- The rounding direction when an integer is converted to a floating-point number is IEEE-754 "round to nearest". (6.3.1.4)
- The rounding direction when a floating-point number is converted to a narrower floating-point number is IEEE-754 "round to even". (6.3.1.5)
- For floating-point constants that are not exactly representable, the implementation uses the nearest representable value. (6.4.4.2)
- The compiler does not contract float expressions. (6.5)
- The default state for the FENV_ACCESS pragma is off. (7.6.1)
- The TI compiler does not define any additional float exceptions (7.6, 7.12)
- The default state for the FP_CONTRACT pragma is off. (7.12.2)
- The "inexact" floating-point exception cannot be raised if the rounded result equals the mathematical result. (F.9)
- The "underflow" and "inexact" floating-point exceptions cannot be raised if the result is tiny but not inexact. (F.9)

J.3.7 Arrays and pointers

- When converting a 64-bit pointer to a 32-bit integer, the pointer is truncated. When converting a pointer to a long, the pointer is considered an unsigned long of the same size, and the normal conversion rules apply.
- When converting a pointer to a long or vice versa, if the bitwise representation of the destination can hold all of the bits in the bitwise representation of the source, the bits are copied exactly. (6.3.2.3)
- The size of the result of subtracting two pointers to elements of the same array is the size of ptrdiff_t, which is defined in [Section 5.4](#). (6.5.6)

J.3.8 Hints

- When the optimizer is used, the register storage-class specifier is ignored. When the optimizer is not used, the compiler will preferentially place register storage class objects into registers to the extent possible. The compiler reserves the right to place any register storage class object somewhere other than a register. (6.7.1)
- The inline function specifier is ignored unless the optimizer is used. For other restrictions on inlining, see [Section 3.10.2](#). (6.7.4)

J.3.9 Structures, unions, enumerations, and bit-fields

- A "plain" int bit-field is treated as a signed int bit-field. (6.7.2, 6.7.2.1)
- In addition to _Bool, signed int, and unsigned int, the compiler allows char, signed char, unsigned char, signed short, unsigned short, signed long, unsigned long, and enum types as bit-field types. (6.7.2.1)
- Bit-fields may not straddle a storage-unit boundary. (6.7.2.1)
- Bit-fields are allocated in endianness order within a unit. See [Section 6.2.2](#). (6.7.2.1)
- Non-bit-field members of structures are aligned as specified in [Section 6.2.1](#). (6.7.2.1)
- The integer type underlying each enumerated type is described in [Section 5.4.1](#). (6.7.2.2)

J.3.10 Qualifiers

- The TI compiler does not shrink or grow volatile accesses. It is the user's responsibility to make sure the access size is appropriate for devices that only tolerate accesses of certain widths. The TI compiler does not change the number of accesses to a volatile variable unless absolutely necessary. This is significant for read-modify-write expressions such as += ; for an architecture which does not have a corresponding read-modify-write instruction, the compiler will be forced to use two accesses, one for

the read and one for the write. Even for architectures with such instructions, it is not guaranteed that the compiler will be able to map such expressions to an instruction with a single memory operand. It is not guaranteed that the memory system will lock that memory location for the duration of the instruction. In a multi-core system, some other core may write the location after a RMW instruction reads it, but before it writes the result. The TI compiler will not reorder two volatile accesses, but it may reorder a volatile and a non-volatile access, so volatile cannot be used to create a critical section. Use some sort of lock if you need to create a critical section. (6.7.3)

J.3.11 Preprocessing directives

- Include directives may have one of two forms, " " or < >. For both forms, the compiler will look for a real file on-disk by that name using the include file search path. See [Section 3.5.2](#). (6.4.7).
- The value of a character constant in a constant expression that controls conditional inclusion matches the value of the same character constant in the execution character set (both are ASCII). (6.10.1).
- The compiler uses the file search path to search for an included < > delimited header file. See [Section 3.5.2](#). (6.10.2).
- The compiler uses the file search path to search for an included " " delimited header file. See [Section 3.5.2](#). (6.10.2).
- There is no arbitrary nesting limit for #include processing. (6.10.2).
- See [Section 5.9](#) for a description of the recognized non-standard pragmas. (6.10.6).
- The date and time of translation are always available from the host. (6.10.8).

J.3.12 Library functions

- Almost all of the library functions required for a hosted implementation are provided by the TI library, with exceptions noted in [Section 5.13.1](#). (5.1.2.1).
- The format of the diagnostic printed by the assert macro is "Assertion failed, (*assertion macro argument*), file *file*, line *line*". (7.2.1.1).
- No strings other than "C" and "" may be passed as the second argument to the setlocale function (7.11.1.1).
- No signal handling is supported. (7.14.1.1).
- The +INF, -INF, +inf, -inf, NAN, and nan styles can be used to print an infinity or NaN. (7.19.6.1, 7.24.2.1).
- The output for %p conversion in the fprintf or fwprintf function is the same as %x of the appropriate size. (7.19.6.1, 7.24.2.1).
- The termination status returned to the host environment by the abort, exit, or _Exit function is not returned to the host environment. (7.20.4.1, 7.20.4.3, 7.20.4.4).
- The system function is not supported. (7.20.4.6).

J.3.13 Architecture

- The values or expressions assigned to the macros specified in the headers float.h, limits.h, and stdint.h are described along with the sizes and format of integer types are described in [Section 5.4](#). (5.2.4.2, 7.18.2, 7.18.3)
- The number, order, and encoding of bytes in any object are described in [Section 6.2.1](#). (6.2.6.1)
- The value of the result of the sizeof operator is the storage size for each type, in terms of bytes. See [Section 6.2.1](#). (6.5.3.4)

5.2 Characteristics of C7000 C++

The C7000 compiler supports C++ as defined in the ANSI/ISO/IEC 14882:2014 standard (C++14), including these features:

- Complete C++ standard library support, with exceptions noted below.
- Templates
- Exceptions, which are enabled with the `--exceptions` option; see [Section 5.7](#).
- Run-time type information (RTTI), which can be enabled with the `--rtti` compiler option.

The compiler supports the 2014 standard of C++ as standardized by the ISO. However, the following features are *not* implemented or fully supported:

- The compiler does not support embedded C++ run-time-support libraries.
- The library supports wide chars (`wchar_t`), in that template functions and classes that are defined for `char` are also available for `wchar_t`. For example, wide char stream classes `wios`, `wiostream`, `wstreambuf` and so on (corresponding to `char` classes `ios`, `iostream`, `streambuf`) are implemented. However, there is no low-level file I/O for wide chars. Also, the C library interface to wide char support (through the C++ headers `<cwchar>` and `<cwctype>`) is limited as described above in the C library.
- No support for `bad_cast` or `bad_type_id` is included in the `typeinfo` header.
- Constant expressions for target-specific types are only partially supported.
- New character types (introduced in the C++11 standard) are not supported.
- Unicode string literals (introduced in the C++11 standard) are not supported.
- Universal character names in literals (introduced in the C++11 standard) are not supported.
- Atomic operations (introduced in the C++11 standard) are not supported.
- Data-dependency ordering for atomics and memory model (introduced in the C++11 standard) is not supported.
- Allowing atomics in signal handlers (introduced in the C++11 standard) is not supported.
- Strong compare and exchange (introduced in the C++11 standard) are not supported.
- Bidirectional fences (introduced in the C++11 standard) are not supported.
- Memory model (introduced in the C++11 standard) is not supported.
- Propagating exceptions (introduced in the C++11 standard) is not supported.
- Thread-local storage (introduced in the C++11 standard) is not supported.
- Dynamic initialization and destruction with concurrency (introduced in the C++11 standard) is not supported.

5.3 Using MISRA C 2004

MISRA C is a set of software development guidelines for the C programming language. It promotes best practices in developing safety-related electronic systems in road vehicles and other embedded systems. MISRA C was originally launched in 1998 by the Motor Industry Software Reliability Association, and has since been adopted across a wide variety of industries. A subsequent update to the guidelines was published as MISRA C:2004.

You can alter your code to work with the MISRA C:2004 rules. The following options and pragmas can be used to enable/disable rules:

- The `--check_misra` option enables checking of the specified MISRA C:2004 rules. This compiler option must be used if you want to enable further control over checking using the `CHECK_MISRA` and `RESET_MISRA` pragmas.
- The `CHECK_MISRA` pragma enables/disables MISRA C:2004 rules at the source level. See [Section 5.9.2](#).
- The `RESET_MISRA` pragma resets the specified MISRA C:2004 rules to their state before any `CHECK_MISRA` pragmas were processed. See [Section 5.9.31](#).

The syntax of the option and the pragmas is:

```
--check_misra={all|required|advisory|none|rulespec}
#pragma CHECK_MISRA ("{all|required|advisory|none|rulespec}")
#pragma RESET_MISRA ("{all|required|advisory|rulespec}")
```

The *rulespec* parameter is a comma-separated list of rule numbers to enable or disable.

Example: `--check_misra=1.1,1.4,1.5,2.1,2.7,7.1,7.2,8.4`

- Enables checking of rules 1.1, 1.4, 1.5, 2.1, 2.7, 7.1, 7.2, and 8.4.

Example: `#pragma CHECK_MISRA("-7.1,-7.2,-8.4")`

- Disables checking of rules 7.1, 7.2, and 8.4.

A typical use case is to use the `--check_misra` option on the command line to specify the rules that should be checked in most of your code. Then, use the `CHECK_MISRA` pragma with a *rulespec* to activate or deactivate certain rules for a particular region of code.

Two options control the severity of certain MISRA C:2004 rules:

- The `--misra_required` option sets the diagnostic severity for required MISRA C:2004 rules.
- The `--misra_advisory` option sets the diagnostic severity for advisory MISRA C:2004 rules.

The syntax for these options is:

```
--misra_advisory={error|warning|remark|suppress}
--misra_required={error|warning|remark|suppress}
```


5.4 Data Types

[Table 5-1](#) lists the size, representation, and range of each scalar data type for the C7000 compiler. Many of the range values are available as standard macros in the header file `limits.h`.

The storage and alignment of data types is described in [Section 6.2.1](#).

Table 5-1. C7000 C/C++ Data Types

Type	Size	Representation	Range	
			Minimum	Maximum
char, signed char	8 bits	ASCII	-128	127
unsigned char	8 bits	ASCII	0	255
_Bool, bool	8 bits	ASCII	0 (false)	1 (true)
short	16 bits	Binary	-32 768	32 767
unsigned short	16 bits	Binary	0	65 535
int, signed int	32 bits	Binary	-2 147 483 648	2 147 483 647
unsigned int, wchar_t	32 bits	Binary	0	4 294 967 295
long, signed long	64 bits	Binary	-9 223 372 036 854 775 808	9 223 372 036 854 775 808
unsigned long	64 bits	Binary	0	18 446 744 073 709 551 615
long long, signed long long	64 bits	Binary	-9 223 372 036 854 775 808	9 223 372 036 854 775 807
unsigned long long	64 bits	Binary	0	18 446 744 073 709 551 615
enum ⁽¹⁾	32 bits	Binary	-2 147 483 648	2 147 483 647
float	32 bits	IEEE 32-bit	1.175 494e-38 ⁽²⁾	3.40 282 346e+38
float complex	64 bits	Array of 2 IEEE 32-bit	1.175 494e-38 for real and imaginary portions separately	3.40 282 346e+38 for real and imaginary portions separately
double	64 bits	IEEE 64-bit	2.22 507 385e-308 ⁽²⁾	1.79 769 313e+308
double complex	128 bits	Array of 2 IEEE 64-bit	2.22 507 385e-308 for real and imaginary portions separately	1.79 769 313e+308 for real and imaginary portions separately
long double	64 bits	IEEE 64-bit	2.22 507 385e-308 ⁽²⁾	1.79 769 313e+308
long double complex	128 bits	Array of 2 IEEE 64-bit	2.22 507 385e-308 for real and imaginary portions separately	1.79 769 313e+308 for real and imaginary portions separately
pointers, references, pointer to data members	64 bits	Binary	0	0xFFFFFFFFFFFFFFFF

⁽¹⁾ For details about the size of an enum type, see [Section 5.4.1](#).

⁽²⁾ Figures are minimum precision.

Negative values for signed types are represented using two's complement.

NOTE: We recommend that your code use the C standard integer types `int64_t` and `int32_t` (et al.) when specific data type sizes are needed for portability across different devices and compilers. These standard integer types are defined in `stdint.h`, which is included as part of the C standard library support included the Runtime Support Library.

The C7000 adopts the LP64 representational convention. That is, the type `int` is 32 bits, while `long` and `pointer` types are 64 bits.

These additional types from C, C99 and C++ are defined as synonyms for standard types:

Table 5-2. C Language Standard Types

Type	Definition
size_t	unsigned long
ptrdiff_t	long
wchar_t	unsigned int
wint_t	int
va_list	char *

5.4.1 Size of Enum Types

An enum type is represented by an underlying integer type. The size of the integer type and whether it is signed is based on the range of values of the enumerated constants.

In strict C89/C99 mode, the compiler allows only enumeration constants with values that will fit in "int" or "unsigned int" (32 bits).

For C++ and relaxed C89/C99, the compiler allows enumeration constants up to the largest integral type (64 bits). The default, which is recommended, is for the underlying type to be the first type in the following list in which all the enumerated constant values can be represented: int, unsigned int, long long, unsigned long long (long and long long are both 64 bits).

5.4.2 Vector Data Types

The C/C++ compiler supports the use of native vector data types in C/C++ source files. Vector data types are useful because they can make use of the natural vector width within the processing cores. Vector data types provide a straightforward way to utilize the SIMD instructions that are available on that architecture. Vector data types also provide a more direct mapping from the abstract model of a vector data object to the physical representation of that data object in a register.

Vector data types are similar to an array, in that a vector contains a specified number of elements of a specified type. However, the vector length can only be one of 2, 3, 4, 8, 16, 32, or 64. Wherever possible, intrinsics that act upon vectors are optimized to make use of efficient single instruction, multiple data (SIMD) instructions on the device.

Support for vector data types is enabled by default. You can use the `--vectypes=off` compiler option if you want to disable the vector data type names that are *not* prefixed with a double-underscore. For example, the `__int4` type is always available, but the `--vectypes=off` option disables the `int4` type. Note that the tables and examples that follow use type names without the double-underscore prefix.

All of the vector data types and related built-in functions that are supported in the C7000 programming model are specified in the "c7x.h" header file.

A vector type name concatenates an element type name and a number representing the vector length. The resulting vector consists of the specified number of elements of the specified type.

The C7000 implementation of vector data types and operations follows the OpenCL C language specification closely. For a detailed description of OpenCL vector data types and operations, please see version 1.2 of [The OpenCL Specification](#), which is available from the [Khronos OpenCL Working Group](#). Section 6.1.2 of the version 1.2 specification provides a detailed description of the built-in vector data types supported in the OpenCL C programming language. The C7000 programming model provides the following built-in vector data types:

Table 5-3. Vector Data Types

Type	Description	Maximum Elements
charn	A vector of <i>n</i> 8-bit signed integer values.	64
ucharn	A vector of <i>n</i> 8-bit unsigned integer values.	64
shortn	A vector of <i>n</i> 16-bit signed integer values.	32

Table 5-3. Vector Data Types (continued)

Type	Description	Maximum Elements
ushortn	A vector of n 16-bit unsigned integer values.	32
intn	A vector of n 32-bit signed integer values.	16
uintn	A vector of n 32-bit unsigned integer values.	16
longn	A vector of n 64-bit signed integer values.	8
ulongn	A vector of n 64-bit unsigned integer values.	8
floatn	A vector of n 32-bit single-precision floating-point values.	16
doublen	A vector of n 64-bit double-precision floating-point values.	8

where n can be a vector length of 2, 3, 4, 8, 16, 32, or 64.

For example, a "uchar8" is a vector of 8 unsigned chars; its length is 8 and its size is 64 bits. A "float4" is a vector of 4 float elements; its length is 4 and its size is 128 bits.

Vectors types are aligned on a boundary equal to the total size of the vector's elements up to 64 bits. Any vector type with a total size of more than 64 bits is aligned to a 64-bit boundary (8 bytes). For example, a short2 has a total size of 32 bits and is aligned on a 4-byte boundary. A long2 has a total size of 128 bits and is aligned on an 8-byte boundary.

The Code Generation Tools also provide an extension for representing vectors of complex types. A prefix of 'c' is used to indicate a complex type name. Each complex type vector element contains a real part and an imaginary part with the real part occupying the lower address in memory. Thus, the complex vector types are as follows:

Table 5-4. Complex Vector Data Types

Type	Description	Maximum Elements
ccharn	A vector of n pairs of 8-bit signed integer values.	32
cshortn	A vector of n pairs of 16-bit signed integer values.	16
cintrn	A vector of n pairs of 32-bit signed integer values.	8
clongn	A vector of n pairs of 64-bit signed integer values.	4
cfloatn	A vector of n pairs of 32-bit floating-point values.	8
cdoublen	A vector of n pairs of 64-bit floating-point values.	4

where n can be a vector length of 1, 2, 4, 8, 16, or 32. Note that 64 is not a valid vector length for complex vector types. For example, a "cfloat2" is a vector of 2 complex floats. Its length is 2 and its size is 128 bits. Each "cfloat2" vector element contains a real float and an imaginary float.

For information about operators and built-in functions used with vector data types, see [Section 5.15](#).

5.5 File Encodings and Character Sets

The compiler accepts source files with one of two distinct encodings:

- **UTF-8 with Byte Order Mark (BOM).** These files may contain extended (multibyte) characters in C/C++ comments. In all other contexts—including string constants, identifiers, assembly files, and linker command files—only 7-bit ASCII characters are supported.
- **Plain ASCII files.** These files must contain only 7-bit ASCII characters.

To choose the UTF-8 encoding in Code Composer Studio, open the Preferences dialog, select **General > Workspace**, and set the **Text File Encoding** to UTF-8.

If you use an editor that does not have a "plain ASCII" encoding mode, you can use Windows-1252 (also called CP-1252) or ISO-8859-1 (also called Latin 1), both of which accept all 7-bit ASCII characters. However, the compiler may not accept extended characters in these encodings, so you should not use extended characters, even in comments.

Wide character (wchar_t) types and operations are supported by the compiler. However, wide character strings may not contain characters beyond 7-bit ASCII. The encoding of wide characters is 7-bit ASCII, 0 extended to the width of the wchar_t type.

5.6 Keywords

The C7000 C/C++ compiler supports all of the standard C89 keywords, including `const`, `volatile`, and `register`. It supports all of the standard C99 keywords, including `inline` and `restrict`. It supports all of the standard C11 keywords. It also supports TI extension keyword `__cregister`. Some keywords are not available in strict ANSI mode.

The following keywords may appear in other target documentation and require the same treatment as the `interrupt` and `restrict` keywords:

- `trap`
- `reentrant`
- `cregister`

5.6.1 The complex Keyword

To use complex data types, you must include the `<complex.h>` header file. If this header file is included, complex support is available for all C/C++ modes, including relaxed and strict ANSI modes and C89 and C99. The `<complex.h>` header file implements math operation and function support for complex data types.

Complex types are implemented as an array of two elements. For example, for the following declaration, the variable is stored as an array of two floats. The real portion of the number is stored in `x._Vals[0]` and the imaginary portion of the number is stored in `x._Vals[1]`.

```
float complex x;
```

5.6.2 The const Keyword

The C/C++ compiler supports the ANSI/ISO standard keyword `const` in all modes. This keyword gives you greater optimization and control over allocation for certain data objects. You can apply the `const` qualifier to the definition of any variable or array to ensure that its value is not altered.

Global objects qualified as `const` are placed in the `.const` section. The linker allocates the `.const` section from ROM or FLASH, which are typically more plentiful than RAM. The `const` data storage allocation rule has the following exceptions:

- If `volatile` is also specified in the object definition. For example, `volatile const int x`. Volatile keywords are assumed to be allocated to RAM. (The program is not allowed to modify a `const volatile` object, but something external to the program might.)
- If the object has automatic storage (allocated on the stack).
- If the object is a C++ object with a "mutable" member.
- If the object is initialized with a value that is not known at compile time (such as the value of another variable).

In these cases, the storage for the object is the same as if the `const` keyword were not used.

The placement of the `const` keyword is important. For example, the first statement below defines a constant pointer `p` to a modifiable `int`. The second statement defines a modifiable pointer `q` to a constant `int`:

```
int * const p = &x;
const int * q = &x;
```

Using the `const` keyword, you can define large constant tables and allocate them into system ROM. For example, to allocate a ROM table, you could use the following definition:

```
const int digits[] = {0,1,2,3,4,5,6,7,8,9};
```

5.6.3 The `__cregister` Keyword

The compiler extends the C/C++ language by adding the `__cregister` keyword to allow high level language access to control registers.

When you use the `__cregister` keyword on an object, the compiler compares the name of the object to a list of standard control registers (see [Table 5-5](#)). If the name matches, the compiler generates the code to reference the control register. If the name does not match, the compiler issues an error.

The following control registers are declared in the `c7x.h` header file. In addition, a large number of Extended Control Registers (ECRs) are declared in `c7x_ecr.h`.

Table 5-5. Control Registers for C7000

Category	Register	Description
General Control Registers	CPUID	CPU ID register
	PMR	Power management register
	DNUM	DSP core number register
	TSC	Time-stamp counter register
	TSR	Task state register
	RP	Return pointer register
	BPCR	Branch predictor control register
Computation Control Registers	STSC	Shadow time stamp counter register
	FPCR	Floating-point control register
	FSR	Flag status register
	GPLY	Galois polynomial register
Event Control Registers	GFPGFR	Galois field polynomial generator function register
	DEPR	Debug event priority register
	IESET	Internal exception event set register
	ESTP_SS	Event service table pointer register, secure supervisor
	ESTP_S	Event service table pointer register, supervisor
	ESTP_GS	Event service table pointer register, guest supervisor
	ECSP_SS	Event context save pointer register, secure supervisor
	ECSP_S	Event context save pointer register, supervisor
	ECSP_GS	Event context save pointer register, guest supervisor
	TCSP	Task context save pointer
	RXMR_SS	Returning execution mode register, secure supervisor
	RXMR_S	Returning execution mode register, supervisor
	AHPEE	Highest priority enabled event register, currently in service
	PHPEE	Highest priority enabled event register, pending
	IEBER	Internal event broadcast enable register
	IERR	Internal exception report register
	IEAR	Internal exception address register
	IESR	Internal exception status register
	IEDR	Internal exception data register
	TCR	Test count register
	TCCR	Test count config register
	GMER	Guest mode enable register
	UMER	User mask enable register
	SPBR	Stack pointer boundary register
	UFCMR	User flag clear mask register
	IPE	Inter-processor event register

Table 5-5. Control Registers for C7000 (continued)

Category	Register	Description
Lookup Table and Histogram Control Registers	LTBR0 to LTBR3	Lookup table base address registers
	LTCR0 to LTCR3	Lookup table configuration registers
	LTER	Lookup table enable register
Debug Control Registers	DBGCTXT	Debug context (overlay) register
	ILCNT	Inner loop counter register
	OLCNT	Outer loop counter initial value register
	LCNTFLG	16-bit predicate flags register
	SCRB	Scoreboard bits register

The `__register` keyword can be used only in file scope. The `__register` keyword is not allowed on any declaration within the boundaries of a function. It can only be used on objects of type integer or pointer. The `__register` keyword is not allowed on objects of any floating-point type or on any structure or union objects.

The `__register` keyword does not imply that the object is volatile. If the control register being referenced is volatile (that is, can be modified by some external control), then the object must be declared with the `volatile` keyword also.

To use the control registers in [Table 5-5](#), you must declare each register as follows. The `c7x.h` include file defines all the control registers through this syntax:

```
extern __register volatile unsigned int register ;
```

Once you have declared the register, you can use the register name directly.

Example 5-1. Define and Use Control Registers

```
extern __register volatile unsigned long __CPUID;

int main()
{
    printf("__CPUID = 0x%lx\n", __CPUID);
}
```

5.6.3.1 Evaluating Flags in the Flag Status Register (FSR) After Floating Point Operations

The Flag Status Register (FSR), which contains bits representing floating point status, can be accessed using the `__get_FSR(type)` API, which is defined in `c7x.h`. The API takes a *type* argument, which refers to a valid scalar or vector floating point type (except for "float3") that is being used with the floating point operation.

The API returns an "OR" of the data bits for all pertinent vector lanes. The result is an 8-bit value containing the following fields:

- Bit 7: SAT - NOT SUPPORTED FOR C7000 OPERATIONS
- Bit 6: UNORD - Compare result is unordered Floating Point Flag
- Bit 5: DEN - Source is a Denorm Floating Point Flag
- Bit 4: INEX - Result is inexact Floating Point Flag
- Bit 3: UNDER - Result is underflow Floating Point Flag
- Bit 2: OVER - Result is overflow Floating Point Flag
- Bit 1: DIV0 - Divide by zero Floating Point Flag
- Bit 0: INVALID - Invalid Operations Floating Point Flag

For example:

```
float4 a = ... ;
float4 b = ... ;
float4 c = a * b;
uint8_t fsr_val = __get_FSR(float4);
```

The `__get_FSR(type)` API is provided to make accessing the FSR easier. The actual hardware register is a 64-bit value that is divided into eight 8-bit chunks. Each 8-bit chunk corresponds to a 64-bit vector slice of data in either the input or output data, depending on the operation being performed. A 64-bit slice may consist of a 64-bit double or two 32-bit float values that are OR'd together by the hardware.

However, for vector operations, while this "OR" is done for every 64-bit slice, the results for all 64-bit slices are not OR'd together by the hardware. The reason for this is that when partial vectors are used (less than 512 bits), the upper lanes of a vector are considered invalid and are ignored and therefore shouldn't be reflected in the final FSR result. To ensure that only the information pertinent to the valid lanes of a vector are reflected, the API allows users to specify the scalar or vector type of the data they are working with. The API will then ensure that only the valid 64-bit vector slices are OR'd together through a sequence of instructions to produce a final 8-bit result. All invalid lanes are therefore ignored.

NOTE: Using the `__get_FSR(type)` API results in performance degradations. This is because the API inserts a sequence of instructions to ensure that only the valid vector lanes are reflected in the final result. The API also prevents loop vectorization throughout a function in which it is used because vectorization would change the number of valid vector lanes in ways the user isn't able to track.

5.6.4 The restrict Keyword

To help the compiler determine memory dependencies, you can qualify a pointer, reference, or array with the restrict keyword. The restrict keyword is a type qualifier that can be applied to pointers, references, and arrays. Its use represents a guarantee by you, the programmer, that within the scope of the pointer declaration the object pointed to can be accessed only by that pointer. Any violation of this guarantee renders the program undefined. This practice helps the compiler optimize certain sections of code because aliasing information can be more easily determined.

In [Example 5-2](#), the restrict keyword is used to tell the compiler that the function func1 is never called with the pointers a and b pointing to objects that overlap in memory. You are promising that accesses through a and b will never conflict; therefore, a write through one pointer cannot affect a read from any other pointers. The precise semantics of the restrict keyword are described in the 1999 version of the ANSI/ISO C Standard.

The "restrict" keyword is a C99 keyword, and cannot be accepted in strict ANSI C89 mode. Use the "__restrict" keyword if the strict ANSI C89 mode must be used. See [Section 5.13](#).

Example 5-2. Use of the restrict Type Qualifier With Pointers

```
void func1(int * restrict a, int * restrict b)
{
    /* func1's code here */
}
```

[Example 5-3](#) illustrates using the restrict keyword when passing arrays to a function. Here, the arrays c and d must not overlap, nor may c and d point to the same array.

Example 5-3. Use of the restrict Type Qualifier With Arrays

```
void func2(int c[restrict], int d[restrict])
{
    int i;

    for(i = 0; i < 64; i++)
    {
        c[i] += d[i];
        d[i] += 1;
    }
}
```

5.6.5 The volatile Keyword

The C/C++ compiler supports the *volatile* keyword in all modes. In addition, the __volatile keyword is supported in relaxed ANSI mode for C89, C99, and C++.

The volatile keyword indicates to the compiler that there is something about how the variable is accessed that requires that the compiler not use overly-clever optimization on expressions involving that variable. For example, the variable may also be accessed by an external program, another thread, or a peripheral device.

The compiler eliminates redundant memory accesses whenever possible, using data flow analysis to figure out when it is legal. However, some memory accesses may be special in some way that the compiler cannot see, and in such cases you should use the volatile keyword to prevent the compiler from optimizing away something important. The compiler does not optimize out any accesses to variables declared volatile. The number of volatile reads and writes will be exactly as they appear in the C/C++ code, no more and no less and in the same order.

Any variable which might be modified by something external to the obvious control flow of the program (such as an interrupt service routine) must be declared volatile. This tells the compiler that an interrupt function might modify the value at any time, so the compiler should not perform optimizations which will change the number or order of accesses of that variable. This is the primary purpose of the volatile keyword. In the following example, the loop intends to wait for a location to be read as 0xFF:

```
unsigned int *ctrl;
while (*ctrl !=0xFF);
```

However, in this example, *ctrl is a loop-invariant expression, so the loop is optimized down to a single-memory read. To get the desired result, define ctrl as:

```
volatile unsigned int *ctrl;
```

Here the *ctrl pointer is intended to reference a hardware location, such as an interrupt flag.

The volatile keyword must also be used when accessing memory locations that represent memory-mapped peripheral devices. Such memory locations might change value in ways that the compiler cannot predict. These locations might change if accessed, or when some other memory location is accessed, or when some signal occurs.

Volatile must also be used for local variables in a function which calls setjmp, if the value of the local variables needs to remain valid if a longjmp occurs.

Example 5-4. Volatile for Local Variables With setjmp

```
#include <stdlib.h>
jmp_buf context;
void function()
{
    volatile int x = 3;
    switch(setjmp(context))
    {
        case 0: setup(); break;
        default:
        {
            /* We only reach here if longjmp occurs. Because x's lifetime begins before setjmp
               and lasts through longjmp, the C standard requires x be declared "volatile". */
            printf("x == %d\n", x);
            break;
        }
    }
}
```

5.7 C++ Exception Handling

The compiler supports the C++ exception handling features defined by the ANSI/ISO 14882 C++ Standard. See *The C++ Programming Language, Third Edition* by Bjarne Stroustrup.

The compiler --exceptions option enables exception handling. The compiler's default is no exception handling support.

For exceptions to work correctly, all C++ files in the application must be compiled with the --exceptions option, regardless of whether exceptions occur in that file. Mixing exception-enabled and exception-disabled object files and libraries can lead to undefined behavior.

Exception handling requires support in the run-time-support library, which come in exception-enabled and exception-disabled forms; you must link with the correct form. When using automatic library selection (the default), the linker automatically selects the correct library [Section 11.3.1.1](#). If you select the library manually, you must use run-time-support libraries whose name contains _eh if you enable exceptions.

Using the --exceptions option causes the compiler to insert exception handling code. This code will increase the size of the program somewhat. In addition, there is a minimal execution time cost even if exceptions are never thrown, and a slight increase in the data size for the exception-handling tables.

See [Section 7.1](#) for details on the run-time libraries.

5.8 Register Variables and Parameters

The C/C++ compiler treats register variables (variables defined with the register keyword) differently, depending on whether you use the `--opt_level (-O)` option.

- **Compiling with optimization**

The compiler ignores any register definitions and allocates registers to variables and temporary values by using an algorithm that makes the most efficient use of registers.

- **Compiling without optimization**

If you use the register keyword, you can suggest variables as candidates for allocation into registers. The compiler uses the same set of registers for allocating temporary expression results as it uses for allocating register variables.

The compiler attempts to honor all register definitions. If the compiler runs out of appropriate registers, it frees a register by moving its contents to memory. If you define too many objects as register variables, you limit the number of registers the compiler has for temporary expression results. This limit causes excessive movement of register contents to memory.

Any object with a scalar type (integral, floating point, or pointer) can be defined as a register variable. The register designator is ignored for objects of other types, such as arrays.

The register storage class is meaningful for parameters as well as local variables. Normally, in a function, some of the parameters are copied to a location on the stack where they are referenced during the function body. The compiler copies a register parameter to a register instead of the stack, which speeds access to the parameter within the function.

For more information about register conventions, see [Section 6.3](#).

5.9 Pragma Directives

Pragma directives tell the compiler how to treat a certain function, object, or section of code. The C7000 C/C++ compiler supports the following pragmas:

- `CALLS` (See [Section 5.9.1](#))
- `CHECK_MISRA` (See [Section 5.9.2](#))
- `CLINK` (See [Section 5.9.3](#))
- `CODE_ALIGN` (See [Section 5.9.5](#))
- `CODE_SECTION` (See [Section 5.9.6](#))
- `COALESCE_LOOP` (See [Section 5.9.4](#))
- `DATA_ALIGN` (See [Section 5.9.7](#))
- `DATA_MEM_BANK` (See [Section 5.9.8](#))
- `DATA_SECTION` (See [Section 5.9.9](#))
- `diag_suppress`, `diag_remark`, `diag_warning`, `diag_error`, `diag_default`, `diag_push`, `diag_pop` (See [Section 5.9.10](#))
- `FORCEINLINE` (See [Section 5.9.11](#))
- `FORCEINLINE_RECURSIVE` (See [Section 5.9.12](#))
- `FUNC_ALWAYS_INLINE` (See [Section 5.9.13](#))
- `FUNC_CANNOT_INLINE` (See [Section 5.9.14](#))
- `FUNC_EXT_CALLED` (See [Section 5.9.15](#))
- `FUNC_IS_PURE` (See [Section 5.9.16](#))
- `FUNC_IS_SYSTEM` (See [Section 5.9.17](#))
- `FUNC_NEVER_RETURNS` (See [Section 5.9.18](#))
- `FUNC_NO_GLOBAL_ASG` (See [Section 5.9.19](#))
- `FUNC_NO_IND_ASG` (See [Section 5.9.20](#))
- `FUNCTION_OPTIONS` (See [Section 5.9.21](#))
- `INTERRUPT` (See [Section 5.9.22](#))
- `LOCATION` (See [Section 5.9.23](#))
- `MUST_ITERATE` (See [Section 5.9.24](#))
- `NOINIT` (See [Section 5.9.25](#))
- `NOINLINE` (See [Section 5.9.26](#))
- `NO_COALESCE_LOOP` (See [Section 5.9.27](#))
- `NO_HOOKS` (See [Section 5.9.28](#))
- `pack` (See [Section 5.9.29](#))
- `PERSISTENT` (See [Section 5.9.25](#))
- `PROB_ITERATE` (See [Section 5.9.30](#))
- `RESET_MISRA` (See [Section 5.9.31](#))
- `RETAIN` (See [Section 5.9.32](#))
- `SET_CODE_SECTION` (See [Section 5.9.33](#))
- `SET_DATA_SECTION` (See [Section 5.9.33](#))
- `STRUCT_ALIGN` (See [Section 5.9.34](#))
- `UNROLL` (See [Section 5.9.35](#))
- `WEAK` (See [Section 5.9.36](#))

Most of these pragmas apply to functions. Except for the `DATA_MEM_BANK` pragma, the arguments *func* and *symbol* cannot be defined or declared inside the body of a function. You must specify the pragma outside the body of a function; and the pragma specification must occur before any declaration, definition, or reference to the *func* or *symbol* argument. If you do not follow these rules, the compiler issues a warning and may ignore the pragma.

For pragmas that apply to functions or symbols, the syntax differs between C and C++.

- In C, you must supply the name of the object or function to which you are applying the pragma as the first argument. Because the entity operated on is specified, a pragma in C can appear some distance away from the definition of that entity.
- In C++, pragmas are positional. They do not name the entity on which they operate as an argument. Instead, they always operate on the next entity defined after the pragma.

5.9.1 The CALLS Pragma

The `CALLS` pragma specifies a set of functions that can be called indirectly from a specified calling function.

The `CALLS` pragma is used by the compiler to embed debug information about indirect calls in object files. Using the `CALLS` pragma on functions that make indirect calls enables such indirect calls to be included in calculations for such functions' inclusive stack sizes. For more information on generating function stack usage information, see the `-cg` option of the Object File Display Utility in [Section 13.1](#).

The `CALLS` pragma can precede either the calling function's definition or its declaration. In C, the pragma must have at least 2 arguments—the first argument is the calling function, followed by at least one function that will be indirectly called from the calling function. In C++, the pragma applies to the next function declared or defined, and the pragma must have at least one argument.

The syntax for the `CALLS` pragma in C is as follows. This indicates that *calling_function* can indirectly call *function_1* through *function_n*.

```
#pragma CALLS ( calling_function, function_1, function_2, ..., function_n )
```

The syntax for the `CALLS` pragma in C++ is:

```
#pragma CALLS ( function_1_mangled_name, ..., function_n_mangled_name )
```

Note that in C++, the arguments to the `CALLS` pragma must be the full mangled names for the functions that can be indirectly called from the calling function.

The GCC-style "calls" function attribute (see [Section 5.14.2](#)), which has the same effect as the `CALLS` pragma, has the following syntax:

```
__attribute__((calls("function_1","function_2",..., "function_n")))
```

5.9.2 The CHECK_MISRA Pragma

The CHECK_MISRA pragma enables/disables MISRA C:2004 rules at the source level. The compiler option `--check_misra` must be used to enable checking in order for this pragma to function at the source level.

The syntax of the pragma in C is:

```
#pragma CHECK_MISRA (" {all|required|advisory|none|rulespec} ")
```

The *rulespec* parameter is a comma-separated list of rule numbers. See [Section 5.3](#) for details.

The RESET_MISRA pragma can be used to reset any CHECK_MISRA pragmas; see [Section 5.9.31](#).

5.9.3 The CLINK Pragma

The CLINK pragma can be applied to a code or data symbol. It causes a `.clink` directive to be generated into the section that contains the definition of the symbol. The `.clink` directive tells the linker that a section is eligible for removal during conditional linking. Thus, if the section is not referenced by any other section in the application being compiled and linked, it will not be included in the resulting output file.

The syntax of the pragma in C is:

```
#pragma CLINK (symbol)
```

The syntax of the pragma in C++ is:

```
#pragma CLINK
```

The RETAIN pragma has the opposite effect of the CLINK pragma. See [Section 5.9.32](#) for more details.

5.9.4 The COALESCE_LOOP Pragma

In order to facilitate nested loop coalescing, in which an outer loop level containing instructions is merged into an inner loop level, the C7000 architecture provides a feature known as the Nested Loop Controller (NLC). This feature implements hardware loop control for no more than one level of loop nesting. This allows the compiler to coalesce loop levels while predicating the execution of outer loop instructions in the inner loop. This reduces loop control overhead and provides for better function unit resource utilization for software pipelined loops. Loop coalescing is something that the compiler attempts to do automatically if the operation is both legal and profitable. Profitability is determined by a heuristic.

The COALESCE_LOOP pragma explicitly enables coalescing of the nested loop construct that follows the pragma. The pragma can only be applied to loops and must appear immediately before a loop construct in C/C++.

The syntax of the pragma in C and C++ is:

```
#pragma COALESCE_LOOP
```

If the compiler cannot guarantee that an inner loop is executed at least one time, then it will not coalesce the loop, even if you have used the COALESCE_LOOP pragma. To inform the compiler that a loop will always be executed, use a MUST_ITERATE pragma just prior to the loop body. For example, the following pragma tells the compiler that the loop executes at least once and no more than 65,535 times.

```
#pragma MUST_ITERATE(1,65535,)
```

5.9.5 The CODE_ALIGN Pragma

The CODE_ALIGN pragma aligns *func* along the specified alignment. The alignment *constant* must be a power of 2. The CODE_ALIGN pragma is useful if you have functions that you want to start at a certain boundary.

The CODE_ALIGN pragma has the same effect as using the GCC-style `aligned` function attribute. See [Section 5.14.2](#).

The syntax of the pragma in C is:

```
#pragma CODE_ALIGN ( func, constant )
```

The syntax of the pragma in C++ is:

```
#pragma CODE_ALIGN ( constant )
```

5.9.6 The CODE_SECTION Pragma

The CODE_SECTION pragma allocates space for the *symbol* in C, or the next symbol declared in C++, in a section named *section name*.

The CODE_SECTION pragma is useful if you have code objects that you want to link into an area separate from the `.text` section.

The CODE_SECTION pragma has the same effect as using the GCC-style `section` function attribute. See [Section 5.14.2](#).

The syntax of the pragma in C is:

```
#pragma CODE_SECTION (symbol , "section name ")
```

The syntax of the pragma in C++ is:

```
#pragma CODE_SECTION (" section name ")
```

The following example demonstrates the use of the CODE_SECTION pragma.

Example 5-5. Using the CODE_SECTION Pragma C Source File

```
#pragma CODE_SECTION(fn, "my_sect")

int fn(int x)
{
    return x;
}
```

5.9.7 The DATA_ALIGN Pragma

The DATA_ALIGN pragma aligns the *symbol* in C, or the next symbol declared in C++, to an alignment boundary. The alignment boundary is the maximum of the symbol's default alignment value or the value of the *constant* in bytes. The constant must be a power of 2. The maximum alignment is 32768.

The DATA_ALIGN pragma cannot be used to reduce an object's natural alignment.

Using the DATA_ALIGN pragma has the same effect as using the GCC-style `aligned` variable attribute. See [Section 5.14.3](#).

The syntax of the pragma in C is:

```
#pragma DATA_ALIGN ( symbol , constant )
```

The syntax of the pragma in C++ is:

```
#pragma DATA_ALIGN ( constant )
```

5.9.8 The DATA_MEM_BANK Pragma

The DATA_MEM_BANK pragma aligns a symbol or variable to a specified internal data memory bank boundary. The *constant* specifies a specific memory bank to start your variables on. C7000 devices contain 16 64-bit memory banks. The value of *constant* can be 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

The syntax of the pragma in C is:

```
#pragma DATA_MEM_BANK ( symbol , constant )
```

The syntax of the pragma in C++ is:

```
#pragma DATA_MEM_BANK ( constant )
```

Only global variables can be aligned with the DATA_MEM_BANK pragma.

The DATA_MEM_BANK pragma allows you to align data on any data memory bank that can hold data of the type size of the *symbol*. This is useful if you need to align data in a particular way to avoid memory bank conflicts.

This pragma increases the amount of space used in data memory by a small amount as padding is used to align data onto the correct bank.

A value of 'n' for the constant argument to the DATA_MEM_BANK pragma causes the last seven bits of the starting address to be a value equal to 'n*8'. For example, for a value of 1, the last seven bits of the starting address will be 0x08. For a value of 14, the last seven bits of the starting address will be 0x70.

The code in [Example 5-6](#) uses the `DATA_MEM_BANK` pragma to specify the alignment of the `x`, `y`, `z`, `w`, and `zz` arrays. It then assigns values to all the array elements and prints the starting address of each array.

Example 5-6. Using the `DATA_MEM_BANK` Pragma

```
#include <stdio.h>

#pragma DATA_MEM_BANK (x, 2)
short x[100];

#pragma DATA_MEM_BANK (z, 0)
#pragma DATA_SECTION (z, ".z_sect")
short z[100];

#pragma DATA_MEM_BANK (w, 4)
#pragma DATA_SECTION (w, ".w_sect")
short w[100];

#pragma DATA_MEM_BANK (zz, 6)
#pragma DATA_SECTION (zz, ".zz_sect")
short zz[100];

static short my_count = 0;

void main()
{
    int i;

    for (i = 0; i < 100; i++)
    {
        w[i] = my_count++;
        x[i] = my_count++;
        z[i] = my_count++;
        zz[i] = my_count++;
    }

    printf("address of w: 0x%08lx\n", (unsigned long)w);
    printf("address of x: 0x%08lx\n", (unsigned long)x);
    printf("address of z: 0x%08lx\n", (unsigned long)z);
    printf("address of zz: 0x%08lx\n", (unsigned long)zz);
}
```

Sample output is as follows:

```
address of w: 0x0000cba0
address of x: 0x0000c610
address of z: 0x0000cc80
address of zz: 0x0000cab0
```

5.9.9 The DATA_SECTION Pragma

The DATA_SECTION pragma allocates space for the *symbol* in C, or the next symbol declared in C++, in a section named *section name*.

The DATA_SECTION pragma is useful if you have data objects that you want to link into an area separate from the .bss or .data section.

Using the DATA_SECTION pragma has the same effect as using the GCC-style `section` variable attribute. See [Section 5.14.3](#).

The syntax of the pragma in C is:

```
#pragma DATA_SECTION ( symbol , " section name " )
```

The syntax of the pragma in C++ is:

```
#pragma DATA_SECTION ( " section name " )
```

Example 5-7. Using the DATA_SECTION Pragma C Source File

```
#pragma DATA_SECTION(bufferB, "my_sect")
char bufferA[512];
char bufferB[512];
```

Example 5-8. Using the DATA_SECTION Pragma C++ Source File

```
char bufferA[512];
#pragma DATA_SECTION("my_sect")
char bufferB[512];
```

5.9.10 The Diagnostic Message Pragmas

The following pragmas can be used to control diagnostic messages in the same ways as the corresponding command line options:

Pragma	Option	Description
diag_suppress <i>num</i>	-pds= <i>num</i> [, <i>num</i> ₂ , <i>num</i> ₃ ...]	Suppress diagnostic <i>num</i>
diag_remark <i>num</i>	-pdsr= <i>num</i> [, <i>num</i> ₂ , <i>num</i> ₃ ...]	Treat diagnostic <i>num</i> as a remark
diag_warning <i>num</i>	-pdsw= <i>num</i> [, <i>num</i> ₂ , <i>num</i> ₃ ...]	Treat diagnostic <i>num</i> as a warning
diag_error <i>num</i>	-pdse= <i>num</i> [, <i>num</i> ₂ , <i>num</i> ₃ ...]	Treat diagnostic <i>num</i> as an error
diag_default <i>num</i>	n/a	Use default severity of the diagnostic
diag_push	n/a	Push the current diagnostics severity state to store it for later use.
diag_pop	n/a	Pop the most recent diagnostic severity state stored with #pragma diag_push to be the current setting.

The syntax of the diag_suppress, diag_remark, diag_warning, and diag_error pragmas in C is:

```
#pragma diag_XXX [=]num[, num2, num3...]
```

Notice that the names of these pragmas are in lowercase.

The diagnostic affected (*num*) is specified using either an error number or an error tag name. The equal sign (=) is optional. Any diagnostic can be overridden to be an error, but only diagnostic messages with a severity of discretionary error or below can have their severity reduced to a warning or below, or be suppressed. The `diag_default` pragma is used to return the severity of a diagnostic to the one that was in effect before any pragmas were issued (i.e., the normal severity of the message as modified by any command-line options).

The diagnostic identifier number is output with the message when you use the `-pden` command line option. The following example suppresses a diagnostic message and then restores the previous diagnostics severity state:

```
#pragma diag_push
#pragma diag_suppress 551
#pragma CHECK_MISRA( "-9.1" )
#pragma diag_pop
```

5.9.11 The **FORCEINLINE** Pragma

The **FORCEINLINE** pragma can be placed before a statement to force any function calls made in that statement to be inlined. It has no effect on other calls to the same functions.

The compiler only inlines a function if it is legal to inline the function. Functions are never inlined if the compiler is invoked with the `--opt_level=off` option. A function can be inlined even if the function is not declared with the `inline` keyword. A function can be inlined even if the compiler is not invoked with any `--opt_level` command-line option.

The syntax of the pragma in C/C++ is:

#pragma FORCEINLINE

For example, in the following example, the `mytest()` and `getname()` functions are inlined, but the `error()` function is not.

```
#pragma FORCEINLINE
if (!mytest(getname(myvar))) {
    error();
}
```

Placing the **FORCEINLINE** pragma before the call to `error()` would inline that function but not the others.

For information about interactions between command-line options, pragmas, and keywords that affect inlining, see [Section 3.10](#).

Notice that the **FORCEINLINE**, **FORCEINLINE_RECURSIVE**, and **NOINLINE** pragmas affect only the C/C++ statement that follows the pragma. The **FUNC_ALWAYS_INLINE** and **FUNC_CANNOT_INLINE** pragmas affect an entire function.

5.9.12 The **FORCEINLINE_RECURSIVE** Pragma

The **FORCEINLINE_RECURSIVE** can be placed before a statement to force any function calls made in that statement to be inlined along with any calls made from those functions. That is, calls that are not visible in the statement but are called as a result of the statement will be inlined.

The syntax of the pragma in C/C++ is:

#pragma FORCEINLINE_RECURSIVE

For information about interactions between command-line options, pragmas, and keywords that affect inlining, see [Section 3.10](#).

5.9.13 The **FUNC_ALWAYS_INLINE** Pragma

The **FUNC_ALWAYS_INLINE** pragma instructs the compiler to always inline the named function.

The compiler only inlines a function if it is legal to inline the function. Functions are never inlined if the compiler is invoked with the `--opt_level=off` option. A function can be inlined even if the function is not declared with the `inline` keyword. A function can be inlined even if the compiler is not invoked with any `--opt_level` command-line option. See [Section 3.10](#) for details about interaction between various types of inlining.

This pragma must appear before any declaration or reference to the function that you want to inline. In C, the argument *func* is the name of the function that will be inlined. In C++, the pragma applies to the next function declared.

The **FUNC_ALWAYS_INLINE** pragma has the same effect as using the GCC-style `always_inline` function attribute. See [Section 5.14.2](#).

The syntax of the pragma in C is:

```
#pragma FUNC_ALWAYS_INLINE ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_ALWAYS_INLINE
```

The following example uses this pragma:

```
#pragma FUNC_ALWAYS_INLINE(functionThatMustGetInlined)
static inline void functionThatMustGetInlined(void) {
    P1OUT |= 0x01;
    P1OUT &= ~0x01;
}
```

Use Caution with the **FUNC_ALWAYS_INLINE** Pragma

NOTE: The **FUNC_ALWAYS_INLINE** pragma overrides the compiler's inlining decisions. Overuse of this pragma could result in increased compilation times or memory usage, potentially enough to consume all available memory and result in compilation tool failures.

5.9.14 The **FUNC_CANNOT_INLINE** Pragma

The **FUNC_CANNOT_INLINE** pragma instructs the compiler that the named function cannot be expanded inline. Any function named with this pragma overrides any inlining you designate in any other way, such as using the `inline` keyword. Automatic inlining is also overridden with this pragma; see [Section 3.10](#).

The pragma must appear before any declaration or reference to the function that you want to keep. In C, the argument *func* is the name of the function that cannot be inlined. In C++, the pragma applies to the next function declared.

The **FUNC_CANNOT_INLINE** pragma has the same effect as using the GCC-style `noinline` function attribute. See [Section 5.14.2](#).

The syntax of the pragma in C is:

```
#pragma FUNC_CANNOT_INLINE ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_CANNOT_INLINE
```

5.9.15 The **FUNC_EXT_CALLED** Pragma

When you use the `--program_level_compile` option, the compiler uses program-level optimization. When you use this type of optimization, the compiler removes any function that is not called, directly or indirectly, by `main()`. You might have C/C++ functions that are called externally instead of `main()`.

The **FUNC_EXT_CALLED** pragma specifies that the optimizer should keep these C functions or any functions these C/C++ functions call. These functions act as entry points into C/C++. The pragma must appear before any declaration or reference to the function to keep. In C, the argument *func* is the name of the function to keep. In C++, the pragma applies to the next function declared.

The syntax of the pragma in C is:

```
#pragma FUNC_EXT_CALLED ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_EXT_CALLED
```

Except for `_c_int00`, which is the name reserved for the system reset interrupt for C/C++ programs, the name of the interrupt (the *func* argument) does not need to conform to a naming convention.

When you use program-level optimization, you may need to use the **FUNC_EXT_CALLED** pragma with certain options.

5.9.16 The **FUNC_IS_PURE** Pragma

The **FUNC_IS_PURE** pragma specifies to the compiler that the named function has no side effects. This allows the compiler to do the following:

- Delete the call to the function if the function's value is not needed
- Delete duplicate functions

The pragma must appear before any declaration or reference to the function. In C, the argument *func* is the name of a function. In C++, the pragma applies to the next function declared.

The syntax of the pragma in C is:

```
#pragma FUNC_IS_PURE ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_IS_PURE
```

5.9.17 The **FUNC_IS_SYSTEM** Pragma

The **FUNC_IS_SYSTEM** pragma specifies to the compiler that the named function has the behavior defined by the ANSI/ISO standard for a function with that name.

The pragma must appear before any declaration or reference to the function that you want to keep. In C, the argument *func* is the name of the function to treat as an ANSI/ISO standard function. In C++, the pragma applies to the next function declared.

The syntax of the pragma in C is:

```
#pragma FUNC_IS_SYSTEM ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_IS_SYSTEM
```

5.9.18 The **FUNC_NEVER_RETURNS** Pragma

The **FUNC_NEVER_RETURNS** pragma specifies to the compiler that the function never returns to its caller.

The pragma must appear before any declaration or reference to the function that you want to keep. In C, the argument *func* is the name of the function that does not return. In C++, the pragma applies to the next function declared.

The syntax of the pragma in C is:

```
#pragma FUNC_NEVER_RETURNS ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_NEVER_RETURNS
```

5.9.19 The **FUNC_NO_GLOBAL_ASG** Pragma

The **FUNC_NO_GLOBAL_ASG** pragma specifies to the compiler that the function makes no assignments to named global variables and contains no asm statements.

The pragma must appear before any declaration or reference to the function that you want to keep. In C, the argument *func* is the name of the function that makes no assignments. In C++, the pragma applies to the next function declared.

The syntax of the pragma in C is:

```
#pragma FUNC_NO_GLOBAL_ASG ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_NO_GLOBAL_ASG
```

5.9.20 The **FUNC_NO_IND_ASG** Pragma

The **FUNC_NO_IND_ASG** pragma specifies to the compiler that the function makes no assignments through pointers and contains no asm statements.

The pragma must appear before any declaration or reference to the function that you want to keep. In C, the argument *func* is the name of the function that makes no assignments. In C++, the pragma applies to the next function declared.

The syntax of the pragma in C is:

```
#pragma FUNC_NO_IND_ASG ( func )
```

The syntax of the pragma in C++ is:

```
#pragma FUNC_NO_IND_ASG
```

5.9.21 The **FUNCTION_OPTIONS** Pragma

The **FUNCTION_OPTIONS** pragma allows you to compile a specific function in a C or C++ file with additional command-line compiler options. The affected function will be compiled as if the specified list of options appeared on the command line after all other compiler options. In C, the pragma is applied to the function specified. In C++, the pragma is applied to the next function.

The syntax of the pragma in C is:

```
#pragma FUNCTION_OPTIONS ( func, "additional options" )
```

The syntax of the pragma in C++ is:

```
#pragma FUNCTION_OPTIONS( "additional options" )
```

Supported options for this pragma are `--opt_level`, `--auto_inline`, `--code_state`, and `--opt_for_speed`. In order to use `--opt_level` and `--auto_inline` with the **FUNCTION_OPTIONS** pragma, the compiler must be invoked with some optimization level (that is, at least `--opt_level=0`).

5.9.22 The **INTERRUPT** Pragma

The **INTERRUPT** pragma enables you to handle interrupts directly with C code.

The syntax of the pragma in C is:

```
#pragma INTERRUPT ( func )
```

The syntax of the pragma in C++ is:

```
#pragma INTERRUPT  
void func( void )
```

The code for the function will return via the IRP (interrupt return pointer).

Hwi Objects and the **INTERRUPT** Pragma

NOTE: The **INTERRUPT** pragma must not be used when SYS/BIOS Hwi objects are used in conjunction with C functions. The `Hwi_enter/Hwi_exit` macros and the Hwi dispatcher contain this functionality, and the use of the C modifier can cause negative results.

5.9.23 The LOCATION Pragma

The compiler supports the ability to specify the run-time address of a variable at the source level. This can be accomplished with the LOCATION pragma or the GCC-style location attribute.

The LOCATION pragma has the same effect as using the GCC-style `location` function attribute. See [Section 5.14.2](#).

The syntax of the pragma in C is:

```
#pragma LOCATION( x , address )
int x
```

The syntax of the pragmas in C++ is:

```
#pragma LOCATION(address )
int x
```

The syntax of the GCC-style attribute (see [Section 5.14.3](#)) is:

```
int x __attribute__((location(address )))
```

The NOINIT pragma may be used in conjunction with the LOCATION pragma to map variables to special memory locations; see [Section 5.9.25](#).

5.9.24 The MUST_ITERATE Pragma

The MUST_ITERATE pragma specifies to the compiler certain properties of a loop. When you use this pragma, you are guaranteeing to the compiler that a loop executes a specific number of times or a number of times within a specified range.

Any time the UNROLL pragma is applied to a loop, MUST_ITERATE should be applied to the same loop. For loops the MUST_ITERATE pragma's third argument, *multiple*, is the most important and should always be specified.

Furthermore, the MUST_ITERATE pragma should be applied to any other loops as often as possible. This is because the information provided via the pragma (especially the minimum number of iterations) aids the compiler in choosing the best loops and loop transformations (that is, software pipelining and nested loop transformations). It also helps the compiler reduce code size.

No statements are allowed between the MUST_ITERATE pragma and the for, while, or do-while loop to which it applies. However, other pragmas, such as UNROLL and PROB_ITERATE, can appear between the MUST_ITERATE pragma and the loop.

5.9.24.1 The MUST_ITERATE Pragma Syntax

The syntax of the pragma for C and C++ is:

```
#pragma MUST_ITERATE ( min, max, multiple )
```

The arguments *min* and *max* are programmer-guaranteed minimum and maximum trip counts. The trip count is the number of times a loop iterates. The trip count of the loop must be evenly divisible by *multiple*. All arguments are optional. For example, if the trip count could be 5 or greater, you can specify the argument list as follows:

```
#pragma MUST_ITERATE(5)
```

However, if the trip count could be any nonzero multiple of 5, the pragma would look like this:

```
#pragma MUST_ITERATE(5, , 5) /* Note the blank field for max */
```

It is sometimes necessary for you to provide min and multiple in order for the compiler to perform unrolling. This is especially the case when the compiler cannot easily determine how many iterations the loop will perform (that is, the loop has a complex exit condition).

When specifying a multiple via the `MUST_ITERATE` pragma, results of the program are undefined if the trip count is not evenly divisible by multiple. Also, results of the program are undefined if the trip count is less than the minimum or greater than the maximum specified.

If no min is specified, zero is used. If no max is specified, the largest possible number is used. If multiple `MUST_ITERATE` pragmas are specified for the same loop, the smallest max and largest min are used.

5.9.24.2 Using `MUST_ITERATE` to Expand Compiler Knowledge of Loops

Through the use of the `MUST_ITERATE` pragma, you can guarantee that a loop executes a certain number of times. The example below tells the compiler that the loop is guaranteed to run exactly 10 times:

```
#pragma MUST_ITERATE(10,10)

for(i = 0; i < trip_count; i++) { ...
```

In this example, the compiler attempts to generate a software pipelined loop even without the pragma. However, if `MUST_ITERATE` is not specified for a loop such as this, the compiler generates code to bypass the loop, to account for the possibility of 0 iterations. With the pragma specification, the compiler knows that the loop iterates at least once and can eliminate the loop-bypassing code.

`MUST_ITERATE` can specify a range for the trip count as well as a factor of the trip count. The following example tells the compiler that the loop executes between 8 and 48 times and the `trip_count` variable is a multiple of 8 (8, 16, 24, 32, 40, 48). The multiple argument allows the compiler to unroll the loop.

```
#pragma MUST_ITERATE(8, 48, 8)
for(i = 0; i < trip_count; i++) { ...
```

You should consider using `MUST_ITERATE` for loops with complicated bounds. In the following example, the compiler would have to generate a divide function call to determine, at run time, the number of iterations performed.

```
for(i2 = ipos[2]; i2 < 40; i2 += 5) { ...
```

The compiler will not do the above. In this case, using `MUST_ITERATE` to specify that the loop always executes eight times allows the compiler to attempt to generate a software pipelined loop:

```
#pragma MUST_ITERATE(8, 8)

for(i2 = ipos[2]; i2 < 40; i2 += 5) { ...
```

Typically, if the `MUST_ITERATE` pragma is used to optimize loop execution, a `DINT` instruction is prepended to the optimized code, the loop code is executed, and then an `RINT` instruction is executed when the loop is terminated.

5.9.25 The `NOINIT` and `PERSISTENT` Pragmas

Global and static variables are zero-initialized by default. However, in applications that use non-volatile memory, it may be desirable to have variables that are not initialized. `Noinit` variables are global or static variables that are not zero-initialized at startup or reset.

Variables can be declared as `noinit` or `persistent` using either pragmas or variable attributes. See [Section 5.14.3](#) for information about using variable attributes in declarations.

`Noinit` and `persistent` variables behave identically with the exception of whether or not they are initialized at load time.

- The `NOINIT` pragma may be used only with uninitialized variables. It prevents such variables from being set to 0 during a reset. It may be used in conjunction with the `LOCATION` pragma to map variables to special memory locations, like memory-mapped registers, without generating unwanted writes.
- The `PERSISTENT` pragma may be used only with statically-initialized variables. It prevents such variables from being initialized during a reset. Persistent variables disable startup initialization; they are given an initial value when the code is loaded, but are never again initialized.

By default, `noinit` or persistent variables are placed in sections named `.TI.noinit` and `.TI.persistent`, respectively. The location of these sections is controlled by the linker command file. Typically `.TI.persistent` sections are placed in FRAM for devices that support FRAM and `.TI.noinit` sections are placed in RAM.

NOTE: When using these pragmas in non-volatile FRAM memory, the memory region could be protected against unintended writes through the device's Memory Protection Unit. Some devices have memory protection enabled by default. Please see the information about memory protection in the datasheet for your device. If the Memory Protection Unit is enabled, it first needs to be disabled before modifying the variables.

If you are using non-volatile RAM, you can define a persistent variable with an initial value of zero loaded into RAM. The program can increment that variable over time as a counter, and that count will not disappear if the device loses power and restarts, because the memory is non-volatile and the boot routines do not initialize it back to zero. For example:

```
#pragma PERSISTENT(x)
#pragma location = 0xC200    // memory address in RAM
int x = 0;

void main() {
    run_init();

    while (1) {
        run_actions(x);
        __delay_cycles(1000000);
        x++;
    }
}
```

The syntax of the pragmas in C is:

```
#pragma NOINIT (x)
int x;
```

```
#pragma PERSISTENT (x)
int x=10;
```

The syntax of the pragmas in C++ is:

```
#pragma NOINIT
int x;
```

```
#pragma PERSISTENT
int x=10;
```

The syntax of the GCC attributes is:

```
int x __attribute__((noinit));
```

```
int x __attribute__((persistent)) = 0;
```

5.9.26 The **NOINLINE** Pragma

The **NOINLINE** pragma can be placed before a statement to prevent any function calls made in that statement from being inlined. It has no effect on other calls to the same functions.

The syntax of the pragma in C/C++ is:

```
#pragma NOINLINE
```

For information about interactions between command-line options, pragmas, and keywords that affect inlining, see [Section 3.10](#).

5.9.27 The **NO_COALESCE_LOOP** Pragma

In order to facilitate nested loop coalescing, in which an outer loop level containing instructions is merged into an inner loop level, the C7000 architecture provides a feature known as the Nested Loop Controller (NLC). This feature implements hardware loop control for no more than one level of loop nesting. This allows the compiler to coalesce loop levels while predicating the execution of outer loop instructions in the inner loop. This reduces loop control overhead and provides for better function unit resource utilization for software pipelined loops. Loop coalescing is something that the compiler attempts to do automatically if the operation is both legal and profitable. Profitability is determined by a heuristic.

The **NO_COALESCE_LOOP** pragma explicitly disables coalescing of the nested loop construct that follows the pragma. The pragma can only be applied to loops and must appear immediately before a loop construct in C/C++.

The syntax of the pragma in C and C++ is:

```
#pragma NO_COALESCE_LOOP
```

5.9.28 The **NO_HOOKS** Pragma

The **NO_HOOKS** pragma prevents entry and exit hook calls from being generated for a function.

The syntax of the pragma in C is:

```
#pragma NO_HOOKS ( func )
```

The syntax of the pragma in C++ is:

```
#pragma NO_HOOKS
```

See [Section 3.14](#) for details on entry and exit hooks.

5.9.29 The pack Pragma

The pack pragma can be used to control the alignment of fields within a class, struct, or union type. The syntax of the pragma in C/C++ can be any of the following.

#pragma pack (<i>n</i>)

The above form of the pack pragma affects all class, struct, or union type declarations that follow this pragma in a file. It forces the maximum alignment of each field to be the value specified by *n*. Valid values for *n* are 1, 2, 4, 8, and 16 bytes.

#pragma pack (push, <i>n</i>)
--

#pragma pack (pop)

The above form of the pack pragma affects only class, struct, and union type declarations between push and pop directives. (A pop directive with no prior push results in a warning diagnostic from the compiler.) The maximum alignment of all fields declared is *n*. Valid values for *n* are 1, 2, 4, 8, and 16 bytes.

#pragma pack (show)

The above form of the pack pragma sends a warning diagnostic to stderr to record the current state of the pack pragma stack. You can use this form while debugging.

For more about packed fields, see [Section 5.14.4](#).

5.9.30 The **PROB_ITERATE** Pragma

The **PROB_ITERATE** pragma specifies to the compiler certain properties of a loop. You assert that these properties are true in the common case. The **PROB_ITERATE** pragma aids the compiler in choosing the best loops and loop transformations (that is, software pipelining and nested loop transformations). **PROB_ITERATE** is useful only when the **MUST_ITERATE** pragma is not used or the **PROB_ITERATE** parameters are more constraining than the **MUST_ITERATE** parameters.

No statements are allowed between the **PROB_ITERATE** pragma and the for, while, or do-while loop to which it applies. However, other pragmas, such as **UNROLL** and **MUST_ITERATE**, may appear between the **PROB_ITERATE** pragma and the loop. The syntax of the pragma for C and C++ is:

```
#pragma PROB_ITERATE( min , max )
```

Where min and max are the minimum and maximum trip counts of the loop in the common case. The trip count is the number of times a loop iterates. Both arguments are optional.

For example, **PROB_ITERATE** could be applied to a loop that executes for eight iterations in the majority of cases (but sometimes may execute more or less than eight iterations):

```
#pragma PROB_ITERATE(8, 8)
```

If only the minimum expected trip count is known (say it is 5), the pragma would look like this:

```
#pragma PROB_ITERATE(5)
```

If only the maximum expected trip count is known (say it is 10), the pragma would look like this:

```
#pragma PROB_ITERATE(, 10) /* Note the blank field for min */
```

5.9.31 The **RESET_MISRA** Pragma

The **RESET_MISRA** pragma resets the specified MISRA C:2004 rules to the state they were before any **CHECK_MISRA** pragmas (see [Section 5.9.2](#)) were processed. For instance, if a rule was enabled on the command line but disabled in the source, the **RESET_MISRA** pragma resets it to enabled. This pragma accepts the same format as the **--check_misra** option, except for the "none" keyword.

The **--check_misra** compiler command-line option must be used to enable MISRA C:2004 rule checking in order for this pragma to function at the source level.

The syntax of the pragma in C is:

```
#pragma RESET_MISRA (" {all|required|advisory|rulespec} ")
```

The *rulespec* parameter is a comma-separated list of rule numbers. See [Section 5.3](#) for details.

5.9.32 The **RETAIN** Pragma

The **RETAIN** pragma can be applied to a code or data symbol.

It causes a **.retain** directive to be generated into the section that contains the definition of the symbol. The **.retain** directive indicates to the linker that the section is ineligible for removal during conditional linking. Therefore, regardless whether or not the section is referenced by another section in the application that is being compiled and linked, it will be included in the output file result of the link.

The **RETAIN** pragma has the same effect as using the **retain** function or variable attribute. See [Section 5.14.2](#) and [Section 5.14.3](#), respectively.

The syntax of the pragma in C is:

```
#pragma RETAIN ( symbol )
```

The syntax of the pragma in C++ is:

```
#pragma RETAIN
```

5.9.33 The SET_CODE_SECTION and SET_DATA_SECTION Pragmas

These pragmas can be used to set the section for all declarations below the pragma.

The syntax of the pragmas in C/C++ is:

```
#pragma SET_CODE_SECTION ("section name")
```

```
#pragma SET_DATA_SECTION ("section name")
```

In [Example 5-9](#) x and y are put in the section mydata. To reset the current section to the default used by the compiler, a blank parameter should be passed to the pragma. An easy way to think of the pragma is that it is like applying the CODE_SECTION or DATA_SECTION pragma to all symbols below it.

Example 5-9. Setting Section With SET_DATA_SECTION Pragma

```
#pragma SET_DATA_SECTION("mydata")
int x;
int y;
#pragma SET_DATA_SECTION()
```

The pragmas apply to both declarations and definitions. If applied to a declaration and not the definition, the pragma that is active at the declaration is used to set the section for that symbol. Here is an example:

Example 5-10. Setting a Section With SET_CODE_SECTION Pragma

```
#pragma SET_CODE_SECTION("func1")
extern void func1();
#pragma SET_CODE_SECTION()
...
void func1() { ... }
```

In [Example 5-10](#) func1 is placed in section func1. If conflicting sections are specified at the declaration and definition, a diagnostic is issued.

The current CODE_SECTION and DATA_SECTION pragmas and GCC attributes can be used to override the SET_CODE_SECTION and SET_DATA_SECTION pragmas. For example:

Example 5-11. Overriding SET_DATA_SECTION Setting

```
#pragma DATA_SECTION(x, "x_data")
#pragma SET_DATA_SECTION("mydata")
int x;
int y;
#pragma SET_DATA_SECTION()
```

In [Example 5-11](#) x is placed in x_data and y is placed in mydata. No diagnostic is issued for this case.

The pragmas work for both C and C++. In C++, the pragmas are ignored for templates and for implicitly created objects, such as implicit constructors and virtual function tables.

5.9.34 The **STRUCT_ALIGN** Pragma

The **STRUCT_ALIGN** pragma is similar to **DATA_ALIGN**, but it can be applied to a structure or union type or typedef. It is inherited by any symbol created from that type. The **STRUCT_ALIGN** pragma is supported only in C.

The syntax of the pragma is:

```
#pragma STRUCT_ALIGN( type , constant expression )
```

This pragma guarantees that the alignment of the named type or the base type of the named typedef is at least equal to that of the expression. (The alignment may be greater as required by the compiler.) The alignment must be a power of 2. The *type* must be a type or a typedef name. If a type, it must be either a structure tag or a union tag. If a typedef, its base type must be either a structure tag or a union tag.

Note that while the top-level object of a type (or a typedef of that type) will be aligned as requested, the type will not be padded to the alignment (as is usual for a struct), nor does the alignment propagate to derived types such as arrays and parent structs. If you want to pad a structure or union so that individual elements are also aligned and/or cause the alignment to apply to derived types, use the "aligned" type attribute described in [Section 5.14.4](#).

Since ANSI/ISO C declares that a typedef is simply an alias for a type (i.e. a struct) this pragma can be applied to the struct, the typedef of the struct, or any typedef derived from them, and affects all aliases of the base type.

This example aligns any `st_tag` structure variables on a page boundary:

```
typedef struct st_tag
{
    int    a;
    short b;
} st_typedef;

#pragma STRUCT_ALIGN (st_tag, 128)
#pragma STRUCT_ALIGN (st_typedef, 128)
```

Any use of **STRUCT_ALIGN** with a basic type (int, short, float) or a variable results in an error.

5.9.35 The **UNROLL** Pragma

The **UNROLL** pragma specifies to the compiler how many times a loop should be unrolled. The **UNROLL** pragma is useful for helping the compiler utilize SIMD instructions. It is also useful in cases where better utilization of software pipeline resources are needed over a non-unrolled loop.

The optimizer must be invoked (use `--opt_level=[1|2|3]` or `-O1`, `-O2`, or `-O3`) in order for pragma-specified loop unrolling to take place. The compiler has the option of ignoring this pragma.

No statements are allowed between the **UNROLL** pragma and the for, while, or do-while loop to which it applies. However, other pragmas, such as **MUST_ITERATE** and **PROB_ITERATE**, can appear between the **UNROLL** pragma and the loop.

The syntax of the pragma for C and C++ is:

```
#pragma UNROLL( n )
```

If possible, the compiler unrolls the loop so there are *n* copies of the original loop. The compiler only unrolls if it can determine that unrolling by a factor of *n* is safe. In order to increase the chances the loop is unrolled, the compiler needs to know certain properties:

- The loop iterates a multiple of *n* times. This information can be specified to the compiler via the multiple argument in the **MUST_ITERATE** pragma.
- The smallest possible number of iterations of the loop
- The largest possible number of iterations of the loop

The compiler can sometimes obtain this information itself by analyzing the code. However, sometimes the compiler can be overly conservative in its assumptions and therefore generates more code than is necessary when unrolling. This can also lead to not unrolling at all. Furthermore, if the mechanism that determines when the loop should exit is complex, the compiler may not be able to determine these properties of the loop. In these cases, you must tell the compiler the properties of the loop by using the `MUST_ITERATE` pragma.

Specifying `#pragma UNROLL(1)` asks that the loop not be unrolled. Automatic loop unrolling also is not performed in this case.

If multiple `UNROLL` pragmas are specified for the same loop, it is undefined which pragma is used, if any.

5.9.36 The *WEAK* Pragma

The `WEAK` pragma gives weak binding to a symbol.

The syntax of the pragma in C is:

```
#pragma WEAK ( symbol )
```

The syntax of the pragma in C++ is:

```
#pragma WEAK
```

The `WEAK` pragma makes *symbol* a weak reference if it is a reference, or a weak definition, if it is a definition. The symbol can be a data or function variable. In effect, unresolved weak *references* do not cause linker errors and do not have any effect at run time. The following apply for weak references:

- Libraries are not searched to resolve weak references. It is not an error for a weak reference to remain unresolved.
- During linking, the value of an undefined weak reference is:
 - Zero if the relocation type is absolute
 - The address of the place if the relocation type is PC-relative
 - The address of the nominal base address if the relocation type is base-relative.

A weak *definition* does not change the rules by which object files are selected from libraries. However, if a link set contains both a weak definition and a non-weak definition, the non-weak definition is always used.

The `WEAK` pragma has the same effect as using the `weak` function or variable attribute. See [Section 5.14.2](#) and [Section 5.14.3](#), respectively.

5.10 The `_Pragma` Operator

The C7000 C/C++ compiler supports the C99 preprocessor `_Pragma()` operator. This preprocessor operator is similar to `#pragma` directives. However, `_Pragma` can be used in preprocessing macros (`#defines`).

The syntax of the operator is:

```
_Pragma (" string_literal ");
```

The argument *string_literal* is interpreted in the same way the tokens following a `#pragma` directive are processed. The *string_literal* must be enclosed in quotes. A quotation mark that is part of the *string_literal* must be preceded by a backward slash.

You can use the `_Pragma` operator to express `#pragma` directives in macros. For example, the `DATA_SECTION` syntax:

```
#pragma DATA_SECTION( func , " section ")
```

Is represented by the `_Pragma()` operator syntax:

```
_Pragma ("DATA_SECTION( func , \" section \")")
```

The following code illustrates using `_Pragma` to specify the `DATA_SECTION` pragma in a macro:

```
...
#define EMIT_PRAGMA(x) _Pragma(#x)
#define COLLECT_DATA(var) EMIT_PRAGMA(DATA_SECTION(var, "mysection"))

COLLECT_DATA(x)
int x;
...
```

The `EMIT_PRAGMA` macro is needed to properly expand the quotes that are required to surround the section argument to the `DATA_SECTION` pragma.

5.11 Application Binary Interface

An Application Binary Interface (ABI) defines how functions that are written separately, and compiled separately can work together. This involves standardizing the data type representation, register conventions, and function structure and calling conventions. An ABI allows ABI-compliant object files to be linked together, regardless of their source, and allows the resulting executable to run on any system that supports that ABI. It defines linkname generation from C symbol names. It also defines the object file format and the debug format, along with documenting how the system is initialized. In the case of C++, it defines C++ name mangling and exception handling support.

The C7000 compiler and linker support only the Embedded Application Binary Interface (EABI) ABI, which works only with object files that use the ELF object file format and the DWARF debug format.

EABI uses the ELF object file format which enables supporting modern language features like early template instantiation and export inline functions support. TI-specific information on EABI mode is described in [Section 6.7.2](#).

For details about the C7000 EABI, see the *C7000 Embedded Application Binary Interface (EABI) Reference Guide* ([SPRUIG4](#)).

5.12 Object File Symbol Naming Conventions (Linknames)

Each externally visible identifier is assigned a unique symbol name to be used in the object file, a so-called *linkname*. This name is assigned by the compiler according to an algorithm which depends on the name, type, and source language of the symbol. This algorithm may add a prefix to the identifier (typically an underscore), and it may *mangle* the name.

User-defined symbols in C code and in assembly code are stored in the same namespace, which means you are responsible for making sure that your C identifiers do not collide with your assembly code identifiers. You may have identifiers that collide with assembly keywords (for instance, register names); in this case, the compiler automatically uses an escape sequence to prevent the collision. The compiler escapes the identifier with double parallel bars, which instructs the assembler not to treat the identifier as a keyword. You are responsible for making sure that C identifiers do not collide with user-defined assembly code identifiers.

Name mangling encodes the types of the parameters of a function in the linkname for a function. Name mangling only occurs for C++ functions which are not declared 'extern "C"'. Mangling allows function overloading, operator overloading, and type-safe linking. Be aware that the return value of the function is not encoded in the mangled name, as C++ functions cannot be overloaded based on the return value.

For example, the general form of a C++ linkname for a function named func is:

`_func__F parmcodes`

Where parmcodes is a sequence of letters that encodes the parameter types of func.

For this simple C++ source file:

```
int foo(int i){ } //global C++ function
```

This is the resulting assembly code:

```
_foo__Fi
```

The linkname of foo is `_foo__Fi`, indicating that foo is a function that takes a single argument of type int. To aid inspection and debugging, a name demangling utility is provided that demangles names into those found in the original C++ source. See [Chapter 14](#) for more information.

The mangling algorithm follows that described in the Itanium C++ ABI (<http://www.codesourcery.com/cxx-abi/abi.html>).

`int foo(int i) { }` would be mangled "`_Z3fooi`"

5.13 Changing the ANSI/ISO C/C++ Language Mode

The language mode command-line options determine how the compiler interprets your source code. You specify one option to identify which language standard your code follows. You can also specify a separate option to specify how strictly the compiler should expect your code to conform to the standard.

Specify one of the following language options to control the language standard that the compiler expects the source to follow. The options are:

- ANSI/ISO C89 (--c89, default for C files)
- ANSI/ISO C99 (--c99, see [Section 5.13.1.](#))
- ANSI/ISO C11 (--c11, see [Section 5.13.2.](#))
- ISO C++14 (--c++14, used for all C++ files, see [Section 5.2.](#))

Use one of the following options to specify how strictly the code conforms to the standard:

- Relaxed ANSI/ISO (--relaxed_ansi or -pr) This is the default.
- Strict ANSI/ISO (--strict_ansi or -ps)

The default is relaxed ANSI/ISO mode. Under relaxed ANSI/ISO mode, the compiler accepts language extensions that could potentially conflict with ANSI/ISO C/C++. Under strict ANSI mode, these language extensions are suppressed so that the compiler will accept all strictly conforming programs. (See [Section 5.13.3.](#))

5.13.1 C99 Support (--c99)

The compiler supports the 1999 standard of C as standardized by the ISO. However, the following list of run-time functions and features are *not* implemented or fully supported:

- inttypes.h
 - wcstoimax() / wcstoumax()
- math.h
 - FP_ILOGB0 / FP_ILOGBNAN macros
 - MATH_ERRNO macro
 - copysign()
 - float_t / double_t types
 - math_errhandling()
 - signbit()
 - The following sets of C99 functions do not support the "long double" type. C89 math functions using float and long double types are supported. (Section numbers are from the C99 standard.)
 - 7.12.4: Trigonometric functions
 - 7.12.5: Hyperbolic functions
 - 7.12.6: Exponential and logarithmic functions
 - 7.12.7: Power and absolute value functions
 - 7.12.9: Nearest integer functions
 - 7.12.10: Remainder functions
 - expm1()
 - ilogb() / log1p() / logb()
 - scalbn() / scalbln()
 - cbrt()
 - hypot()
 - erf() / erfc()
 - lgamma() / tgamma()
 - nearbyint()
 - rint() / lrint() / llrint()

- lround() / llround()
- remainder() / remquo()
- nan()
- nextafter() / nexttoward()
- fdim() / fmax() / fmin() / fma()
- isgreater() / isgreaterequal() / isless() / islessequal() / islessgreater() / isunordered()
- stdio.h
 - The %e specifier may produce "-0" when "0" is expected by the standard
 - snprintf() does not properly pad with spaces when writing to a wide character array
- stdlib.h
 - vfscanf() / vscanf() / vsscanf() return value on floating point matching failure is incorrect
- wchar.h
 - getws() / fputws()
 - mbrlen()
 - mbsrtowcs()
 - wcscat()
 - wcschr()
 - wcscmp() / wcsncmp()
 - wcsncpy() / wcsncpy()
 - wcsftime()
 - wcsrtombs()
 - wcsstr()
 - wcstok()
 - wcsxfrm()
 - Wide character print / scan functions
 - Wide character conversion functions

5.13.2 C11 Support (--c11)

The compiler supports the 2011 standard of C as standardized by the ISO. However, in addition to the list in [Section 5.13.1](#), the following run-time functions and features are not implemented or fully supported in C11 mode:

- threads.h

5.13.3 Strict ANSI Mode and Relaxed ANSI Mode (--strict_ansi and --relaxed_ansi)

Under relaxed ANSI/ISO mode (the default), the compiler accepts language extensions that could potentially conflict with a strictly conforming ANSI/ISO C/C++ program. Under strict ANSI mode, these language extensions are suppressed so that the compiler will accept all strictly conforming programs.

Use the --strict_ansi option when you know your program is a conforming program and it will not compile in relaxed mode. In this mode, language extensions that conflict with ANSI/ISO C/C++ are disabled and the compiler will emit error messages where the standard requires it to do so. Violations that are considered discretionary by the standard may be emitted as warnings instead.

Examples:

The following is strictly conforming C code, but will not be accepted by the compiler in the default relaxed mode. To get the compiler to accept this code, use strict ANSI mode. The compiler will suppress the inline keyword language exception, and inline may then be used as an identifier in the code.

```
int main()
{
    int inline = 0;
    return 0;
}
```

The following is not strictly conforming code. The compiler will not accept this code in strict ANSI mode. To get the compiler to accept it, use relaxed ANSI mode. The compiler will provide the int16 type extension and will accept the code.

```
extern int16 myFunc(void);
```

```
int main()
{
    return 0;
}
```

The following code is accepted in all modes. The __int16 type does not conflict with the ANSI/ISO C standard, so it is always available as a language extension.

```
extern __int16 myFunc(void);
```

```
int main()
{
    return 0;
}
```

The default mode is relaxed ANSI. This mode can be selected with the `--relaxed_ansi` (or `-pr`) option. Relaxed ANSI mode accepts the broadest range of programs. It accepts all TI language extensions, even those which conflict with ANSI/ISO, and ignores some ANSI/ISO violations for which the compiler can do something reasonable. Some GCC language extensions described in [Section 5.14](#) may conflict with strict ANSI/ISO standards, but many do not conflict with the standards.

5.14 GNU and Clang Language Extensions

The GNU compiler collection (GCC) defines a number of language features not found in the ANSI/ISO C and C++ standards. The definition and examples of these extensions (for GCC version 4.7) can be found at the GNU web site, <http://gcc.gnu.org/onlinedocs/gcc-4.7.2/gcc/C-Extensions.html#C-Extensions>. Most of these extensions are also available for C++ source code.

The compiler also supports the following Clang macro extensions, which are described in the [Clang 6 Documentation](#):

- `__has_feature` (up to tests described for Clang 3.5)
- `__has_extension` (up to tests described for Clang 3.5)
- `__has_include`
- `__has_include_next`
- `__has_builtin` (see [Section 5.14.5](#))
- `__has_attribute`

5.14.1 Extensions

Most of the GCC language extensions are available in the TI compiler when compiling in relaxed ANSI mode (`--relaxed_ansi`).

The extensions that the TI compiler supports are listed in [Table 5-6](#), which is based on the list of extensions found at the GNU web site. The shaded rows describe extensions that are not supported.

Table 5-6. GCC Language Extensions

Extensions	Descriptions
Statement expressions	Putting statements and declarations inside expressions (useful for creating smart 'safe' macros)
Local labels	Labels local to a statement expression
Labels as values	Pointers to labels and computed gotos
Nested functions	As in Algol and Pascal, lexical scoping of functions
Constructing calls	Dispatching a call to another function
Naming types ⁽¹⁾	Giving a name to the type of an expression
typeof operator	typeof referring to the type of an expression
Generalized lvalues	Using question mark (?) and comma (,) and casts in lvalues
Conditionals	Omitting the middle operand of a ?: expression
long long	Double long word integers and long long int type
Hex floats	Hexadecimal floating-point constants
Complex	Data types for complex number
Zero length	Zero-length arrays
Variadic macros	Macros with a variable number of arguments
Variable length	Arrays whose length is computed at run time
Empty structures	Structures with no members
Subscripting	Any array can be subscripted, even if it is not an lvalue.
Escaped newlines	Slightly looser rules for escaped newlines
Multi-line strings ⁽¹⁾	String literals with embedded newlines
Pointer arithmetic	Arithmetic on void pointers and function pointers
Initializers	Non-constant initializers
Compound literals	Compound literals give structures, unions, or arrays as values
Designated initializers	Labeling elements of initializers
Cast to union	Casting to union type from any member of the union
Case ranges	'Case 1 ... 9' and such
Mixed declarations	Mixing declarations and code

⁽¹⁾ Feature defined for GCC 3.0; definition and examples at <http://gcc.gnu.org/onlinedocs/gcc-4.7.2/gcc/C-Extensions.html#C-Extensions>

Table 5-6. GCC Language Extensions (continued)

Extensions	Descriptions
Function attributes	Declaring that functions have no side effects, or that they can never return
Attribute syntax	Formal syntax for attributes
Function prototypes	Prototype declarations and old-style definitions
C++ comments	C++ comments are recognized.
Dollar signs	A dollar sign is allowed in identifiers.
Character escapes	The character ESC is represented as <code>\e</code>
Variable attributes	Specifying the attributes of variables
Type attributes	Specifying the attributes of types
Alignment	Inquiring about the alignment of a type or variable
Inline	Defining inline functions (as fast as macros)
Assembly labels	Specifying the assembler name to use for a C symbol
Extended asm	Assembler instructions with C operands
Constraints	Constraints for asm operands
Wrapper headers	Wrapper header files can include another version of the header file using <code>#include_next</code>
Alternate keywords	Header files can use <code>__const__</code> etc
Explicit reg vars	Defining variables residing in specified registers
Incomplete enum types	Define an enum tag without specifying its possible values
Function names	Printable strings which are the name of the current function
Return address	Getting the return or frame address of a function (limited support)
Other built-ins	Other built-in functions (see Section 5.14.5)
Vector extensions	Using vector operations (OpenCL syntax, see Section 5.15)
Target built-ins	Built-in functions specific to particular targets
Pragmas	Pragmas accepted by GCC
Unnamed fields	Unnamed struct/union fields within structs/unions
Thread-local	Per-thread variables
Binary constants	Binary constants using the <code>'0b'</code> prefix.

5.14.2 Function Attributes

The following GCC function attributes are supported:

- `alias`
- `aligned`
- `always_inline`
- `calls`
- `const`
- `constructor`
- `deprecated`
- `format`
- `format_arg`
- `malloc`
- `noinline`
- `noreturn`
- `pure`
- `section`
- `unused`
- `used`

- visibility
- warn_unused_result
- weak

The following additional TI-specific function attribute is supported:

- retain

For example, this function declaration uses the **alias** attribute to make "my_alias" a function alias for the "myFunc" function:

```
void my_alias() __attribute__((alias("myFunc")));
```

The **aligned** function attribute has the same effect as the CODE_ALIGN pragma. See [Section 5.9.5](#)

The **always_inline** function attribute has the same effect as the FUNC_ALWAYS_INLINE pragma. See [Section 5.9.13](#)

The **calls** attribute has the same effect as the CALLS pragma, which is described in [Section 5.9.1](#).

The **format** attribute is applied to the declarations of printf, fprintf, sprintf, snprintf, vprintf, fprintf, vsprintf, vsnprintf, scanf, fscanf, vfscanf, vscanf, vsscanf, and sscanf in stdio.h. Thus when GCC extensions are enabled, the data arguments of these functions are type checked against the format specifiers in the format string argument and warnings are issued when there is a mismatch. These warnings can be suppressed in the usual ways if they are not desired.

The **malloc** attribute is applied to the declarations of malloc, calloc, realloc and memalign in stdlib.h.

The **noinline** function attribute has the same effect as the FUNC_CANNOT_INLINE pragma. See [Section 5.9.14](#)

The **retain** attribute has the same effect as the RETAIN pragma ([Section 5.9.32](#)). That is, the section that contains the function will not be omitted from conditionally linked output even if it is not referenced elsewhere in the application.

The **section** attribute when used on a function has the same effect as the CODE_SECTION pragma. See [Section 5.9.6](#)

The **weak** attribute has the same effect as the WEAK pragma ([Section 5.9.36](#)).

5.14.3 Variable Attributes

The following variable attributes are supported:

- aligned
- deprecated
- location
- mode
- noinit
- packed
- persistent
- retain
- section
- transparent_union
- unused
- used
- weak

The **aligned** attribute when used on a variable has the same effect as the DATA_ALIGN pragma. See [Section 5.9.7](#)

The **location** attribute has the same effect as the LOCATION pragma. See [Section 5.9.23](#).

The **noinit** and **persistent** attributes apply to the ROM initialization model and allow an application to avoid initializing certain global variables during a reset. The alternative RAM initialization model initializes variables only when the image is loaded; no variables are initialized during a reset. See the "RAM Model vs. ROM Model" section and its subsections in the

The **noinit** attribute can be used on uninitialized variables; it prevents those variables from being set to 0 during a reset. The **persistent** attribute can be used on initialized variables; it prevents those variables from being initialized during a reset. By default, variables marked **noinit** or **persistent** will be placed in sections named `.TI.noinit` and `.TI.persistent`, respectively. The location of these sections is controlled by the linker command file. Typically `.TI.persistent` sections are placed in FRAM for devices that support FRAM and `.TI.noinit` sections are placed in RAM. Also see [Section 5.9.25](#).

The **packed** attribute may be applied to individual fields within a struct or union. The packed attribute for structure and union fields is available only when there is hardware support for unaligned accesses.

The **retain** attribute has the same effect as the `RETAIN` pragma ([Section 5.9.32](#)). That is, the section that contains the variable will not be omitted from conditionally linked output even if it is not referenced elsewhere in the application.

The **section** attribute when used on a variable has the same effect as the `DATA_SECTION` pragma. See [Section 5.9.9](#)

The **used** attribute is defined in GCC 4.2 (see <http://gcc.gnu.org/onlinedocs/gcc-4.2.4/gcc/Variable-Attributes.html#Variable-Attributes>).

The **weak** attribute has the same effect as the `WEAK` pragma ([Section 5.9.36](#)).

5.14.4 Type Attributes

The following type attributes are supported:

- aligned
- deprecated
- packed
- transparent_union
- unused
- visibility

Using the **aligned** type attribute causes the individual elements of a structure, union, or other type to be padded (as is usual for a struct) as needed to achieve the specified alignment for all elements. In addition, any derived types have the same alignment. For example:

```
struct __attribute__((aligned(32))) myStruct { char c1; int i; char c2; };
```

The **packed** attribute is supported for struct and union types. It is available only for target architectures that have hardware support for unaligned access if the `--relaxed_ansi` option is used.

Members of a packed structure are stored as closely to each other as possible, omitting additional bytes of padding usually added to preserve word-alignment. For example, assuming a word-size of 4 bytes ordinarily has 3 bytes of padding between members `c1` and `i`, and another 3 bytes of trailing padding after member `c2`, leading to a total size of 12 bytes:

```
struct unpacked_struct { char c1; int i; char c2;};
```

However, the members of a packed struct are byte-aligned. Thus the following does not have any bytes of padding between or after members and totals 6 bytes:

```
struct __attribute__((__packed__)) packed_struct { char c1; int i; char c2; };
```

Subsequently, packed structures in an array are packed together without trailing padding between array elements.

Bit fields of a packed structure are bit-aligned. The byte alignment of adjacent struct members that are not bit fields does not change. However, there are no bits of padding between adjacent bit fields.

The **packed** attribute can only be applied to the original definition of a structure or union type. It cannot be applied with a typedef to a non-packed structure that has already been defined, nor can it be applied to the declaration of a struct or union object. Therefore, any given structure or union type can only be packed or non-packed, and all objects of that type will inherit its packed or non-packed attribute.

The packed attribute is not applied recursively to structure types that are contained within a packed structure. Thus, in the following example the member `s` retains the same internal layout as in the first example above. There is no padding between `c` and `s`, so `s` falls on an unaligned boundary:

```
struct __attribute__((__packed__)) outer_packed_struct { char c; struct unpacked_struct s; };
```

It is illegal to implicitly or explicitly cast the address of a packed struct member as a pointer to any non-packed type except an unsigned char. In the following example, `p1`, `p2`, and the call to `foo` are all illegal.

```
void foo(int *param);
struct packed_struct ps;

int *p1 = &ps.i;
int *p2 = (int *)&ps.i;
foo(&ps.i);
```

However, it is legal to explicitly cast the address of a packed struct member as a pointer to an unsigned char:

```
unsigned char *pc = (unsigned char *)&ps.i;
```

The TI compiler also supports an **unpacked** attribute for an enumeration type to allow you to indicate that the representation is to be an integer type that is no smaller than `int`; in other words, it is not *packed*.

5.14.5 Built-In Functions

The following built-in functions are supported:

- `__builtin_abs()`
- `__builtin_constant_p()`
- `__builtin_expect()`
- `__builtin_fabs()`
- `__builtin_fabsf()`
- `__builtin_frame_address()`
- `__builtin_labs()`
- `__builtin_memcpy()`
- `__builtin_return_address()`

The `__builtin_frame_address()` function always returns zero.

The `__builtin_return_address()` function always returns zero.

5.15 Operations and Functions for Vector Data Types

The C/C++ compiler supports the use of native vector data types in C/C++ source files. Vector data types are described in [Section 5.4.2](#). These vector data types are useful for parallel programming applications.

The implementation of vector data types and operations follows the OpenCL C language specification closely. For a detailed description of OpenCL vector data types and operations, please see [The OpenCL Specification](#) version 1.2, which is available from the [Khronos OpenCL Working Group](#).

Various types of operations can be performed on vectors. These include vector literals and concatenation ([Section 5.15.1](#)), unary and binary operators ([Section 5.15.2](#)), swizzle operators for component access ([Section 5.15.4](#)), and conversion operators ([Section 5.15.6](#)).

5.15.1 Vector Literals and Concatenation

You can specify the values to use for vector initialization or assignment using literals or scalar variables. When all of the components assigned to a vector are constants, the result is a vector literal. Otherwise, the vector's value is determined at run-time.

For example, the values assigned to `vec_a` and `vec_b` in the following declarations are vector literals and are known during compilation:

```
short4 vec_a = (short4)(1, 2, 3, 4);
float2 vec_b = (float2)(3.2, -2.3);
```

The following statement initializes all the elements of the vector to the same value, which is 1 in this case:

```
ushort4 myushort4 = (ushort4)(1);
```

The value of `myvec` in the following function is not resolved until run-time:

```
void foo(int a, int b)
{
    int2 myvec = (int2)(a, b); ...
}
```

Shorter vectors can be concatenated together to form longer vectors. In the following example, two `int` variables are concatenated into an `int2` variable:

```
void foo(int a, int b)
{
    int2 myvec = (int2)(a, b);
    ...
}
```

The following example concatenates two `int2` variables into an `int4` variable, which is passed to an external function:

```
extern void bar(int4 v4);

void foo(int a, int b)
{
    int2 myv2_a = (int2)(a, 1);
    int2 myv2_b = (int2)(b, 2);

    int4 myv4 = (int4)(myv2_a, myv2_b);

    bar(myv4);
}
```


5.15.2 Unary and Binary Operators for Vectors

When unary operators (such as negate: -) and binary operators (such as +) are applied to a vector, the operator is applied to each element in the vector. That is, each element in the resulting vector is the result of applying the operator to the corresponding elements in the source vector(s).

Table 5-7. Unary Operators Supported for Vector Types

Operator	Description
-	negate
~	bitwise complement
!	logical not (integer vectors only)

The following example declares an int4 vector called pos_i4 and initializes it to the values 1, 2, 3, and 4. It then uses the negate operator to initialize the values of another int4 vector, neg_i4, to the values -1, -2, -3, and -4.

```
int4 pos_i4 = (int4)(1, 2, 3, 4);
int4 neg_i4 = -pos_i4;
```

Table 5-8. Binary Operators Supported for Vector Types

Operator	Description
+, -, *, /	arithmetic operators (also supported for complex vectors)
=, +=, -=, *=, /=	assignment operators
%	modulo operator (integer vectors only)
&, , ^, <<, >>	bitwise operators
>, >=, ==, !=, <=, <	relational operators
++, --	increment / decrement operators (prefix and postfix; integer vectors only; also supported for the real portion of complex vectors)
&&,	logical operators (integer vectors only)

The following example uses the =, ++, and + operators on vectors of type int4. Assume that the iv4 argument initially contains (1, 2, 3, 4). On exit from foo(), iv4 will contain (3, 4, 5, 6).

```
void foo(int4 iv4)
{
    int4 local_iva = iv4++;           /* local_iva = (1, 2, 3, 4) */
    int4 local_ivb = iv4++;           /* local_ivb = (2, 3, 4, 5) */

    int4 local_ivc = local_iva + local_ivb; /* local_ivc = (3, 5, 7, 9) */
}
```

The arithmetic operators and increment / decrement operators can be used with complex vector types. The increment / decrement operators add or subtract by 1+0i.

The following example multiplies and divides complex vectors of type cfloat2. For details about the rules for complex multiplication and division, please see Annex G of the [C99 C language specification](#).

```
void foo()
{
    cfloat2 va = (cfloat2)(1.0, -2.0, 3.0, -4.0);
    cfloat2 vb = (cfloat2)(4.0, -2.0, -4.0, 2.0);

    /* vc = (0.0, -10.0), (-4.0, 22.0) */
    cfloat2 vc = va * vb;

    /* vd = (0.4, -0.3), (-1.0, 0.5) */
    cfloat2 vd = va / vb;
    ...
}
```

5.15.3 Ternary Operators for Vectors (?:)

Ternary operators are supported for vector types by the C7000 compiler, however the code that is generated will not be optimal and the results will be evaluated lane-by-lane. Consider the following example if `src1` and `src2` are vectors:

```
int16 ex_ternary(int16 src1, int16 src2)
{
    return (src1 > src2) ? (src1 - src2) : (src2 - src1);
}
```

To generate more optimal code, you should instead use the vector comparison intrinsics listed in the `c7x.h` runtime support header file to construct a vector predicate as well as the vector select intrinsic `__select(vpred, ...)`. Vector predicates are described in [Section 5.15.8](#).

Or, use conditional operations, such as `__add(vpred, ...)` and `__sub_cond(vpred, ...)`, to implement the same behavior as shown in the following example.

```
int16 ex_ternary_supported(int16 src1, int16 src2)
{
    vpred condition = __cmp_gt_pred(src1, src2);

    int16 result1 = src1 - src2; // if-clause
    int16 result2 = src2 - src1; // else-clause

    return __select(condition, result1, result2); // Lane-dependent select operation
}
```

5.15.4 Swizzle Operators for Vectors

The programming model implementation supports the following "swizzle" operators. These operators are used as suffixes to a variable name. They can be used on either side (left or right) of an assignment operator. When used on the left hand side of an assignment, each component must be uniquely identifiable.

.x, .y, .z, or .w—Access an element of a vector whose length is ≤ 4 .

```
char4 my_c4 = (char4)(1, 2, 3, 4);
char tmp = my_c4.y * my_c4.w; /* ".y" accesses 2nd element
                               * ".w" accesses 4th element
                               * tmp = 2 * 4 = 8; */
```

.s0, .s1, ..., .s9, .sa, ..., .sf—Access one of up to 16 elements in a vector.

```
uchar16 ucvec16 = (uchar16)(1, 2, 3, 4, 5, 6, 7, 8,
                             9, 10, 11, 12, 13, 14, 15, 16);
uchar8 ucvec8 = (uchar8)(2, 4, 6, 8, 10, 12, 14, 16);

int tmp = ucvec16.sa * ucvec8.s7; /* ".sa" is 11th element of ucvec16
                                   * ".s7" is 8th element of ucvec8
                                   * tmp = 11 * 16 = 176; */
```

.s[0], .s[1], ..., .s[63]—Access one of up to 64 elements in a vector.

```
uchar16 ucvec16 = (uchar16)(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16);
uchar8 ucvec8 = (uchar8)(2, 4, 6, 8, 10, 12, 14, 16);

int tmp = ucvec16.s[10] * ucvec8.s[7];
/* ".s[10]" is 11th element of ucvec16; ".s[7]" is 8th element of ucvec8
   * tmp = 11 * 16 = 176; */
```

.even, .odd—Access the even or odd elements of a vector, where the zeroth element is even.

```
ushort4 usvec4 = (ushort4)(1, 2, 3, 4);
ushort2 usvecodd = usvec4.odd; /* usvecodd = (ushort2)(2, 4); */
ushort2 usveceven = usvec4.even; /* usveceven = (ushort2)(1, 3); */
```

.hi, .lo—Access the elements in the upper half of a vector with **.hi** or the elements in the lower half of a vector with **.lo**.

```
ushort8 usvec8 = (ushort8)(1, 2, 3, 4, 5, 6, 7, 8);
ushort4 usvechi = usvec8..hi; /* usvechi = (ushort4)(5, 6, 7, 8); */
ushort4 usveclo = usvec8..lo; /* usveclo = (ushort4)(1, 2, 3, 4); */
```

.r— Access the real parts of each of the elements in a complex type vector.

```
cfloat2 cfa = (cfloat2)(1.0, -2.0, 3.0, -4.0);
float2 rfa = cfa..r; /* rfa = (float2)(1.0, 3.0); */
```

.i— Access the imaginary parts of each of the elements in a complex type vector.

```
cfloat2 cfa = (cfloat2)(1.0, -2.0, 3.0, -4.0);
float2 ifa = cfa..i; /* ifa = (float2)(-2.0, -4.0); */
```

Swizzle operators can be combined to access a subset of the subset of elements. The result of the combination must be well-defined. For example, after the following code runs, `usvec4` contains (1, 2, 5, 4).

```
ushort4 usvec4 = (ushort4)(1, 2, 3, 4);

usvec4..hi.even = 5;
```

5.15.5 Unsupported Vector Comparison Operators

Comparisons of vectors as conditions in `if`-statements are not supported by the C7000 compiler. For example if `src1` and `src2` are vectors, the following would be an unsupported use:

```
int ex_compare_unsupported(ushort16 src1, ushort16 src2)
{
    if (src1 > src2) { return 1; } // Unsupported, will not work properly
    else             { return 2; }
}
```

You should instead use the vector comparison intrinsics listed in the `c7x.h` runtime support header file to construct a vector predicate. Vector predicates are described in [Section 5.15.8](#).

5.15.6 Conversion Functions for Vectors

You cannot use standard type casting on vector data types. Instead, `convert_<destination type>(<source type>)` functions are provided to convert the elements of one vector type object into another vector type object. This is done on an element-by-element basis, and the source vector type and the destination vector type must be of the same length. That is, 4-element vectors can only be converted to other types of 4-element vectors.

The following example initializes a `short2` vector using two ints concatenated to form an `int2` vector:

```
void foo(int a, int b)
{
    short2 svec2 = convert_short2((int2)(a, b));
    ...
}
```

If the data stored by a vector element is outside the range of values that can be stored in the destination type, by default the value is truncated. However, if you add the `_sat` modifier (for "saturated") to the function name, values that are outside the range of the destination type are set to the maximum value of the destination type (or minimum for negative values outside the range). The `_sat` modifier cannot be used when converting an integer vector to a floating-point vector. In the following example, any values larger than 32,767 stored in an element of `myint4` are set to as 32,767 in the corresponding element of `myshort4`.

```
int4 myint4;

short4 myshort4 = convert_short4_sat( myint4 );
```

Likewise, when converting between floating-point and integer vectors, one of the following modifiers can be added to the function name to specify how the floating-point values should be rounded:

- **_rte** — Round to nearest even integer
- **_rtz** — Round toward zero (default for converting floats to integers)
- **_rtp** — Round toward positive infinity
- **_rtn** — Round toward negative infinity

When converting an integer type to a float, rounding is not necessary. Rounding from a larger float type (double) to a smaller float type (float) does require rounding. The default rounding method for double to float conversions is **_rte**.

The following example converts the data stored in a float4 to an int4. It uses the **_rtp** modifier, so values are rounded up toward positive infinity:

```
float4 myfloat4;

int4 myint4 = convert_int4_rtp( myfloat4 );
```

The **_sat** modifier can be combined with a rounding modifier. The following example rounds floating values toward even and sets values greater than the maximum possible short value to the maximum value:

```
float4 myfloat4;

int4 myshort4 = convert_short4_sat_rte( myfloat4 );
```

If vector data types are enabled, you can also use the `convert_<type>()` functions for scalar (non-vector) types such as short and int. The result is the same as type casting the source type. Conversions between scalar types and vector types is not allowed, because the source and destination types must contain the same number of elements.

The `convert_<destination type>()` functions are not available for use with complex vector types.

5.15.7 Re-Interpretation Functions for Vectors

The `as_<destination type>(<source type object>)` functions are provided to re-interpret the original type of an object as another vector type. The source type and destination type must be the same size in number of bits. An error is returned if the sizes are different.

While arithmetic conversion is performed by the conversion functions described in the previous section, no arithmetic conversion is performed by the re-interpretation functions. For example, suppose a float value of 1.0 is re-interpreted as an int value. Since the float value of 1.0 is represented in hex as 0x3f800000, the value in the resulting int is 1,065,353,216.

The following example reinterprets a non-vector variable of the long type (64 bits) to a float2 vector (2 elements of 32 bits each). The least significant 32-bits of mylong are placed in fltvec2.s0 and the most significant 32-bits of mylong are placed in fltvec2.s1. No arithmetic conversion is performed.

```
extern long mylong;

float2 fltvec2 = as_float2(mylong);
```

If the sizes of the source and destination types are different, an error occurs.

If vector data types are enabled, you can also use the `as_<type>()` functions for scalar (non-vector) types. The types must have the same number of bits. The following example re-interprets a float value as an int value. Since the float value of 1.0 is represented in hex as 0x3f800000, the value in the resulting int is 1,065,353,216.

```
float myfloat = 1.0f;

myint = as_int(myfloat);
```

The `as_<destination type>()` functions are not available for use with complex vector types.

5.15.8 Vector Predicate Type

The vector predicate capability is managed through a special, opaque type named `__vpred`. Each bit of a vector predicate value corresponds to one byte lane in a native vector type. Because the maximum vector size is 64 bytes, a vector predicate value is 64 bits in size.

5.15.8.1 Constructing a Vector Predicate Type

Values of type `__vpred` can only be constructed using intrinsics that produce a vector predicate, which are listed in the `c7x_vpred.h` runtime support header file, including:

- Vector Comparison intrinsics: `__cmp_{eq, ge, gt, le, lt}_pred(...)`
Note: Comparisons between partial vectors (less than 512 bits in size) will produce a vector predicate value in which the upper, invalid lanes are masked to false.
- Vector Predicate Mask intrinsics: `__mask_{char, short, int, long}`
- Vector Predicate Instructions that operate on other vector predicates: `__negate(__vpred src)`

5.15.8.2 Using a Vector Predicate Type

A constructed vector predicate value of type `__vpred` can be used in any intrinsic shown to accept this value as an operand. Intrinsics that rely on vector predicate types are listed in `c7x_vpred.h`. Other operations on vector predicates—predicated add, predicated subtract, predicated shift, and predicated store—can be performed. Most operations can be made vector predicable using the vector select `__select(vpred, ...)` intrinsic:

```
int16 ex_compare_and_select(int16 src1, int16 src2)
{
    vpred condition = __cmp_gt_pred(src1, src2);

    int16 result1 = src1 - src2; // if-clause
    int16 result2 = src2 - src1; // else-clause

    return __select(condition, result1, result2);
}
```

5.15.8.3 Boolean Vector Types

The C7000 compiler supports a high-level Boolean vector type abstraction that can be used with any predicated intrinsic on the C7000. These intrinsics are listed in `c7x.h`. However, this feature is not fully supported and use of these types will not yield efficient and effective code. Instead, we encourage use of the low-level vector predicate type described in [Section 5.15.8](#), because it reflects the architecture capability more directly.

5.16 C7000 Intrinsics

The C7000 compiler provides intrinsics to provide functionality for ISA instructions and routines that cannot be leveraged by way of a simple C/C++ operator.

Most instructions defined for the C7000 ISA are available via intrinsics, which are listed in the `c7x.h` runtime-support header file. These intrinsics are subdivided into the following usage categories:

- High-level, OpenCL-like overloaded intrinsics ([Section 5.16.1](#))
- Intrinsics defined for special load or store instructions ([Section 5.16.2](#))
- Low-level, direct-mapped intrinsics ([Section 5.16.3](#))
- Intrinsics used to perform lookup table and histogram operations ([Section 5.16.4](#))
- Legacy intrinsics used to migrate code written for the C6000 compiler ([Section 5.16.6](#))
- Intrinsics to control the Streaming Engine and Stream Address Generator (see the [Section 4.14](#))

5.16.1 Overloaded, OpenCL-Like Intrinsics

The first set of intrinsics provided by the C7000 compiler pertains to operations for which multiple scalar and vector types apply. As such, for each operation to which they apply, these intrinsics have the same name and are overloaded based on the input type(s). Their names are inspired by the OpenCL naming convention (see the [OpenCL Registry](#) for details.) Because they are overloaded, these intrinsics are the most abstract and high-level of all of the supported intrinsics.

For example, the C7000 ISA defines a set of absolute value instructions for vectors of bytes (VABSB for up to 64 elements), vectors of half-words (VABSH for up to 32 elements), vectors of words (VABSW for up to 16 elements), vectors of double-words (VABSD for up to 8 elements), vectors of single-precision floating point (VABSSP for up to 16 elements), and vectors of double-precision floating point (VABSDP for up to 8 elements). In spite of this variability, the same intrinsic name is used to access all operations, and the operation is distinguished solely based upon input operand type. This is contained in `c7x.h` as follows:

```
/*-----
 * ID: __abs
 *-----*/
VABSB
char = __abs(char);
char2 = __abs(char2);
char3 = __abs(char3);
char4 = __abs(char4);
char8 = __abs(char8);
char16 = __abs(char16);
char32 = __abs(char32);
char64 = __abs(char64);

VABSH
short = __abs(short);
short2 = __abs(short2);
short3 = __abs(short3);
short4 = __abs(short4);
short8 = __abs(short8);
short16 = __abs(short16);
short32 = __abs(short32);

VABSW
int = __abs(int);
int2 = __abs(int2);
int3 = __abs(int3);
int4 = __abs(int4);
int8 = __abs(int8);
int16 = __abs(int16);

VABSD
long = __abs(long);
long2 = __abs(long2);
long3 = __abs(long3);
```

```

long4 = __abs(long4);
long8 = __abs(long8);

VABSSP
float = __abs(float);
float2 = __abs(float2);
float3 = __abs(float3);
float4 = __abs(float4);
float8 = __abs(float8);
float16 = __abs(float16);

VABSDP
double = __abs(double);
double2 = __abs(double2);
double3 = __abs(double3);
double4 = __abs(double4);
double8 = __abs(double8);

```

As long as the intrinsic name is used (`__abs(...)` in this case), the compiler generates the correct corresponding instruction for the input type used. See `c7x.h` for a complete list.

5.16.2 Ininsics Defined for Special Load and Store Instructions

The C7000 ISA supports several load and store operations that cannot be leveraged using simple C/C++ operators. Instead, an overloaded, OpenCL-like intrinsic is provided for those operations using prefixes “`__vload_`” and “`__vstore_`” for loads and stores, respectively, in conformity with the OpenCL naming convention. Overloaded intrinsics are provided for the following load and store operations:

- Vector Load and Duplicate: `__vload_dup(...)`
- Vector Load and Duplicate Group: `__vload_dup_vec(...)`
- Vector Load and Unpack: `__vload_unpack_{short, int, long}(...)`
- Vector Load and Deinterleave: `__vload_deinterleave_{int, long}(...)`
- Vector Interleave and Store: `__vstore_interleave(...)`
- Vector Packing Store: `__vstore_{packl, packh, packhsl, pack_byte}(...)`
- Vector Reverse Bit Store: `__vstore_reverse_bit(...)`
- Vector Predicated Store: `__vstore_pred(vpred, ...)`
- Vector Interleave, Predicated Store: `__vstore_pred_interleave(vpred, ...)`
- Vector Predicated Packing Store:
`__vstore_pred_{packl, packh, packhsl, pack_byte}(vpred, ...)`
- Vector Predicated Reverse Bit Store: `__vstore_pred_reverse_bit(vpred, ...)`
- Vector Constant Store: `__vstore_const_{2word, 4word, 8word, 16word}(...)`
- Store of Vector Predicate: `__store_predicate_{char, short, int, long}(...)`
- Atomic Swap: `__atomic_swap(...)`
- Atomic Compare and Swap: `__atomic_compare_swap(...)`

5.16.3 Direct-Mapped Intrinsics

Intrinsics are also provided to facilitate a direct-map between an intrinsic and a corresponding C7000 instruction. As such, these intrinsics are *not overloaded*; they are therefore the least abstracted from the hardware and are therefore considered *low-level*. The primary purpose of these low-level intrinsics is to ensure that no other instructions are generated other than those desired by the programmer. This is particularly useful for operations that require operand *interleaving* on input or operand *deinterleaving* on output.

All direct-mapped intrinsics are listed in `c7x_direct.h`, which is included by the top-level `c7x.h` file.

For example, the C7000 instruction VCMATMPYHW (vector complex matrix multiply) requires that its second source operand be interleaved along 64-bit boundaries. It also requires that its output also be deinterleaved along 64-bit boundaries. As listed in `c7x.h` and `c7x_direct.h`, the C7000 compiler provides two interfaces into this instruction:

- High-level, OpenCL-like intrinsic:

```
/*-----
 * ID: __cmatmpy_ext
 *-----*/
/*

VCMATMPYHW
cint2 = __cmatmpy_ext(cshort2, cshort4);
cint4 = __cmatmpy_ext(cshort4, cshort8);
cint8 = __cmatmpy_ext(cshort8, cshort16);
*/
```

- Low-level intrinsic:

```
/*-----
 * ID: __vcmatmpyhw_vww
 *-----*/
/*

VCMATMPYHW
__vcmatmpyhw_vww(cshort16, cshort16, cshort16, cint8&, cint8&);
*/
```

If you choose to use the overloaded, OpenCL-like “`__cmatmpy_ext(...)`” intrinsic, the compiler will assume that both the input and output data is *not interleaved* and will attempt to abstract this. Therefore, the compiler will insert special instructions to interleave the input prior to instruction execution, and it will also insert special instructions to deinterleave the output after instruction execution. *This method leans toward programmer ease-of-use at the expense of instruction cycles.*

More advanced programmers may instead opt to use the direct-mapped, low-level “`__vcmatmpyhw_vww(...)`” intrinsic and manage the interleaving and deinterleaving themselves. In this case, the interleaved input is shown as a pair of `cshort16` vectors, and the output is given as a pair of `cint8` vectors, each of which are determined by the maximum width and basic type supported by the VCMATMPYHW instruction.

5.16.4 Lookup Table and Histogram Intrinsics

The intrinsics used to configure and use the C7000 lookup table and histogram features are listed in `c7x_luthist.h`, which is included as part of C7000 runtime support.

5.16.5 Matrix-Multiply Accelerator (MMA) Intrinsics

The intrinsics used to configure and use the Matrix-Multiply Accelerator (MMA) are listed in `c7x_mma.h`, which is included as part of C7000 runtime support.

5.16.6 Legacy Intrinsics

The C7000 runtime support defines C6000 legacy intrinsics that can be used to compile C6000 source code using the C7000 compiler. Compiling source code containing these intrinsics should be done according to information provided in the *C6000-to-C7000 Migration User's Guide* (SPRUIG5) as well as the `c6x_migration.h` runtime support header file.

Run-Time Environment

This chapter describes the C7000 C/C++ run-time environment. To ensure successful execution of C/C++ programs, it is critical that all run-time code maintain this environment.

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6.1 Memory

The C7000 compiler treats memory as a single linear block that is partitioned into subblocks of code and data. Each subblock of code or data generated by a C program is placed in its own continuous memory space. The compiler assumes that a full 48-bit address space is available in target memory.

The Linker Defines the Memory Map

NOTE: The linker, not the compiler, defines the memory map and allocates code and data into target memory. The compiler assumes nothing about the types of memory available, about any locations not available for code or data (holes), or about any locations reserved for I/O or control purposes. The compiler produces relocatable code that allows the linker to allocate code and data into the appropriate memory spaces. For example, you can use the linker to allocate global variables into on-chip RAM or to allocate executable code into external ROM. You can allocate each block of code or data individually into memory, but this is not a general practice (an exception to this is memory-mapped I/O, although you can access physical memory locations with C/C++ pointer types).

6.1.1 Sections

The compiler produces relocatable blocks of code and data called *sections*. The sections are allocated into memory in a variety of ways to conform to a variety of system configurations. For more information about sections and allocating them, see the introductory object file information in [Chapter 8](#). For details about C7000 section names, see the *C7000 Embedded Application Binary Interface (EABI) Reference Guide* ([SPRUIG4](#)).

There are two basic types of sections:

- **Initialized sections** contain data or executable code. Initialized sections are usually, but not always, read-only. The C/C++ compiler creates the following initialized sections:
 - The **.args section** contains the command argument for a host-based loader. This section is read-only. See the `--arg_size` option for details.
 - The **.binit section** contains boot time copy tables. This is a read-only section. For details on BINIT, see [Section 12.8.4.2](#).
 - The **.cinit section** is created only if you are using the `--rom_model` option. It contains tables for explicitly initialized global and static variables.
 - The **.got section** contains the global offset table.
 - The **.init_array section** contains the table for calling global constructors.
 - The **.ovly section** contains copy tables for unions in which different sections have the same run address. This is a read-only section.
 - The **.data section** reserves space for non-const, initialized global and static variables.
 - The **.c7xabi.exidx section** contains the index table for exception handling. The **.c7xabi.exstab section** contains stack unwinding instructions for exception handling. These sections are read-only. See the `--exceptions` option for details.
 - The **.name.load section** contains the compressed image of section *name*. This section is read-only. See [Section 12.8](#) for information on copy tables.
 - The **.const section** contains string literals, floating-point constants, and data defined with the C/C++ qualifier *const* (provided the constant is not also defined as *volatile* or one of the exceptions described in [Section 5.6.2](#)). This is a read-only section. String literals are placed in the `.const:.string` subsection to enable greater link-time placement control.
 - The **.text section** contains all the executable code and compiler-generated constants. This section is usually read-only.
 - The **.TI.crctab section** contains CRC checking tables. This is a read-only section.
- **Uninitialized sections** reserve space in memory (usually RAM). A program can use this space at run time to create and store variables. The compiler creates the following uninitialized sections:
 - The **.bss section** reserves space for uninitialized global and static variables. These variables are allocated by the assembler.

- The **.common section** reserves space for uninitialized global and static variables. These variables are allocated by the linker. Unused uninitialized variables are usually created as common symbols (unless you specify `--common=off`), so that they can be excluded from the resulting application.
- The **.stack section** reserves memory for the system stack.
- The **.systemem section** reserves space for dynamic memory allocation. This space is used by dynamic memory allocation routines, such as `malloc()`, `calloc()`, `realloc()`, or `new()`. If a C/C++ program does not use these functions, the compiler does not create the `.systemem` section.

Use Only Code in Program Memory

NOTE: With the exception of code sections, the initialized and uninitialized sections cannot be allocated into internal program memory.

The assembler creates the default sections `.text`, `.`, and `.data`. You can instruct the compiler to create additional sections by using the `CODE_SECTION` and `DATA_SECTION` pragmas (see [Section 5.9.6](#) and [Section 5.9.9](#)).

6.1.2 C/C++ System Stack

The C/C++ compiler uses a stack to:

- Save function return addresses
- Allocate local variables
- Pass arguments to functions
- Save temporary results

The run-time stack grows from the high addresses to the low addresses. The compiler uses the D15 register to manage this stack. D15 is the *stack pointer* (SP), which points to the next unused location on the stack.

The linker sets the stack size, creates a global symbol, `__TI_STACK_SIZE`, and assigns it a value equal to the stack size in bytes. The default stack size is 0x2000 bytes. You can change the stack size at link time by using the `--stack_size` option with the linker command. For more information on the `--stack_size` option, see [Section 12.4](#).

At system initialization, SP is set to the first 8-byte (64-bit) aligned address that is 16 bytes before the end (highest numerical address) of the `.stack` section. The SP is 8-byte aligned so that most 64-bit and smaller objects do not cross memory bank boundaries, which are 64-bits in size, and by convention, SP will always point to a free 16-byte location to optimize stack usage on function calls.

The C/C++ environment automatically decrements SP at the entry to a function to reserve all the space necessary for the execution of that function when the space required is greater than the 16 bytes reserved for each stack frame.

For more information about the stack and stack pointer, see [Section 6.4](#).

Stack Overflow

NOTE: The compiler provides no means to check for stack overflow during compilation or at run time. A stack overflow disrupts the run-time environment, causing your program to fail. Be sure to allow enough space for the stack to grow. You can use the `--entry_hook` option to add code to the beginning of each function to check for stack overflow; see [Section 3.14](#).

6.1.3 Dynamic Memory Allocation

The run-time-support library supplied with the C7000 compiler contains several functions (such as malloc, calloc, and realloc) that allow you to allocate memory dynamically for variables at run time.

Memory is allocated from a global pool, or heap, that is defined in the section. You can set the size of the .sysmem section by using the --heap_size=size option with the linker command. The linker also creates a global symbol, __TI_SYSMEM_SIZE, and assigns it a value equal to the size of the heap in bytes. The default size is 1K bytes. For more information on the --heap_size option, see [Section 12.4](#).

If you use any C I/O function, the RTS library allocates an I/O buffer for each file you access. This buffer will be a bit larger than BUFSIZ, which is defined in stdio.h and defaults to 256. Make sure you allocate a heap large enough for these buffers or use setvbuf to change the buffer to a statically-allocated buffer.

Dynamically allocated objects are not addressed directly (they are always accessed with pointers) and the memory pool is in a separate section (.sysmem); therefore, the dynamic memory pool can have a size limited only by the amount of available memory in your system. To conserve space in the .bss section, you can allocate large arrays from the heap instead of defining them as global or static. For example, instead of a definition such as:

```
struct big table[100];
```

Use a pointer and call the malloc function:

```
struct big *table  
table = (struct big *)malloc(100*sizeof(struct big));
```

When allocating from a heap, make sure the size of the heap is large enough for the allocation. This is particularly important when allocating variable-length arrays.

6.2 Object Representation

This section explains how various data objects are sized, aligned, and accessed.

6.2.1 Data Type Storage

For basic (scalar) types, the minimum alignment of an object is the size of its type. The minimum alignment for an object with an array type is that specified by the type of its elements.

For general information about data types, see [Section 5.4. Table 6-1](#) lists register and memory storage for various data types:

Table 6-1. Data Representation in Registers and Memory

Data Type	Register Storage	Memory Storage
char	Bits 0-7 of register	8 bits aligned to 8-bit boundary
unsigned char	Bits 0-7 of register	8 bits aligned to 8-bit boundary
short	Bits 0-15 of register	16 bits aligned to 16-bit boundary
unsigned short	Bits 0-15 of register	16 bits aligned to 16-bit boundary
int	Bits 0-31 of register	32 bits aligned to 32-bit boundary
unsigned int	Bits 0-31 of register	32 bits aligned to 32-bit boundary
long	Entire scalar register or bits 0-63 of vector register	64 bits aligned to 64-bit boundary
unsigned long	Entire scalar register or bits 0-63 of vector register.	64 bits aligned to 64-bit boundary
enum ⁽¹⁾	Bits 0-31 of register or entire register	32 bits aligned to 32-bit boundary or 64 bits aligned to 64-bit boundary
float	Bits 0-31 of register	32 bits aligned to 32-bit boundary
double	Entire scalar register or bits 0-63 of vector register.	64 bits aligned to 64-bit boundary
long double	Entire scalar register or bits 0-63 of vector register.	64 bits aligned to 64-bit boundary
struct	Members are stored as their individual types require.	Storage is a multiple of the alignment to the boundary of largest member type; members are stored and aligned as their individual types require.
array	Members are stored as their individual types require.	Members are stored as their individual types require. All arrays inside a structure are aligned according to the type of each element in the array.
pointer to data member	Entire scalar register or bits 0-63 of vector register.	64 bits aligned to 64-bit boundary
pointer to member function	Components stored as their individual types require	64 bits aligned to 64-bit boundary
cchar	Bits 0-15 of register	8 bits aligned to 8-bit boundary
cshort	Bits 0-31 of register	16 bits aligned to 16-bit boundary
cint	Entire scalar register or bits 0-63 of vector register	64 bits aligned to 32-bit boundary
cfloat	Entire scalar register or bits 0-63 of vector register	64 bits aligned to 32-bit boundary
clong	Bits 0-127 of vector register	128 bits aligned to 64-bit boundary
cdouble	Bits 0-127 of vector register	128 bits aligned to 64-bit boundary

⁽¹⁾ For details about the size of an enum type, see [Section 5.4.1](#).

For vector data types, the minimum alignment of an object is specified by the type of its elements.

6.2.1.3 long Data Types (signed and unsigned)

The long and unsigned long data types are stored in a full 64-bit register (see [Figure 6-3](#)). In big-endian mode, the lower address is loaded into bits 32-63 of the register and the higher address is loaded into bits 0-31 of the register. In little-endian mode, the lower address is loaded into bits 0-31 of the register and the higher address is loaded into bits 32-63s of the register.

Figure 6-3. 64-Bit Data Storage Format Signed 64-bit long

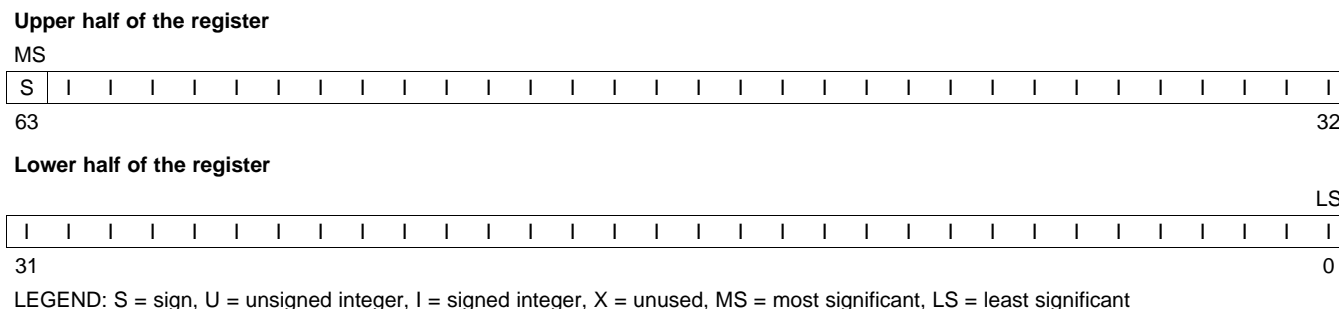
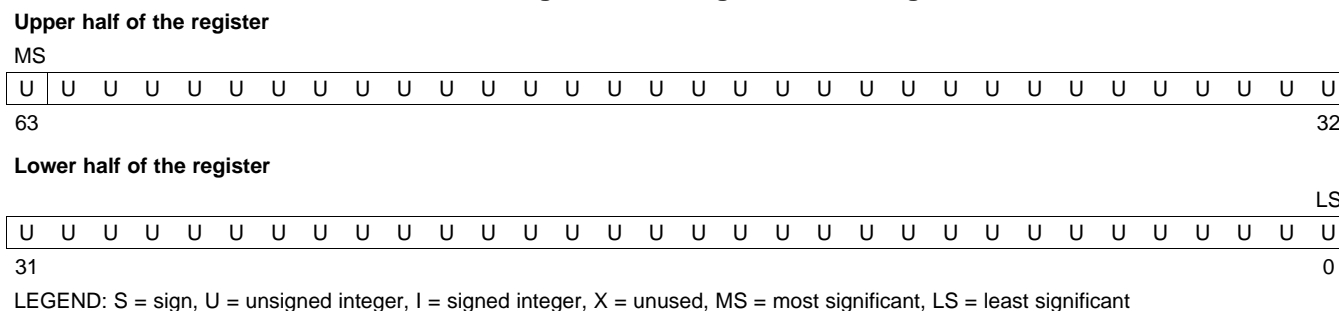


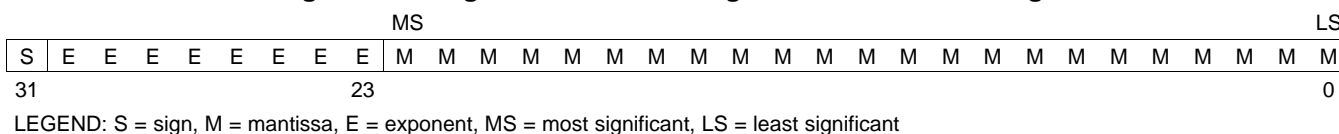
Figure 6-4. Unsigned 64-bit long



6.2.1.4 float Data Type

The float data type is stored in memory as 32-bit objects. The value is stored in the single-precision floating-point format (binary32) defined by the IEEE 754 standard.

Figure 6-5. Single-Precision Floating-Point Char Data Storage Format



6.2.1.5 double and long double Data Types

The `double` and `long double` data types are stored in a full 64-bit register. The value is stored in the double-precision floating-point format (binary64) defined by the IEEE 754 standard. That is, the exponent is 11 bits long, and the mantissa is 52 bits long.

6.2.1.6 Pointer to Data Member Types

Pointer to data member objects are stored in memory like an unsigned int (64-bit) integral type. Its value is the byte offset to the data member in the class, plus 1. The zero value is reserved to represent the NULL pointer.

6.2.1.7 Pointer to Member Function Types

Pointer to member function objects have a layout equivalent to:

```
struct __mptr {
    __vptp f;
    ptrdiff_t d;
};
```

where `_vptp` is the following union:

```
union {
    void (*f) ();
    int 0;
}
```

The parameter `f` is the pointer to the member function if it is nonvirtual. The `0` is the offset to the virtual function pointer within the class object. The parameter `d` is the offset to be added to the beginning of the class object for this pointer.

6.2.1.8 Structures and Arrays

A struct is aligned to a boundary required by the member it contains with the strictest alignment requirement. For example, if the largest alignment required by a member of the struct is 16-bit alignment (for example, a `short`), then the entire struct is aligned to a 16-bit boundary. If the struct contains a type that requires 64-bit alignment (such as a `double` or `long`), then the struct is aligned to a 64-bit boundary.

If a struct member is itself a struct, the size and alignment of the inner struct must be determined before the size and alignment of the outer struct may be determined.

Members of structs have sizes and alignments equal to those they would have as independent objects, unless the packed attribute is used. An array member of a struct is aligned to the alignment of its element type; this may differ from the alignment the element would have if it were an independent top-level (static) object.

Structs always have size equal to a multiple of the struct alignment. This sometimes requires padding after the last member to round the size up to a multiple of the struct alignment. The size of a structure includes any necessary padding between members. For example, if the largest member of a struct is of type `float`, the size of the struct will be a multiple of 32 bits.

Static scope arrays (sometimes called top-level arrays) are aligned on an 8-byte (64-bit) boundary.

6.2.2 Bit Fields

Bit fields are the only objects that are packed within a byte. That is, two bit fields can be stored in the same byte. Bit fields can range in size from 1 to 64 bits in C or larger in C++.

For big-endian mode, bit fields are packed into registers from most significant bit (MSB) to least significant bit (LSB) in the order in which they are defined. Bit fields are packed in memory from most significant byte (MSbyte) to least significant byte (LSbyte). For little-endian mode, bit fields are packed into registers from the LSB to the MSB in the order in which they are defined, and packed in memory from LSbyte to MSbyte.

The size, alignment, and type of bit fields adhere to these rules:

- Bit fields up to long are supported.

- Bit fields are treated as the declared signed or unsigned type.
- The size and alignment of the struct containing a bit field depends on the declared type of the bit field. For example, consider the struct:

```
struct st
{
    int a:4;
};
```

This struct uses up 4 bytes and is aligned at 4 bytes.

- Unnamed bit fields do affect the alignment of the struct or union. For example, consider the struct:

```
struct st
{
    char a:4;
    int :22;
};
```

This struct uses 4 bytes and is aligned at a 4-byte boundary.

- Bit fields declared volatile are accessed according to the bit field's declared type. A volatile bit field reference generates exactly one reference to its storage; multiple volatile bit field accesses are not merged.

Figure 6-6 illustrates bit-field packing, using the following bit field definitions:

```
struct{
    int A:7;
    int B:10;
    int C:3;
    int D:2;
    int E:9;
}x;
```

A0 represents the least significant bit of the field A; A1 represents the next least significant bit, etc. Again, storage of bit fields in memory is done with a byte-by-byte, rather than bit-by-bit, transfer.

Figure 6-6. Bit-Field Packing in Big-Endian and Little-Endian Formats

Big-endian register

MS																LS															
A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	C	C	C	D	D	E	E	E	E	E	E	E	X				
6	5	4	3	2	1	0	9	8	7	6	5	4	3	2	1	0	2	1	0	1	0	8	7	6	5	4	3	2	1	0	X
31																0															

Big-endian memory

Byte 0								Byte 1								Byte 2								Byte 3							
A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	B	C	C	C	C	D	D	E	E	E	E	E	E	E	E	X
6	5	4	3	2	1	0	9	8	7	6	5	4	3	2	1	0	2	1	0	1	0	8	7	6	5	4	3	2	1	0	X

Little-endian register

MS																LS															
X	E	E	E	E	E	E	E	E	E	D	D	C	C	C	B	B	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A
X	8	7	6	5	4	3	2	1	0	1	0	2	1	0	9	8	7	6	5	4	3	2	1	0	6	5	4	3	2	1	0
31																0															

Little-endian memory

Byte 0								Byte 1								Byte 2								Byte 3							
B	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	E	E	D	D	C	C	C	B	X	E	E	E	E	E	E	E
0	6	5	4	3	2	1	0	8	7	6	5	4	3	2	1	1	0	1	0	2	1	0	9	X	8	7	6	5	4	3	2

LEGEND: X = not used, MS = most significant, LS = least significant

6.2.3 Character String Constants

In C, a character string constant is used in one of the following ways:

- To initialize an array of characters. For example:

```
char s[] = "abc";
```

When a string is used as an initializer, it is simply treated as an initialized array; each character is a separate initializer. For more information about initialization, see [Section 6.7](#).

- In an expression. For example:

```
strcpy (s, "abc");
```

When a string is used in an expression, the string itself is defined in the `.const:string` section, along with a unique label that points to the string; the terminating 0 byte is explicitly added by the compiler.

String labels have the form `CSLn`, where `C` is the compiler-generated symbol prefix and `n` is a number assigned by the compiler to make the label unique. The number begins at 0 and is increased by 1 for each string defined.

The label `CSLn` represents the address of the string constant. The compiler uses this label to reference the string expression.

Because strings are stored in the `.const` section (possibly in ROM) and shared, it is bad practice for a program to modify a string constant. The following code is an example of incorrect string use:

```
const char    *a = "abc"
a[1] = 'x';           /* Incorrect! undefined behavior */
```

6.3 Register Conventions

Strict conventions associate specific registers with specific operations in the C/C++ environment.

The register conventions dictate how the compiler uses registers and how values are preserved across function calls.

The registers in [Table 6-2](#) are available to the compiler for allocation to register variables and temporary expression results. If the compiler cannot allocate a register of a required type, spilling occurs. Spilling is the process of moving a register's contents to memory to free the register for another purpose.

The C7000 has two datapaths: an A-side datapath with 64-bit “scalar” registers, and a B-side datapath with 512-bit “vector” registers. The lower 64-bits of any B-side vector register can also be accessed as a scalar register by removing the ‘V’ from its name. Scalar registers are not limited to storing scalar values; a vector can be stored in a scalar register if it fits.

D15 is the Stack Pointer (SP). The stack pointer must always remain aligned on a 2-word (8-byte) boundary. The SP points at the first aligned address below (less than) the currently allocated stack.

RP, D15 (SP), A8-A15, B14/VB14, and B15/VB15 are *callee-save* registers. That is, a called function is required to preserve them so they have the same value on return from a function as they had at the point of the call.

All other registers are *caller-save*; that is, they are not preserved across a call, so if their value is needed following the call, the caller is responsible for saving and restoring their contents.

Table 6-2. Register Usage

Register	File	Preserved by Callee?	Role in Calling Convention
A0	A side scalar	no	
A1		no	Pointer to return-by-reference value
A2		no	
A3		no	
A4		no	1st scalar argument
A5		no	2nd scalar argument
A6		no	3rd scalar argument
A7		no	4th scalar argument
A8		yes	5th scalar argument
A9		yes	6th scalar argument
A10		yes	7th scalar argument
A11		yes	8th scalar argument
A12		yes	9th scalar argument
A13		yes	
A14		yes	
A15		yes	
AL0-AL7	A side local L	no	
AM0-AM7	A side local M	no	

Table 6-2. Register Usage (continued)

Register	File	Preserved by Callee?	Role in Calling Convention
VB0	B side vector	no	1st vector argument
VB1		no	2nd vector argument
VB2		no	3rd vector argument
VB3		no	4th vector argument
VB4		no	5th vector argument
VB5		no	6th vector argument
VB6		no	7th vector argument
VB7		no	8th vector argument
VB8		no	9th vector argument
VB9		no	10th vector argument
VB10		no	11th vector argument
VB11		no	12th vector argument
VB12		no	13th vector argument
VB13		no	14th vector argument
VB14		yes	15th vector argument
VB15		yes	16th vector argument
VBL0-VBL7	B side local L	no	
VBM-VBM7	B side local M	no	
D0-D14	D unit local	no	
D15		yes	Stack Pointer
RP	Control	yes	Return Pointer
P0	Vector predicates	no	1st vector predicate argument
P1		no	2nd vector predicate argument
P2		no	3rd vector predicate argument
P3		no	4th vector predicate argument
P4		no	5th vector predicate argument
P5		no	6th vector predicate argument
P6		no	7th vector predicate argument
P7		no	8th vector predicate argument
CUCR0-CUCR3	C-unit Control Register	no	

All other control registers are not saved or restored by the compiler.

The compiler assumes that control registers not listed in [Table 6-2](#) that can have an effect on compiled code have default values.

6.4 Function Structure and Calling Conventions

The C/C++ compiler imposes a strict set of rules on function calls. Except for special run-time support functions, any function that calls or is called by a C/C++ function must follow these rules. Failure to adhere to these rules can disrupt the C/C++ environment and cause a program to fail.

For details on the calling conventions, refer to the *C7000 Embedded Application Binary Interface (EABI) Reference Guide* ([SPRUIG4](#)).

6.4.1 How a Function Makes a Call

A function (parent function) performs the following tasks when it calls another function (child function).

The C7000 has dedicated instructions and registers to manage call and return operations. The CALL instruction saves the return address in the Return Pointer (RP) register and transfers control to the called function. The RET instruction restores the PC from the RP, thereby returning control to the callee.

The C7000 CPU has a pipeline model that can function in both a protected or unprotected state. The CPU must be in the protected state, not unprotected state, when a call or return is made.

A function (parent function) performs the following tasks when it calls another function (child function):

- Arguments passed to a function are placed in registers or on the stack.
 - If arguments are passed to a function, as many as can fit are placed in the nine "scalar" and sixteen "vector" registers that are available for argument passing.
 - Arguments whose declared type is 64 bits or less are assigned to scalar registers A4 through A12.
 - Arguments whose declared is between 64 and 512 bits in size are passed in vector registers VB0-VB15.
 - Arguments that are declared as vector predicates are passed in vector predicate registers P0-P7.
 - Arguments larger than 512 bits are passed by reference. See the "Values Passed and Returned by Reference" section in the *C7000 Embedded Application Binary Interface (EABI) Reference Guide (SPRUIG4)*.
 - Any remaining arguments are placed on the stack at increasing addresses, such that the first one will be at address SP+16 upon entry to the callee.
 - Each argument with a scalar or vector type is placed at the next available address correctly aligned for its type.
 - Structures are aligned to the next power of two greater than or equal to their size, up to a maximum of 8 bytes.
 - Each argument reserves an amount of stack space equal to its size rounded up to the next multiple of its alignment.
 - For a variadic C function (declared with an ellipsis indicating that it is called with varying numbers of arguments), the last explicitly declared argument and all remaining arguments are passed on the stack, so that its stack address can act as a reference for accessing the undeclared arguments.
 - An argument that is not declared in a prototype and whose size is less than the size of int is passed as an int, in accordance with the C language.
- The calling function must save register RP so that it is not overwritten by the CALL instruction. It must also save any live local or global registers that are not preserved by the called function (as part of the save-on-entry register set). The save-on-entry register set includes A8-A15, B14/VB14, and B15/VB15.
- The caller (parent) calls the function (child).

See the "Calling Conventions" chapter in the *C7000 Embedded Application Binary Interface (EABI) Reference Guide (SPRUIG4)* for more information.

6.4.2 How a Called Function Responds

A called function (child function) must perform the following tasks:

1. The called function (child) already has 16 bytes of reserved stack frame space available, but if the space required to store its local variables, temporary storage areas, and arguments to functions is larger than 16 bytes, then the called function allocates additional space on the stack.
2. If the called function calls any other functions, it must make sure that 16 bytes of unused space is also allocated on the stack and reserved for its called functions. The called function must also save its return address on the stack. Otherwise, it is left in the return register (RP) and is overwritten by the next function call.
3. If the called function modifies any save-on-entry registers (A8-A15, VB14-VB15), it must save them, either in other registers or on the stack. The called function can modify any other registers without saving them because they will have been saved by a caller function prior to the call if they were used.
4. If the called function expects a structure argument, effort is made to pass the structure by value if its

value can fit into a 64-bit or 512-bit argument register. Otherwise, the called function receives a pointer to the structure instead. If writes are made to the structure from within the called function, space for a local copy of the structure must be allocated on the stack and the local structure must be copied from the passed pointer to the structure. If no writes are made to the structure, it can be referenced in the called function indirectly through the pointer argument.

You must be careful to declare functions properly that accept structure arguments, both at the point where they are called (so that the structure argument is passed as an address) and at the point where they are declared (so the function knows to copy the structure to a local copy).

5. The called function executes the code for the function.
6. The return value is handled as follows:
 - If the called function returns any integer, pointer, float, double, long double, long type, or vector data type less than or equal to 64 bits in size, the return value is placed in register A4.
 - If the called function returns a vector data type greater than 64 bits in size, the return value is placed in register VB0.
 - If the called function returns a vector predicate type, the return value is placed in register P0.
 - If the called function returns a structure, it is returned by value if it is small enough to fit into register A4 or register VB0. Otherwise, the caller allocates space for the structure and passes the address of the return space to the called function in register A1. To return a structure, the called function copies the structure to the memory block pointer to by the extra argument.

In this way, the caller can be smart about telling the called function where to return the structure. For example, in the statement $s = f(x)$, where s is a structure and f is a function that returns a structure, the caller can actually make the call as $f(\&s, x)$. The function f then copies the return structure directly into s , performing the assignment automatically.

If the caller does not use the return structure value, an address value of 0 can be passed as the first argument. This directs the called function not to copy the return structure.

You must be careful to declare functions properly that return structures, both at the point where they are called (so that the extra argument is passed) and at the point where they are declared (so the function knows to copy the result).

7. Any save-on-entry register (A8-A15, B14/VB14, B15/VB15) that was saved in Step 3 is restored.
8. The value of the return register (RP) is also restored if it was saved.
9. Any space that was allocated during this call sequence is reclaimed.
10. The function returns by invoking the RET instruction, which returns to the location contained in the return register (RP).

6.4.3 Accessing Arguments and Local Variables

A function accesses its stack arguments and local nonregister variables indirectly through register D15 (SP), which points to the top of the stack. Since the stack grows toward smaller addresses, the local and argument data for a function are accessed with a positive offset from SP. Local variables, temporary storage, and the area reserved for stack arguments to functions called by this function are accessed with offsets from the SP.

For more information, see [Section 6.4.2](#). For more information on the C/C++ System stack, see [Section 6.1.2](#).

6.5 Accessing Linker Symbols in C and C++

See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

6.6 Run-Time-Support Arithmetic Routines

The run-time-support library contains a number of assembly language functions that provide arithmetic routines for C/C++ math operations that the C7000 instruction set does not provide, such as integer division, integer remainder, and floating-point operations.

These routines follow the standard C/C++ calling sequence. The compiler automatically adds these routines when appropriate; they are not intended to be called directly by your programs.

The source code for these functions is provided in the `lib/src` source directory. The source code has comments that describe the operation of the functions. You can extract, inspect, and modify any of the math functions. Be sure, however, that you follow the calling conventions and register-saving rules outlined in this chapter. [Table 6-3](#) summarizes the run-time-support functions used for arithmetic.

Table 6-3. C7000 Run-Time-Support Arithmetic Functions

Return Type	C Function	Description
void	<code>__c7xabi_abort_msg (const char *)</code>	Report failed assertion. (See notes below.)
double	<code>__c7xabi_divd (double, double)</code>	Divide two double-precision floats.
float	<code>__c7xabi_divf (float, float)</code>	Divide two single-precision floats.
int	<code>__c7xabi_divi (int, int)</code>	32-bit signed integer division.
long long	<code>__c7xabi_divlli (long long, long long)</code>	64-bit signed integer division.
unsigned	<code>__c7xabi_divu (unsigned, unsigned)</code>	32-bit unsigned integer division.
unsigned long long	<code>__c7xabi_divull (unsigned long long, unsigned long long)</code>	64-bit unsigned integer division.
long long	<code>__c7xabi_fixdlli (double)</code>	Convert double-precision float to 64-bit integer.
unsigned	<code>__c7xabi_fixdu (double)</code>	Convert double-precision float to 32-bit unsigned integer.
unsigned long long	<code>__c7xabi_fixdull (double)</code>	Convert double-precision float to 64-bit unsigned integer.
long long	<code>__c7xabi_fixfli (float)</code>	Convert single-precision float to 64-bit integer.
unsigned	<code>__c7xabi_fixfu (float)</code>	Convert single-precision float to 32-bit unsigned integer.
unsigned long long	<code>__c7xabi_fixfull (float)</code>	Convert single-precision float to 64-bit unsigned integer.
double	<code>__c7xabi_ftllid (long long)</code>	Convert 64-bit integer to double-precision float.
float	<code>__c7xabi_ftllif (long long)</code>	Convert 64-bit integer to single-precision float.
double	<code>__c7xabi_ftlud (unsigned)</code>	Convert 32-bit unsigned integer to double-precision float.
float	<code>__c7xabi_ftluf (unsigned)</code>	Convert 32-bit unsigned integer to single-precision float.
double	<code>__c7xabi_ftulld (unsigned long long)</code>	Convert 64-bit unsigned integer to double-precision float.
float	<code>__c7xabi_ftullf (unsigned long long)</code>	Convert 64-bit unsigned integer to single-precision float.
int	<code>__c7xabi_remi (int, int)</code>	32-bit integer modulo.
long long	<code>__c7xabi_relli (long long, long long)</code>	64-bit integer modulo.
unsigned	<code>__c7xabi_remu (unsigned, unsigned)</code>	32-bit unsigned integer modulo.
unsigned long long	<code>__c7xabi_renull (unsigned long long, unsigned long long)</code>	64-bit unsigned integer modulo.
void	<code>__c7xabi_strasg (int*, const int*, unsigned)</code>	Block copy. (See notes below.)
	<code>__c7xabi_unwind_cpp_pr0</code>	Short frame unwinding, 16-bit scope.
	<code>__c7xabi_unwind_cpp_pr1</code>	Long frame unwinding, 16-bit scope.
	<code>__c7xabi_unwind_cpp_pr2</code>	Long frame unwinding, 32-bit scope.
	<code>__c7xabi_unwind_cpp_pr3</code>	Unwinding, 24-bit encoding, 16-bit scope.

`__c7xabi_abort_msg()` Function:

```
void __c7xabi_abort_msg(const char *msg)
```

The function `__c7xabi_abort_msg()` is generated to print a diagnostic message when a run-time assertion (for example, the C `assert` macro) fails. It must not return. That is, it must call `abort` or terminate the program by other means.

`__c7xabi_strasg()` Function:

```
void __c7xabi_strasg(int* dst, const int* src, unsigned cnt)
```


The function `__c7xabi_strasg()` is generated by the compiler for efficient out-of-line structure or array copy operations. The `cnt` argument is the size in bytes.

6.7 System Initialization

Before you can run a C/C++ program, you must create the C/C++ run-time environment. The C/C++ boot routine performs this task using a function called `c_int00` (or `_c_int00`). The run-time-support source library, `rts.src`, contains the source to this routine in a module named `boot.c` (or `boot.asm`).

To begin running the system, the `c_int00` function can be branched to or called, but it is usually vectored to by reset hardware. You must link the `c_int00` function with the other object files. This occurs automatically when you use the `--rom_model` or `--ram_model` link option and include a standard run-time-support library as one of the linker input files.

When C/C++ programs are linked, the linker sets the entry point value in the executable output file to the symbol `c_int00`.

The `c_int00` function performs the following tasks to initialize the environment:

1. Defines a section called `.stack` for the system stack and sets up the initial stack pointers
2. Performs C autoinitialization of global/static variables. For more information, see [Section 6.7.2](#).
3. Initializes global variables by copying the data from the initialization tables to the storage allocated for the variables in the `.bss` section. If you are initializing variables at load time (`--ram_model` option), a loader performs this step before the program runs (it is not performed by the boot routine).
4. Calls C++ initialization routines for file scope construction from the global constructor table. For more information, see [Section 6.7.2.6](#).
5. Calls the `main()` function to run the C/C++ program

You can replace or modify the boot routine to meet your system requirements. However, the boot routine *must* perform the operations listed above to correctly initialize the C/C++ environment.

6.7.1 Boot Hook Functions for System Pre-Initialization

Boot hooks are points at which you may insert application functions into the C/C++ boot process. Default boot hook functions are provided with the run-time support (RTS) library. However, you can implement customized versions of these boot hook functions, which override the default boot hook functions in the RTS library if they are linked before the run-time library. Such functions can perform any application-specific initialization before continuing with the C/C++ environment setup.

The following boot hook functions are available:

`_system_pre_init()`: This function provides a place to perform application-specific initialization. It is invoked after the stack pointer is initialized but before any C/C++ environment setup is performed. By default, `_system_pre_init()` should return a non-zero value. The default C/C++ environment setup is bypassed if `_system_pre_init()` returns 0.

`_system_post_cinit()`: This function is invoked during C/C++ environment setup, after C/C++ global data is initialized but before any C++ constructors are called. This function should not return a value.

6.7.2 Automatic Initialization of Variables

Any global variables declared as preinitialized must have initial values assigned to them before a C/C++ program starts running. The process of retrieving these variables' data and initializing the variables with the data is called autoinitialization. Internally, the compiler and linker coordinate to produce compressed initialization tables. Your code should not access the initialization table.

6.7.2.1 Zero Initializing Variables

In ANSI C, global and static variables that are not explicitly initialized must be set to 0 before program execution. The C/C++ compiler supports preinitialization of uninitialized variables by default. This can be turned off by specifying the linker option `--zero_init=off`.

6.7.2.2 Direct Initialization

The compiler uses direct initialization to initialize global variables. For example, consider the following C code:

```
int i    = 23;
int a[5] = { 1, 2, 3, 4, 5 };
```

The compiler allocates the variables 'i' and 'a[]' to .data section and the initial values are placed directly.

```
.global i
.data
.align 4

i:
    .field      23,32                ; i @ 0

.global a
.data
.align 4

a:
    .field      1,32                ; a[0] @ 0
    .field      2,32                ; a[1] @ 32
    .field      3,32                ; a[2] @ 64
    .field      4,32                ; a[3] @ 96
    .field      5,32                ; a[4] @ 128
```

Each compiled module that defines static or global variables contains these .data sections. The linker treats the .data section like any other initialized section and creates an output section. In the load-time initialization model, the sections are loaded into memory and used by the program. See [Section 6.7.2.5](#).

In the run-time initialization model, the linker uses the data in these sections to create initialization data and an additional compressed initialization table. The boot routine processes the initialization table to copy data from load addresses to run addresses. See [Section 6.7.2.3](#).

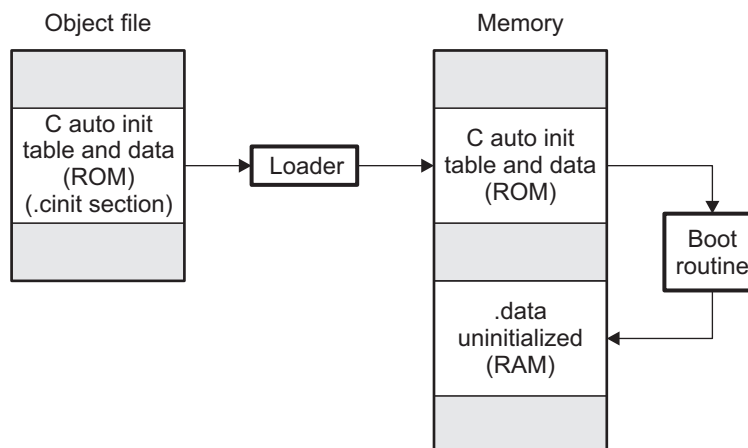
6.7.2.3 Autoinitialization of Variables at Run Time

Autoinitializing variables at run time is the default method of autoinitialization. To use this method, invoke the linker with the --rom_model option.

Using this method, the linker creates a compressed initialization table and initialization data from the direct initialized sections in the compiled module. The table and data are used by the C/C++ boot routine to initialize variables in RAM using the table and data in ROM.

[Figure 6-7](#) illustrates autoinitialization at run time. Use this method in any system where your application runs from code burned into ROM.

Figure 6-7. Autoinitialization at Run Time



6.7.2.4 Autoinitialization Tables

The compiled object files do not have initialization tables. The variables are initialized directly. The linker, when the `--rom_model` option is specified, creates C auto initialization table and the initialization data. The linker creates both the table and the initialization data in an output section named `.cinit`.

The autoinitialization table has the following format:

`__TI_CINIT_Base:`

48-bit load address	48-bit run address
⋮	⋮
48-bit load address	48-bit run address

`__TI_CINIT_Limit:`

The linker defined symbols `__TI_CINIT_Base` and `__TI_CINIT_Limit` point to the start and end of the table, respectively. Each entry in this table corresponds to one output section that needs to be initialized. The initialization data for each output section could be encoded using different encoding.

The load address in the C auto initialization record points to initialization data with the following format:

8-bit index	Encoded data
-------------	--------------

The first 8-bits of the initialization data is the handler index. It indexes into a handler table to get the address of a handler function that knows how to decode the following data.

The handler table is a list of 32-bit function pointers.

`__TI_Handler_Table_Base:`

48-bit handler 1 address
⋮
48-bit handler n address

`__TI_Handler_Table_Limit:`

The *encoded data* that follows the 8-bit index can be in one of the following format types. For clarity the 8-bit index is also depicted for each format.

6.7.2.4.1 Length Followed by Data Format

8-bit index	24-bit padding	32-bit length (N)	N byte initialization data (not compressed)
-------------	----------------	-------------------	---

The compiler uses 24-bit padding to align the length field to a 32-bit boundary. The 32-bit length field encodes the length of the initialization data in bytes (N). N byte initialization data is not compressed and is copied to the run address as is.

The run-time support library has a function `__TI_zero_init()` to process this type of initialization data. The first argument to this function is the address pointing to the byte after the 8-bit index. The second argument is the run address from the C auto initialization record.

6.7.2.4.2 Zero Initialization Format

8-bit index	24-bit padding	32-bit length (N)
-------------	----------------	-------------------

The compiler uses 24-bit padding to align the length field to a 32-bit boundary. The 32-bit length field encodes the number of bytes to be zero initialized.

The run-time support library has a function `__TI_zero_init()` to process the zero initialization. The first argument to this function is the address pointing to the byte after the 8-bit index. The second argument is the run address from the C auto initialization record.

6.7.2.4.3 Run Length Encoded (RLE) Format

8-bit index	Initialization data compressed using run length encoding
-------------	--

The data following the 8-bit index is compressed using Run Length Encoded (RLE) format. uses a simple run length encoding that can be decompressed using the following algorithm:

1. Read the first byte, Delimiter (D).
2. Read the next byte (B).
3. If $B \neq D$, copy B to the output buffer and go to step 2.
4. Read the next byte (L).
 - a. If $L == 0$, then length is either a 16-bit, a 24-bit value, or we've reached the end of the data, read next byte (L).
 1. If $L == 0$, length is a 24-bit value or the end of the data is reached, read next byte (L).
 - a. If $L == 0$, the end of the data is reached, go to step 7.
 - b. Else $L \leq 16$, read next two bytes into lower 16 bits of L to complete 24-bit value for L.
 2. Else $L \leq 8$, read next byte into lower 8 bits of L to complete 16-bit value for L.
 - b. Else if $L > 0$ and $L < 4$, copy D to the output buffer L times. Go to step 2.
 - c. Else, length is 8-bit value (L).
5. Read the next byte (C); C is the repeat character.
6. Write C to the output buffer L times; go to step 2.
7. End of processing.

The run-time support library has a routine `__TI_decompress_rle24()` to decompress data compressed using RLE. The first argument to this function is the address pointing to the byte after the 8-bit index. The second argument is the run address from the C auto initialization record.

RLE Decompression Routine

NOTE: The previous decompression routine, `__TI_decompress_rle()`, is included in the run-time-support library for decompressing RLE encodings generated by older versions of the linker.

6.7.2.4.4 Lempel-Ziv-Storer-Szymanski Compression (LZSS) Format

8-bit index	Initialization data compressed using LZSS
-------------	---

The data following the 8-bit index is compressed using LZSS compression. The run-time support library has the routine `__TI_decompress_lzss()` to decompress the data compressed using LZSS. The first argument to this function is the address pointing to the byte after the 8-bit index. The second argument is the run address from the C auto initialization record.

6.7.2.5 Initialization of Variables at Load Time

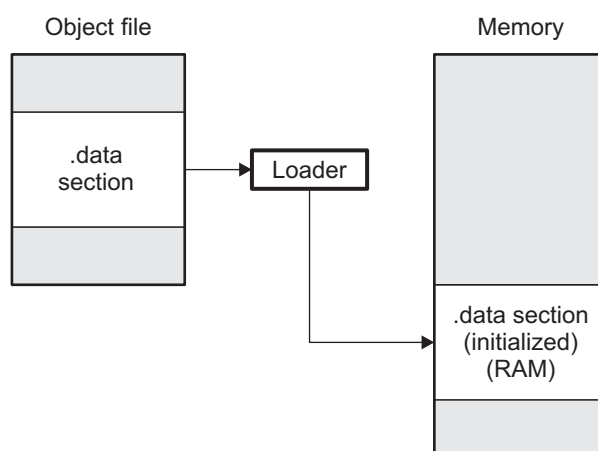
Initialization of variables at load time enhances performance by reducing boot time and by saving the memory used by the initialization tables. To use this method, invoke the linker with the `--ram_model` option.

When you use the `--ram_model` link option, the linker does not generate C autoinitialization tables and data. The direct initialized sections (`.data`) in the compiled object files are combined according to the linker command file to generate initialized output sections. The loader loads the initialized output sections into memory. After the load, the variables are assigned their initial values.

Since the linker does not generate the C autoinitialization tables, no boot time initialization is performed.

Figure 6-8 illustrates the initialization of variables at load time.

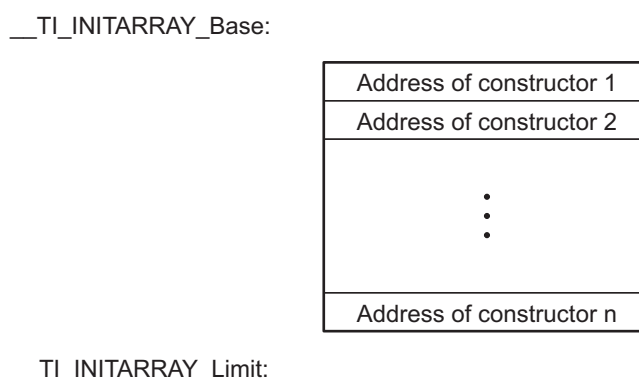
Figure 6-8. Initialization at Load Time



6.7.2.6 Global Constructors

All global C++ variables that have constructors must have their constructor called before `main()`. The compiler builds a table of global constructor addresses that must be called, in order, before `main()` in a section called `.init_array`. The linker combines the `.init_array` section from each input file to form a single table in the `.init_array` section. The boot routine uses this table to execute the constructors. The linker defines two symbols to identify the combined `.init_array` table as shown below. This table is not null terminated by the linker.

Figure 6-9. Constructor Table



Using Run-Time-Support Functions and Building Libraries

Some of the features of C/C++ (such as I/O, dynamic memory allocation, string operations, and trigonometric functions) are provided as an ANSI/ISO C/C++ standard library, rather than as part of the compiler itself. The TI implementation of this library is the run-time-support library (RTS). The C/C++ compiler implements the ISO standard library except for those facilities that handle signal and locale issues (properties that depend on local language, nationality, or culture). Using the ANSI/ISO standard library ensures a consistent set of functions that provide for greater portability.

In addition to the ANSI/ISO-specified functions, the run-time-support library includes routines that give you processor-specific commands and direct C language I/O requests. These are detailed in [Section 7.1](#) and [Section 7.2](#).

A library-build utility is provided with the code generation tools that lets you create customized run-time-support libraries. This process is described in [Section 7.4](#).

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7.1 C and C++ Run-Time Support Libraries

C7000 compiler releases include pre-built run-time support (RTS) libraries that provide all the standard capabilities. Separate libraries are provided for each target CPU version, big and little endian support, and C++ exception support. See [Section 7.1.7](#) for information on the library-naming conventions.

The run-time-support library contains the following:

- ANSI/ISO C/C++ standard library
- C I/O library
- Low-level support functions that provide I/O to the host operating system
- Fundamental arithmetic routines
- System startup routine, `_c_int00`
- Compiler helper functions (to support language features that are not directly efficiently expressible in C/C++)

The run-time-support libraries do not contain functions involving signals and locale issues.

The C++ library supports wide chars, in that template functions and classes that are defined for `char` are also available for wide `char`. For example, wide `char` stream classes `wios`, `wiostream`, `wstreambuf` and so on (corresponding to `char` classes `ios`, `iostream`, `streambuf`) are implemented. However, there is no low-level file I/O for wide chars. Also, the C library interface to wide `char` support (through the C++ headers `<wchar>` and `<cwctype>`) is limited as described in [Section 5.1](#).

TI does not provide documentation that covers the functionality of the C++ library. TI suggests referring to one of the following sources:

- *The Standard C++ Library: A Tutorial and Reference*, Nicolai M. Josuttis, Addison-Wesley, ISBN 0-201-37926-0
- *The C++ Programming Language* (Third or Special Editions), Bjarne Stroustrup, Addison-Wesley, ISBN 0-201-88954-4 or 0-201-70073-5

7.1.1 Linking Code With the Object Library

When you link your program, you must specify the object library as one of the linker input files so that references to the I/O and run-time-support functions can be resolved. You can either specify the library or allow the compiler to select one for you. See [Section 11.3.1](#) for further information.

When a library is linked, the linker includes only those library members required to resolve undefined references. For more information about linking, see [Chapter 12](#).

C, C++, and mixed C and C++ programs can use the same run-time-support library. Run-time-support functions and variables that can be called and referenced from both C and C++ will have the same linkage.

7.1.2 Header Files

You must use the header files provided with the compiler run-time support when using functions from C/C++ standard library. Set the `C7X_C_DIR` environment variable to the include directory where the tools are installed.

The following header files provide TI extensions to the C standard:

- `c7x.h` -- Provides intrinsic definitions.
- `c7x_direct.h` -- Provides low-level "direct-mapped" intrinsic definitions. Automatically included by `c7x.h`.
- `c7x_vpred.h` -- Provides low-level vector predication intrinsic definitions. Automatically included by `c7x.h`.
- `c7x_mma.h` -- Provides MMA intrinsic definitions. Automatically included by `c7x.h`.
- `c6x_migration.h` -- Provides definitions of legacy C6000 intrinsics.
- `c7x_luthist.h` -- Defines intrinsics for lookup table and histogram features. Automatically included by `c7x.h`.
- `c7x_strm.h` -- Defines intrinsics for the Streaming Engine (SE) and Stream Address Generator (SA).

(See [Section 4.14.](#)) Automatically included by `c7x.h`.

- `cpy_tbl.h` -- Declares the `copy_in()` RTS function, which is used to move code or data from a load location to a separate run location at run-time. This function helps manage overlays.
- `_data_synch.h` -- Declares functions used by the RTS library to help with shared data synchronization. For example, these functions are used when flushing the local data cache to global shared memory.
- `file.h` -- Declares functions used by low-level I/O functions in the RTS library.
- `gsm.h` -- Provides basic DSP operations and GSM math operations defined by the European Telecommunications Standards Institute (ETSI).
- `_lock.h` -- Used when declaring system-wide mutex locks. This header file is deprecated; use `_reg_mutex_api.h` and `_mutex.h` instead.
- `memory.h` -- Provides the `memalign()` function, which is not required by the C standard.
- `_mutex.h` -- Declares functions used by the RTS library to help facilitate mutexes for specific resources that are owned by the RTS. For example, these functions are used for heap or file table allocation.
- `_pthread.h` -- Declares low-level mutex infrastructure functions and provides support for recursive mutexes.
- `_reg_mutex_api.h` -- Declares a function that can be used by an RTOS to register an underlying lock mechanism and/or thread ID mechanism that is implemented in the RTOS but is called indirectly by the RTS' `_mutex.h` functions.
- `_reg_synch_api.h` -- Declares a function that can be used by an RTOS to register an underlying cache synchronization mechanism that is implemented in the RTOS but is called indirectly by the RTS' `_data_synch.h` functions.
- `strings.h` -- Provides additional string functions, including `bcmp()`, `bcopy()`, `bzero()`, `ffs()`, `index()`, `rindex()`, `strcasecmp()`, and `strncasecmp()`. See the v7.6 release notes for details on these functions.

The following standard C header files are provided with the compiler: `assert.h`, `complex.h`, `ctype.h`, `errno.h`, `float.h`, `inttypes.h`, `iso646.h`, `limits.h`, `locale.h`, `math.h`, `setjmp.h`, `signal.h`, `stdarg.h`, `stdbool.h`, `stddef.h`, `stdint.h`, `stdio.h`, `stdlib.h`, `string.h`, `time.h`, `wchar.h`, and `wctype.h`.

The following standard C++ header files are provided with the compiler: `algorithm`, `bitset`, `cassert`, `cctype`, `cerrno`, `cfloat`, `ciso646`, `climits`, `clocale`, `cmath`, `complex`, `csetjmp`, `csignal`, `cstdarg`, `cstddef`, `cstdio`, `cstdlib`, `cstring`, `ctime`, `cwchar`, `cwctype`, `deque`, `exception`, `fstream`, `functional`, `hash_map`, `hash_set`, `io manip`, `ios`, `iosfwd`, `iostream`, `istream`, `iterator`, `limits`, `list`, `locale`, `map`, `memory`, `new`, `numeric`, `ostream`, `queue`, `rope`, `set`, `sstream`, `stack`, `stdexcept`, `streambuf`, `string`, `stringstream`, `typeinfo`, `utility`, `valarray`, and `vector`.

The following header files are for use with older C++ code: `fstream.h`, `io manip.h`, `iostream.h`, `new.h`, `stdiostream.h`, `stl.h`, and `stringstream.h`.

The following header files are for internal use by TI components and should not be directly included by your applications: `_data_synch.h`, `_fmt_specifier.h`, `_isfuncdcl.h`, `_isfuncdef.h`, `_mutex.h`, `_pthread.h`, `access.h`, `c60asm.i`, `cpp_inline_math.h`, `elf_linkage.h`, `elfnames.h`, `linkage.h`, `mathf.h`, `mathl.h`, `pprof.h`, `unaccess.h`, `wchar.h`, `xcomplex`, `xdebug`, `xhash`, `xiosbase`, `xlocale`, `xlocinfo`, `xlocinfo.h`, `xlocmes`, `xlocmon`, `xlocnum`, `xloctime`, `xmemory`, `xstddef`, `xstring`, `xtree`, `xutility`, `xwcc.h`, `ymath.h`, and `yvals.h`.

7.1.3 Modifying a Library Function

You can inspect or modify library functions by examining the source code in the `lib/src` subdirectory of the compiler installation. For example, `C:\ti\ccsv7\tools\compiler\c7000_#.##\lib\src`.

Once you have located the relevant source code, change the specific function file and rebuild the library.

You can use this source tree to rebuild the `rts7100_le.lib`, `rts7100_le_eh.lib`, `rts7100_be.lib`, or `rts7100_be_eh.lib` library or to build a new library. See [Section 7.1.7](#) for details on library naming and [Section 7.4](#) for details on building

7.1.4 Support for String Handling

The library includes the header files `<string.h>` and `<strings.h>`, which provide the following functions for string handling beyond those required.

- `string.h`
 - `strdup()`, which duplicates a string by dynamically allocating memory and copying the string to this allocated memory
 - `strcmp()` and `strncmp()`, which perform case-sensitive string comparisons
 - `memcpy()`, which copies memory from one location to another
 - `memcmp()`, which compares sections of memory
- `strings.h`
 - `bcmp()`, which is equivalent to `memcmp()`
 - `bcopy()`, which is equivalent to `memmove()`
 - `bzero()`, which is equivalent to `memset(.., 0, ...)`;
 - `ffs()`, which finds the first bit set and returns the index of that bit
 - `index()`, which is equivalent to `strchr()`
 - `rindex()`, which is equivalent to `strrchr()`
 - `strcasecmp()` and `strncasecmp()`, which perform case-insensitive string comparisons

7.1.5 Minimal Support for Internationalization

The library includes the header files `<locale.h>`, `<wchar.h>`, and `<wctype.h>`, which provide APIs to support non-ASCII character sets and conventions. Our implementation of these APIs is limited in the following ways:

- The library has minimal support for wide and multibyte characters. The type `wchar_t` is implemented as unsigned int. The wide character set is equivalent to the set of values of type `char`. The library includes the header files `<wchar.h>` and `<wctype.h>` but does not include all the functions specified in the standard. See [Section 5.5](#) for more information about extended character sets.
- The C library includes the header file `<locale.h>` but with a minimal implementation. The only supported locale is the C locale. That is, library behavior that is specified to vary by locale is hard-coded to the behavior of the C locale, and attempting to install a different locale via a call to `setlocale()` will return `NULL`.

7.1.6 Allowable Number of Open Files

In the `<stdio.h>` header file, the value for the macro `FOPEN_MAX` has the value of the macro `_NFILE`, which is set to 10. The impact is that you can only have 10 files simultaneously open at one time (including the pre-defined streams - `stdin`, `stdout`, `stderr`).

The C standard requires that the minimum value for the `FOPEN_MAX` macro is 8. The macro determines the maximum number of files that can be opened at one time. The macro is defined in the `stdio.h` header file and can be modified by changing the value of the `_NFILE` macro and recompiling the library.

7.1.7 Library Naming Conventions

By default, the linker uses automatic library selection to select the correct run-time-support library (see [Section 11.3.1.1](#)) for your application. If you select the library manually, you must select the matching library using a naming scheme like the following:

```
rts7100_[endian][_eh].lib
```

<i>endian</i>	Indicates endianness:
le	Little-endian library
be	Big-endian library
<i>eh</i>	Indicates whether the library has exception handling support
(blank)	exception handling not supported
_eh	exception handling support

7.2 The C I/O Functions

The C I/O functions make it possible to access the host's operating system to perform I/O. The capability to perform I/O on the host gives you more options when debugging and testing code.

The I/O functions are logically divided into layers: high level, low level, and device-driver level.

With properly written device drivers, the C-standard high-level I/O functions can be used to perform I/O on custom user-defined devices. This provides an easy way to use the sophisticated buffering of the high-level I/O functions on an arbitrary device.

Debugger Required for Default HOST

NOTE: For the default HOST device to work, there must be a debugger to handle the C I/O requests; the default HOST device cannot work by itself in an embedded system. To work in an embedded system, you will need to provide an appropriate driver for your system.

NOTE: C I/O Mysteriously Fails

If there is not enough space on the heap for a C I/O buffer, operations on the file will silently fail. If a call to `printf()` mysteriously fails, this may be the reason. The heap needs to be at least large enough to allocate a block of size `BUFSIZ` (defined in `stdio.h`) for every file on which I/O is performed, including `stdout`, `stdin`, and `stderr`, plus allocations performed by the user's code, plus allocation bookkeeping overhead. Alternately, declare a char array of size `BUFSIZ` and pass it to `setvbuf` to avoid dynamic allocation. To set the heap size, use the `--heap_size` option when linking.

NOTE: Open Mysteriously Fails

The run-time support limits the total number of open files to a small number relative to general-purpose processors. If you attempt to open more files than the maximum, you may find that the open will mysteriously fail. You can increase the number of open files by extracting the source code from `rts.src` and editing the constants controlling the size of some of the C I/O data structures. The macro `_NFILE` controls how many `FILE` (`fopen`) objects can be open at one time (`stdin`, `stdout`, and `stderr` count against this total). (See also `FOPEN_MAX`.) The macro `_NSTREAM` controls how many low-level file descriptors can be open at one time (the low-level files underlying `stdin`, `stdout`, and `stderr` count against this total). The macro `_NDEVICE` controls how many device drivers are installed at one time (the HOST device counts against this total).

7.2.1 High-Level I/O Functions

The high-level functions are the standard C library of stream I/O routines (printf, scanf, fopen, getchar, and so on). These functions call one or more low-level I/O functions to carry out the high-level I/O request. The high-level I/O routines operate on FILE pointers, also called *streams*.

Portable applications should use only the high-level I/O functions.

To use the high-level I/O functions, include the header file `stdio.h`, or `cstdio` for C++ code, for each module that references a C I/O function.

For example, given the following C program in a file named `main.c`:

```
#include <stdio.h>

void main()
{
    FILE *fid;

    fid = fopen("myfile", "w");
    fprintf(fid, "Hello, world\n");
    fclose(fid);

    printf("Hello again, world\n");
}
```

Issuing the following compiler command compiles, links, and creates the file `main.out` from the run-time-support library:

```
cl7x main.c -z --heap_size=1000 --output_file=main.out
```

Executing `main.out` results in

```
Hello, world
```

being output to a file and

```
Hello again, world
```

being output to your host's stdout window.

7.2.1.1 Formatting and the Format Conversion Buffer

The internal routine behind the C I/O functions—such as `printf()`, `vsnprintf()`, and `snprintf()`—reserves stack space for a format conversion buffer. The buffer size is set by the macro `FORMAT_CONVERSION_BUFFER`, which is defined in `format.h`. Consider the following issues before reducing the size of this buffer:

- The default buffer size is 510 bytes. If `MINIMAL` is defined, the size is set to 32, which allows integer values without width specifiers to be printed.
- Each conversion specified with `%xxxx` (except `%s`) must fit in `FORMAT_CONVERSION_BUFSIZE`. This means any individual formatted float or integer value, accounting for width and precision specifiers, needs to fit in the buffer. Since the actual value of any representable number should easily fit, the main concern is ensuring the width and/or precision size meets the constraints.
- The length of converted strings using `%s` are unaffected by any change in `FORMAT_CONVERSION_BUFSIZE`. For example, you can specify `printf("%s value is %d", some_really_long_string, intval)` without a problem.
- The constraint is for each individual item being converted. For example a format string of `%d item1 %f item2 %e item3` does not need to fit in the buffer. Instead, each converted item specified with a `%` format must fit.
- There is no buffer overrun check.

7.2.2 Overview of Low-Level I/O Implementation

The low-level functions are comprised of seven basic I/O functions: open, read, write, close, lseek, rename, and unlink. These low-level routines provide the interface between the high-level functions and the device-level drivers that actually perform the I/O command on the specified device.

The low-level functions are designed to be appropriate for all I/O methods, even those which are not actually disk files. Abstractly, all I/O channels can be treated as files, although some operations (such as lseek) may not be appropriate. See [Section 7.2.3](#) for more details.

The low-level functions are inspired by, but not identical to, the POSIX functions of the same names.

The low-level functions operate on file descriptors. A file descriptor is an integer returned by open, representing an opened file. Multiple file descriptors may be associated with a file; each has its own independent file position indicator.

open	Open File for I/O				
Syntax	<pre>#include <file.h> int open (const char * path , unsigned flags , int file_descriptor);</pre>				
Description	<p>The open function opens the file specified by <i>path</i> and prepares it for I/O.</p> <ul style="list-style-type: none"> The <i>path</i> is the filename of the file to be opened, including an optional directory path and an optional device specifier (see Section 7.2.5). The <i>flags</i> are attributes that specify how the file is manipulated. The flags are specified using the following symbols: <pre>O_RDONLY (0x0000) /* open for reading */ O_WRONLY (0x0001) /* open for writing */ O_RDWR (0x0002) /* open for read & write */ O_APPEND (0x0008) /* append on each write */ O_CREAT (0x0200) /* open with file create */ O_TRUNC (0x0400) /* open with truncation */ O_BINARY (0x8000) /* open in binary mode */</pre> <p>Low-level I/O routines allow or disallow some operations depending on the flags used when the file was opened. Some flags may not be meaningful for some devices, depending on how the device implements files.</p> The <i>file_descriptor</i> is assigned by open to an opened file. The next available file descriptor is assigned to each new file opened. 				
Return Value	<p>The function returns one of the following values:</p> <table> <tr> <td>non-negative file descriptor</td><td>if successful</td></tr> <tr> <td>-1</td><td>on failure</td></tr> </table>	non-negative file descriptor	if successful	-1	on failure
non-negative file descriptor	if successful				
-1	on failure				

close ***Close File for I/O***

Syntax	<pre>#include <file.h> int close (int file_descriptor);</pre>				
Description	<p>The close function closes the file associated with <i>file_descriptor</i>.</p> <p>The <i>file_descriptor</i> is the number assigned by open to an opened file.</p>				
Return Value	<p>The return value is one of the following:</p> <table> <tr> <td>0</td><td>if successful</td></tr> <tr> <td>-1</td><td>on failure</td></tr> </table>	0	if successful	-1	on failure
0	if successful				
-1	on failure				

read ***Read Characters from a File***

Syntax	<pre>#include <file.h> int read (int file_descriptor , char * buffer , unsigned count);</pre>						
Description	<p>The read function reads <i>count</i> characters into the <i>buffer</i> from the file associated with <i>file_descriptor</i>.</p> <ul style="list-style-type: none"> • The <i>file_descriptor</i> is the number assigned by open to an opened file. • The <i>buffer</i> is where the read characters are placed. • The <i>count</i> is the number of characters to read from the file. 						
Return Value	<p>The function returns one of the following values:</p> <table> <tr> <td>0</td><td>if EOF was encountered before any characters were read</td></tr> <tr> <td>#</td><td>number of characters read (may be less than <i>count</i>)</td></tr> <tr> <td>-1</td><td>on failure</td></tr> </table>	0	if EOF was encountered before any characters were read	#	number of characters read (may be less than <i>count</i>)	-1	on failure
0	if EOF was encountered before any characters were read						
#	number of characters read (may be less than <i>count</i>)						
-1	on failure						

write ***Write Characters to a File***

Syntax	<pre>#include <file.h> int write (int file_descriptor , const char * buffer , unsigned count);</pre>				
Description	<p>The write function writes the number of characters specified by <i>count</i> from the <i>buffer</i> to the file associated with <i>file_descriptor</i>.</p> <ul style="list-style-type: none"> • The <i>file_descriptor</i> is the number assigned by open to an opened file. • The <i>buffer</i> is where the characters to be written are located. • The <i>count</i> is the number of characters to write to the file. 				
Return Value	<p>The function returns one of the following values:</p> <table> <tr> <td>#</td><td>number of characters written if successful (may be less than <i>count</i>)</td></tr> <tr> <td>-1</td><td>on failure</td></tr> </table>	#	number of characters written if successful (may be less than <i>count</i>)	-1	on failure
#	number of characters written if successful (may be less than <i>count</i>)				
-1	on failure				

lseek	<i>Set File Position Indicator</i>
Syntax for C	<pre>#include <file.h> off_t lseek (int file_descriptor , off_t offset , int origin);</pre>
Description	<p>The lseek function sets the file position indicator for the given file to a location relative to the specified origin. The file position indicator measures the position in characters from the beginning of the file.</p> <ul style="list-style-type: none"> • The <i>file_descriptor</i> is the number assigned by open to an opened file. • The <i>offset</i> indicates the relative offset from the <i>origin</i> in characters. • The <i>origin</i> is used to indicate which of the base locations the <i>offset</i> is measured from. The <i>origin</i> must be one of the following macros: SEEK_SET (0x0000) Beginning of file SEEK_CUR (0x0001) Current value of the file position indicator SEEK_END (0x0002) End of file
Return Value	<p>The return value is one of the following:</p> <pre># new value of the file position indicator if successful (off_t)-1 on failure</pre>
unlink	<i>Delete File</i>
Syntax	<pre>#include <file.h> int unlink (const char * path);</pre>
Description	<p>The unlink function deletes the file specified by <i>path</i>. Depending on the device, a deleted file may still remain until all file descriptors which have been opened for that file have been closed. See Section 7.2.3.</p> <p>The <i>path</i> is the filename of the file, including path information and optional device prefix. (See Section 7.2.5.)</p>
Return Value	<p>The function returns one of the following values:</p> <pre>0 if successful -1 on failure</pre>

rename	<i>Rename File</i>				
Syntax for C	<pre>#include {<stdio.h> <file.h>} int rename (const char * old_name , const char * new_name);</pre>				
Syntax for C++	<pre>#include {<cstdio> <file.h>} int std::rename (const char * old_name , const char * new_name);</pre>				
Description	<p>The rename function changes the name of a file.</p> <ul style="list-style-type: none"> • The <i>old_name</i> is the current name of the file. • The <i>new_name</i> is the new name for the file. <hr/> <p>NOTE: The optional device specified in the new name must match the device of the old name. If they do not match, a file copy would be required to perform the rename, and rename is not capable of this action.</p> <hr/>				
Return Value	<p>The function returns one of the following values:</p> <table> <tr> <td>0</td><td>if successful</td></tr> <tr> <td>-1</td><td>on failure</td></tr> </table> <hr/> <p>NOTE: Although rename is a low-level function, it is defined by the C standard and can be used by portable applications.</p> <hr/>	0	if successful	-1	on failure
0	if successful				
-1	on failure				

7.2.3 Device-Driver Level I/O Functions

At the next level are the device-level drivers. They map directly to the low-level I/O functions. The default device driver is the HOST device driver, which uses the debugger to perform file operations. The HOST device driver is automatically used for the default C streams stdin, stdout, and stderr.

The HOST device driver shares a special protocol with the debugger running on a host system so that the host can perform the C I/O requested by the program. Instructions for C I/O operations that the program wants to perform are encoded in a special buffer named `_CIOBUF_` in the `.cio` section. The debugger halts the program at a special breakpoint (C\$\$IO\$\$), reads and decodes the target memory, and performs the requested operation. The result is encoded into `_CIOBUF_`, the program is resumed, and the target decodes the result.

The HOST device is implemented with seven functions, `HOSTopen`, `HOSTclose`, `HOSTread`, `HOSTwrite`, `HOSTlseek`, `HOSTunlink`, and `HOSTrename`, which perform the encoding. Each function is called from the low-level I/O function with a similar name.

A device driver is composed of seven required functions. Not all function need to be meaningful for all devices, but all seven must be defined. Here we show the names of all seven functions as starting with `DEV`, but you may choose any name except for `HOST`.

DEV_open

Open File for I/O

Syntax

```
int DEV_open (const char * path , unsigned flags , int llv_fd );
```

Description

This function finds a file matching *path* and opens it for I/O as requested by *flags*.

- The *path* is the filename of the file to be opened. If the name of a file passed to open has a device prefix, the device prefix will be stripped by open, so DEV_open will not see it. (See [Section 7.2.5](#) for details on the device prefix.)
- The *flags* are attributes that specify how the file is manipulated. The flags are specified using the following symbols:

```
O_RDONLY   (0x0000)   /* open for reading */
O_WRONLY   (0x0001)   /* open for writing */
O_RDWR     (0x0002)   /* open for read & write */
O_APPEND    (0x0008)   /* append on each write */
O_CREAT     (0x0200)   /* open with file create */
O_TRUNC     (0x0400)   /* open with truncation */
O_BINARY    (0x8000)   /* open in binary mode */
```

See POSIX for further explanation of the flags.

- The *llv_fd* is treated as a suggested low-level file descriptor. This is a historical artifact; newly-defined device drivers should ignore this argument. This differs from the low-level I/O open function.

This function must arrange for information to be saved for each file descriptor, typically including a file position indicator and any significant flags. For the HOST version, all the bookkeeping is handled by the debugger running on the host machine. If the device uses an internal buffer, the buffer can be created when a file is opened, or the buffer can be created during a read or write.

Return Value

This function must return -1 to indicate an error if for some reason the file could not be opened; such as the file does not exist, could not be created, or there are too many files open. The value of errno may optionally be set to indicate the exact error (the HOST device does not set errno). Some devices might have special failure conditions; for instance, if a device is read-only, a file cannot be opened O_WRONLY.

On success, this function must return a non-negative file descriptor unique among all open files handled by the specific device. The file descriptor need not be unique across devices. The device file descriptor is used only by low-level functions when calling the device-driver-level functions. The low-level function open allocates its own unique file descriptor for the high-level functions to call the low-level functions. Code that uses only high-level I/O functions need not be aware of these file descriptors.

DEV_close	<i>Close File for I/O</i>
Syntax	int DEV_close (int <i>dev_fd</i>);
Description	<p>This function closes a valid open file descriptor.</p> <p>On some devices, DEV_close may need to be responsible for checking if this is the last file descriptor pointing to a file that was unlinked. If so, it is responsible for ensuring that the file is actually removed from the device and the resources reclaimed, if appropriate.</p>
Return Value	<p>This function should return -1 to indicate an error if the file descriptor is invalid in some way, such as being out of range or already closed, but this is not required. The user should not call close() with an invalid file descriptor.</p>
DEV_read	<i>Read Characters from a File</i>
Syntax	int DEV_read (int <i>dev_fd</i> , char * <i>buf</i> , unsigned <i>count</i>);
Description	<p>The read function reads <i>count</i> bytes from the input file associated with <i>dev_fd</i>.</p> <ul style="list-style-type: none"> • The <i>dev_fd</i> is the number assigned by open to an opened file. • The <i>buf</i> is where the read characters are placed. • The <i>count</i> is the number of characters to read from the file.
Return Value	<p>This function must return -1 to indicate an error if for some reason no bytes could be read from the file. This could be because of an attempt to read from a O_WRONLY file, or for device-specific reasons.</p> <p>If count is 0, no bytes are read and this function returns 0.</p> <p>This function returns the number of bytes read, from 0 to count. 0 indicates that EOF was reached before any bytes were read. It is not an error to read less than count bytes; this is common if there are not enough bytes left in the file or the request was larger than an internal device buffer size.</p>
DEV_write	<i>Write Characters to a File</i>
Syntax	int DEV_write (int <i>dev_fd</i> , const char * <i>buf</i> , unsigned <i>count</i>);
Description	<p>This function writes <i>count</i> bytes to the output file.</p> <ul style="list-style-type: none"> • The <i>dev_fd</i> is the number assigned by open to an opened file. • The <i>buffer</i> is where the write characters are placed. • The <i>count</i> is the number of characters to write to the file.
Return Value	<p>This function must return -1 to indicate an error if for some reason no bytes could be written to the file. This could be because of an attempt to read from a O_RDONLY file, or for device-specific reasons.</p>

DEV_lseek	<i>Set File Position Indicator</i>
Syntax	off_t DEV_lseek (int dev_fd , off_t offset , int origin);
Description	<p>This function sets the file's position indicator for this file descriptor as lseek.</p> <p>If lseek is supported, it should not allow a seek to before the beginning of the file, but it should support seeking past the end of the file. Such seeks do not change the size of the file, but if it is followed by a write, the file size will increase.</p>
Return Value	<p>If successful, this function returns the new value of the file position indicator.</p> <p>This function must return -1 to indicate an error if for some reason no bytes could be written to the file. For many devices, the lseek operation is nonsensical (e.g. a computer monitor).</p>
DEV_unlink	<i>Delete File</i>
Syntax	int DEV_unlink (const char * path);
Description	<p>Remove the association of the pathname with the file. This means that the file may no longer be opened using this name, but the file may not actually be immediately removed.</p> <p>Depending on the device, the file may be immediately removed, but for a device which allows open file descriptors to point to unlinked files, the file will not actually be deleted until the last file descriptor is closed. See Section 7.2.3.</p>
Return Value	<p>This function must return -1 to indicate an error if for some reason the file could not be unlinked (delayed removal does not count as a failure to unlink.)</p> <p>If successful, this function returns 0.</p>
DEV_rename	<i>Rename File</i>
Syntax	int DEV_rename (const char * old_name , const char * new_name);
Description	<p>This function changes the name associated with the file.</p> <ul style="list-style-type: none"> • The <i>old_name</i> is the current name of the file. • The <i>new_name</i> is the new name for the file.
Return Value	<p>This function must return -1 to indicate an error if for some reason the file could not be renamed, such as the file doesn't exist, or the new name already exists.</p>
	<hr/> <p>NOTE: It is inadvisable to allow renaming a file so that it is on a different device. In general this would require a whole file copy, which may be more expensive than you expect.</p> <hr/> <p>If successful, this function returns 0.</p>

7.2.4 Adding a User-Defined Device Driver for C I/O

The function `add_device` allows you to add and use a device. When a device is registered with `add_device`, the high-level I/O routines can be used for I/O on that device.

You can use a different protocol to communicate with any desired device and install that protocol using `add_device`; however, the HOST functions should not be modified. The default streams `stdin`, `stdout`, and `stderr` can be remapped to a file on a user-defined device instead of HOST by using `freopen()` as in [Example 7-1](#). If the default streams are reopened in this way, the buffering mode will change to `_IOFBF` (fully buffered). To restore the default buffering behavior, call `setvbuf` on each reopened file with the appropriate value (`_IOLBF` for `stdin` and `stdout`, `_IONBF` for `stderr`).

The default streams `stdin`, `stdout`, and `stderr` can be mapped to a file on a user-defined device instead of HOST by using `freopen()` as shown in [Example 7-1](#). Each function must set up and maintain its own data structures as needed. Some function definitions perform no action and should just return.

Example 7-1. Mapping Default Streams to Device

```
#include <stdio.h>
#include <file.h>
#include "mydevice.h"

void main()
{
    add_device("mydevice", _MSA,
              MYDEVICE_open, MYDEVICE_close,
              MYDEVICE_read, MYDEVICE_write,
              MYDEVICE_lseek, MYDEVICE_unlink, MYDEVICE_rename);

    /*-----*/
    /* Re-open stderr as a MYDEVICE file */
    /*-----*/
    if (!freopen("mydevice:stderrfile", "w", stderr))
    {
        puts("Failed to freopen stderr");
        exit(EXIT_FAILURE);
    }

    /*-----*/
    /* stderr should not be fully buffered; we want errors to be seen as */
    /* soon as possible. Normally stderr is line-buffered, but this example */
    /* doesn't buffer stderr at all. This means that there will be one call */
    /* to write() for each character in the message. */
    /*-----*/
    if (setvbuf(stderr, NULL, _IONBF, 0))
    {
        puts("Failed to setvbuf stderr");
        exit(EXIT_FAILURE);
    }

    /*-----*/
    /* Try it out! */
    /*-----*/
    printf("This goes to stdout\n");
    fprintf(stderr, "This goes to stderr\n"); }
```

NOTE: Use Unique Function Names

The function names `open`, `read`, `write`, `close`, `lseek`, `rename`, and `unlink` are used by the low-level routines. Use other names for the device-level functions that you write.

Use the low-level function `add_device()` to add your device to the `device_table`. The device table is a statically defined array that supports *n* devices, where *n* is defined by the macro `_NDEVICE` found in `stdio.h/cstdio`.

The first entry in the device table is predefined to be the host device on which the debugger is running. The low-level routine `add_device()` finds the first empty position in the device table and initializes the device fields with the passed-in arguments. For a complete description, see [the add_device function](#).

7.2.5 The device Prefix

A file can be opened to a user-defined device driver by using a device prefix in the pathname. The device prefix is the device name used in the call to `add_device` followed by a colon. For example:

```
FILE *fptr = fopen("mydevice:file1", "r");
int fd = open("mydevice:file2, O_RDONLY, 0);
```

If no device prefix is used, the HOST device will be used to open the file.

add_device

Add Device to Device Table

Syntax for C

```
#include <file.h>
```

```
int add_device(char * name,
               unsigned flags,
               int (* dopen )(const char *path, unsigned flags, int llv_fd),
               int (* dclose )(int dev_fd),
               int (* dread )(int dev_fd, char *buf, unsigned count),
               int (* dwrite )(int dev_fd, const char *buf, unsigned count),
               off_t (* dlseek )(int dev_fd, off_t ioffset, int origin),
               int (* dunlink )(const char * path),
               int (* drename )(const char *old_name, const char *new_name));
```

Defined in

lowlev.c (in the lib/src subdirectory of the compiler installation)

Description

The `add_device` function adds a device record to the device table allowing that device to be used for I/O from C. The first entry in the device table is predefined to be the HOST device on which the debugger is running. The function `add_device()` finds the first empty position in the device table and initializes the fields of the structure that represent a device.

To open a stream on a newly added device use `fopen()` with a string of the format *devicename : filename* as the first argument.

- The *name* is a character string denoting the device name. The name is limited to 8 characters.
- The *flags* are device characteristics. The flags are as follows:
 - _SSA** Denotes that the device supports only one open stream at a time
 - _MSA** Denotes that the device supports multiple open streams
 More flags can be added by defining them in `file.h`.
- The *dopen*, *dclose*, *dread*, *dwrite*, *dlseek*, *dunlink*, and *drename* specifiers are function pointers to the functions in the device driver that are called by the low-level functions to perform I/O on the specified device. You must declare these functions with the interface specified in [Section 7.2.2](#). The device driver for the HOST that the C7000 debugger is run on are included in the C I/O library.

Return Value

The function returns one of the following values:

- 0 if successful
- 1 on failure

Example

[Example 7-2](#) does the following:

- Adds the device *mydevice* to the device table
- Opens a file named *test* on that device and associates it with the FILE pointer *fid*
- Writes the string *Hello, world* into the file
- Closes the file

[Example 7-2](#) illustrates adding and using a device for C I/O:

Example 7-2. Program for C I/O Device

```
#include <file.h>
#include <stdio.h>
/*****
/* Declarations of the user-defined device drivers */
*****/
extern int MYDEVICE_open(const char *path, unsigned flags, int fno);
extern int MYDEVICE_close(int fno);
extern int MYDEVICE_read(int fno, char *buffer, unsigned count);
extern int MYDEVICE_write(int fno, const char *buffer, unsigned count);
extern off_t MYDEVICE_lseek(int fno, off_t offset, int origin);
extern int MYDEVICE_unlink(const char *path);
extern int MYDEVICE_rename(const char *old_name, char *new_name);
main()
{
    FILE *fid;
    add_device("mydevice", _MSA, MYDEVICE_open, MYDEVICE_close, MYDEVICE_read,
              MYDEVICE_write, MYDEVICE_lseek, MYDEVICE_unlink, MYDEVICE_rename);
    fid = fopen("mydevice:test", "w");
    fprintf(fid, "Hello, world\n");

    fclose(fid);
}
```

7.3 Handling Reentrancy (`_register_lock()` and `_register_unlock()` Functions)

The C standard assumes only one thread of execution, with the only exception being extremely narrow support for signal handlers. The issue of reentrancy is avoided by not allowing you to do much of anything in a signal handler. However, SYS/BIOS applications have multiple threads which need to modify the same global program state, such as the CIO buffer, so reentrancy is a concern.

Part of the problem of reentrancy remains your responsibility, but the run-time-support environment does provide rudimentary support for multi-threaded reentrancy by providing support for critical sections. This implementation does not protect you from reentrancy issues; this remains your responsibility.

The run-time-support environment provides hooks to install critical section primitives. By default, a single-threaded model is assumed, and the critical section primitives are not employed. In a multi-threaded system such as SYS/BIOS, the kernel arranges to install semaphore lock primitive functions in these hooks, which are then called when the run-time-support enters code that needs to be protected by a critical section.

Throughout the run-time-support environment where a global state is accessed, and thus needs to be protected with a critical section, there are calls to the function `_lock()`. This calls the provided primitive, if installed, and acquires the semaphore before proceeding. Once the critical section is finished, `_unlock()` is called to release the semaphore.

Usually SYS/BIOS is responsible for creating and installing the primitives, so you do not need to take any action. However, this mechanism can be used in multi-threaded applications that do not use the SYS/BIOS locking mechanism.

You should not define the functions `_lock()` and `_unlock()` functions directly; instead, the installation functions are called to instruct the run-time-support environment to use these new primitives:

```
void _register_lock (void ( *lock)());
```

```
void _register_unlock(void (*unlock)());
```

The arguments to `_register_lock()` and `_register_unlock()` should be functions which take no arguments and return no values, and which implement some sort of global semaphore locking:

```
extern volatile sig_atomic_t *sema = SHARED_SEMAPHORE_LOCATION;
static int sema_depth = 0;
static void my_lock(void)
{
    while (ATOMIC_TEST_AND_SET(sema, MY_UNIQUE_ID) != MY_UNIQUE_ID);
    sema_depth++;
}
static void my_unlock(void)
{
    if (--sema_depth) ATOMIC_CLEAR(sema);
}
```

The run-time-support nests calls to `_lock()`, so the primitives must keep track of the nesting level.

7.4 Library-Build Process

When using the C/C++ compiler, you can compile your code under a number of different configurations and options that are not necessarily compatible with one another. Because it would be infeasible to include all possible run-time-support library variants, compiler releases pre-build only a small number of very commonly-used libraries such as `rts7100_le.lib`.

To provide maximum flexibility, the run-time-support source code is provided as part of each compiler release. You can build the missing libraries as desired. The linker can also automatically build missing libraries. This is accomplished with a new library build process, the core of which is the executable `mklib`, which is available beginning with CCS 5.1.

7.4.1 Required Non-Texas Instruments Software

To use the self-contained run-time-support build process to rebuild a library with custom options, the following are required:

- `sh` (Bourne shell)
- `gmake` (GNU make 3.81 or later)

More information is available from GNU at <http://www.gnu.org/software/make>. GNU make (`gmake`) is also available in earlier versions of Code Composer Studio. GNU make is also included in some UNIX support packages for Windows, such as the MKS Toolkit, Cygwin, and Interix. The GNU make used on Windows platforms should explicitly report "This program build for Windows32" when the following is executed from the Command Prompt window:

```
gmake -h
```

All three of these programs are provided as a non-optional feature of CCS 5.1. They are also available as part of the optional XDC Tools feature if you are using an earlier version of CCS.

The `mklib` program looks for these executables in the following order:

1. in your `PATH`
2. in the directory `getenv("CCS_UTILS_DIR")/cygwin`
3. in the directory `getenv("CCS_UTILS_DIR")/bin`
4. in the directory `getenv("XDCROOT")`
5. in the directory `getenv("XDCROOT")/bin`

If you are invoking `mklib` from the command line, and these executables are not in your path, you must set the environment variable `CCS_UTILS_DIR` such that `getenv("CCS_UTILS_DIR")/bin` contains the correct programs.

7.4.2 Using the Library-Build Process

You should normally let the linker automatically rebuild libraries as needed. If necessary, you can run `mklib` directly to populate libraries. See [Section 7.4.2.2](#) for situations when you might want to do this.

7.4.2.1 Automatic Standard Library Rebuilding by the Linker

The linker looks for run-time-support libraries primarily through the `C7X_C_DIR` environment variable. Typically, one of the pathnames in `C7X_C_DIR` is *your install directory/lib*, which contains all of the pre-built libraries, as well as the index library `libc.a`. The linker looks in `C7X_C_DIR` to find a library that is the best match for the build attributes of the application. The build attributes are set indirectly according to the command-line options used to build the application. Build attributes include things like CPU revision. If the library name is explicitly specified (e.g. `-library=rts7100_le.lib`), run-time support looks for that library exactly. If the library name is not specified, the linker uses the index library `libc.a` to pick an appropriate library. If the library is specified by path (e.g. `-library=/foo/rts7100_le.lib`), it is assumed the library already exists and it will not be built automatically.

The index library describes a set of libraries with different build attributes. The linker will compare the build attributes for each potential library with the build attributes of the application and will pick the best fit. For details on the index library, see [Chapter 10](#).

Now that the linker has decided which library to use, it checks whether the run-time-support library is present in C7X_C_DIR . The library must be in exactly the same directory as the index library libc.a. If the library is not present, the linker invokes mklib to build it. This happens when the library is missing, regardless of whether the user specified the name of the library directly or allowed the linker to pick the best library from the index library.

The mklib program builds the requested library and places it in 'lib' directory part of C7X_C_DIR in the same directory as the index library, so it is available for subsequent compilations.

Things to watch out for:

- The linker invokes **mklib** and waits for it to finish before finishing the link, so you will experience a one-time delay when an uncommonly-used library is built for the first time. Build times of 1-5 minutes have been observed. This depends on the power of the host (number of CPUs, etc).
- In a shared installation, where an installation of the compiler is shared among more than one user, it is possible that two users might cause the linker to rebuild the same library at the same time. The **mklib** program tries to minimize the race condition, but it is possible one build will corrupt the other. In a shared environment, all libraries which might be needed should be built at install time; see [Section 7.4.2.2](#) for instructions on invoking **mklib** directly to avoid this problem.
- The index library must exist, or the linker is unable to rebuild libraries automatically.
- The index library must be in a user-writable directory, or the library is not built. If the compiler installation must be installed read-only (a good practice for shared installation), any missing libraries must be built at installation time by invoking **mklib** directly.
- The **mklib** program is specific to a certain version of a certain library; you cannot use one compiler version's run-time support's **mklib** to build a different compiler version's run-time support library.

7.4.2.2 Invoking mklib Manually

You may need to invoke **mklib** directly in special circumstances:

- The compiler installation directory is read-only or shared.
- You want to build a variant of the run-time-support library that is not pre-configured in the index library **libc.a** or known to mklib. (e.g. a variant with source-level debugging turned on.)

7.4.2.2.1 Building Standard Libraries

You can invoke mklib directly to build any or all of the libraries indexed in the index library **libc.a**. The libraries are built with the standard options for that library; the library names and the appropriate standard option sets are known to mklib.

This is most easily done by changing the working directory to be the compiler run-time-support library directory 'lib' and invoking the **mklib** executable there:

```
mklib --pattern=rts7100_le.lib
```

7.4.2.2.2 Shared or Read-Only Library Directory

If the compiler tools are to be installed in shared or read-only directory, mklib cannot build the standard libraries at link time; the libraries must be built before the library directory is made shared or read-only.

At installation time, the installing user must build all of the libraries which will be used by any user. To build all possible libraries, change the working directory to be the compiler RTS library directory 'lib' and invoke the mklib executable there:

```
mklib --all
```

Some targets have many libraries, so this step can take a long time. To build a subset of the libraries, invoke mklib individually for each desired library.

7.4.2.2.3 Building Libraries With Custom Options

You can build a library with any extra custom options desired. This is useful for building a version of the library with silicon exception workarounds enabled. The generated library is not a standard library, and must not be placed in the 'lib' directory. It should be placed in a directory local to the project which needs it. To build a debugging version of the library rts7100_le.lib, change the working directory to the 'lib' directory and run the command:

```
mklib --pattern=rts7100_le.lib --name=rts7100_le_debug.lib --install_to=$Project/Debug
--extra_options=<options_list>
```

7.4.2.2.4 The mklib Program Option Summary

Run the following command to see the full list of options. These are described in [Table 7-1](#).

```
mklib --help
```

Table 7-1. The mklib Program Options

Option	Effect
--index=filename	The index library (libc.a) for this release. Used to find a template library for custom builds, and to find the source files (in the lib/src subdirectory of the compiler installation). REQUIRED.
--pattern=filename	Pattern for building a library. If neither --extra_options nor --options are specified, the library will be the standard library with the standard options for that library. If either --extra_options or --options are specified, the library is a custom library with custom options. REQUIRED unless --all is used.
--all	Build all standard libraries at once.
--install_to=directory	The directory into which to write the library. For a standard library, this defaults to the same directory as the index library (libc.a). For a custom library, this option is REQUIRED.
--compiler_bin_dir=directory	The directory where the compiler executables are. When invoking mklib directly, the executables should be in the path, but if they are not, this option must be used to tell mklib where they are. This option is primarily for use when mklib is invoked by the linker.
--name=filename	File name for the library with no directory part. Only useful for custom libraries.
--options='str'	Options to use when building the library. The default options (see below) are <i>replaced</i> by this string. If this option is used, the library will be a custom library.
--extra_options='str'	Options to use when building the library. The default options (see below) are also used. If this option is used, the library will be a custom library.
--list_libraries	List the libraries this script is capable of building and exit. ordinary system-specific directory.
--log=filename	Save the build log as <i>filename</i> .
--tmpdir=directory	Use <i>directory</i> for scratch space instead of the ordinary system-specific directory.
--gmake=filename	Gmake-compatible program to invoke instead of "gmake"
--parallel=N	Compile <i>N</i> files at once ("gmake -j <i>N</i> ").
--query=filename	Does this script know how to build FILENAME?
--help or --h	Display this help.
--quiet or --q	Operate silently.
--verbose or --v	Extra information to debug this executable.

Examples:

To build all standard libraries and place them in the compiler's library directory:

```
mklib --all --index=$C_DIR/lib
```

To build one standard library and place it in the compiler's library directory:

```
mklib --pattern=rts7100_le.lib --index=$C_DIR/lib
```

To build a custom library that is just like rts7100_le.lib, but has symbolic debugging support enabled:

```
mklib --pattern=rts7100_le.lib --extra_options="-g" --index=$C_DIR/lib --
install_to=$Project/Debug --name=rts7100_le_debug.lib
```


7.4.3 Extending mklib

The **mklib** API is a uniform interface that allows Code Composer Studio to build libraries without needing to know exactly what underlying mechanism is used to build it. Each library vendor (e.g. the TI compiler) provides a library-specific copy of 'mklib' in the library directory that can be invoked, which understands a standardized set of options, and understands how to build the library. This allows the linker to automatically build application-compatible versions of any vendor's library without needing to register the library in advance, as long as the vendor supports mklib.

7.4.3.1 Underlying Mechanism

The underlying mechanism can be anything the vendor desires. For the compiler run-time-support libraries, mklib is just a wrapper that knows how to use the files in the lib/src subdirectory of the compiler installation and invoke gmake with the appropriate options to build each library. If necessary, mklib can be bypassed and the Makefile used directly, but this mode of operation is not supported by TI, and you are responsible for any changes to the Makefile. The format of the Makefile and the interface between mklib and the Makefile is subject to change without notice. The mklib program is the forward-compatible path.

7.4.3.2 Libraries From Other Vendors

Any vendor who wishes to distribute a library that can be rebuilt automatically by the linker must provide:

- An index library (like 'libc.a', but with a different name)
- A copy of mklib specific to that library
- A copy of the library source code (in whatever format is convenient)

These things must be placed together in one directory that is part of the linker's library search path (specified either in C7X_C_DIR or with the linker --search_path option).

If mklib needs extra information that is not possible to pass as command-line options to the compiler, the vendor will need to provide some other means of discovering the information (such as a configuration file written by a wizard run from inside CCS).

The vendor-supplied mklib must at least accept all of the options listed in [Table 7-1](#) without error, even if they do not do anything.

Introduction to Object Modules

The linker creates executable object files from object modules. These executable object files can be executed by a C7000 CPU.

Object modules make modular programming easier because they encourage you to think in terms of *blocks* of code and data. These blocks are known as sections. The linker provides directives that allow you to create and manipulate sections.

This chapter focuses on the concept and use of sections.

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8.1 Object File Format Specifications

The object files created by the Code Generation Tools conform to the ELF (Executable and Linking Format) binary format, which is used by the Embedded Application Binary Interface (EABI). See the *C7000 Embedded Application Binary Interface (EABI) Reference Guide* ([SPRUIG4](#)) for information on the EABI ABI.

The C7000 has a 48-bit address space for both code and data. Accordingly, object files use the ELF64 format.

8.2 Executable Object Files

The linker can be used to produce static executable object modules. An executable object module has the same format as object files that are used as linker input. The sections in an executable object module, however, have been combined and placed in target memory, and the relocations are all resolved.

To run a program, the data in the executable object module must be transferred, or loaded, into target system memory. See [Chapter 9](#) for details about loading and running programs.

8.3 Introduction to Sections

The smallest unit of an object file is a *section*. A section is a block of code or data that occupies contiguous space in the memory map. Each section of an object file is separate and distinct.

ELF format executable object files contain *segments*. An ELF segment is a meta-section. It represents a contiguous region of target memory. It is a collection of *sections* that have the same property, such as writable or readable. An ELF loader needs the segment information, but does not need the section information. The ELF standard allows the linker to omit ELF section information entirely from the executable object file.

Object files usually contain three default sections:

.text section	Contains executable code ⁽¹⁾
.data section	Usually contains initialized data
.bss	Usually reserves space for uninitialized variables

The linker allows you to create, name, and link other kinds of sections. The .text, .data, and .bss sections are archetypes for how sections are handled.

There are two basic types of sections:

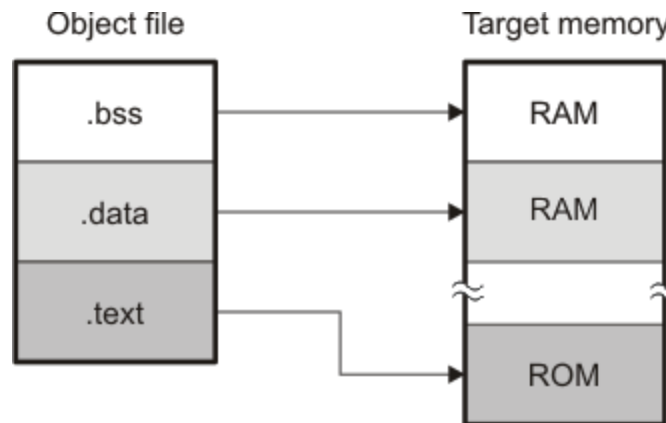
Initialized sections	Contain data or code. The .text and .data sections are initialized.
Uninitialized sections	Reserve space in the memory map for uninitialized data. The .bss section is uninitialized.

One of the linker's functions is to relocate sections into the target system's memory map; this function is called *placement*. Because most systems contain several types of memory, using sections can help you use target memory more efficiently. All sections are independently relocatable; you can place any section into any allocated block of target memory. For example, you can define a section that contains an initialization routine and then allocate the routine in a portion of the memory map that contains ROM. For information on section placement, see [Section 11.3.5](#).

⁽¹⁾ Some targets allow content other than text, such as constants, in .text sections.

Figure 8-1 shows an example of the relationship between sections in an object file and a hypothetical target memory. ROM may be EEPROM, FLASH or some other type of physical memory in an actual system.

Figure 8-1. Partitioning Memory Into Logical Blocks



8.3.1 Special Section Names

You can use the `.sect` and `.usect` directives to create any section name you like, but certain sections are treated in a special manner by the linker and the compiler's run-time support library. If you create a section with the same name as a special section, you should take care to follow the rules for that special section.

A few common special sections are:

- `.text` -- Used for program code.
- `.data` -- Used for initialized non-const objects (global variables).
- `.bss` -- Used for uninitialized objects (global variables).
- `.const` -- Used for initialized const objects (string constants, variables declared `const`).
- `.cinit` -- Used to initialize C global variables at startup.
- `.stack` -- Used for the function call stack.
- `.sysmem` - Used for the dynamic memory allocation pool.

For more information on sections, see [Section 11.3.5](#).

8.4 How the Linker Handles Sections

The linker has two main functions related to sections. First, the linker uses the sections in object files as building blocks; it combines input sections to create output sections in an executable output module. Second, the linker chooses memory addresses for the output sections; this is called *placement*. Two linker directives support these functions:

- The `MEMORY` directive allows you to define the memory map of a target system. You can name portions of memory and specify their starting addresses and their lengths.
- The `SECTIONS` directive tells the linker how to combine input sections into output sections and where to place these output sections in memory.

Subsections let you manipulate the placement of sections with greater precision. You can specify the location of each subsection with the linker's `SECTIONS` directive. If you do not specify a subsection, the subsection is combined with the other sections with the same base section name. See [Section 12.5.5.1](#).

It is not always necessary to use linker directives. If you do not use them, the linker uses the target processor's default placement algorithm described in [Section 12.7](#). When you *do* use linker directives, you must specify them in a linker command file.

Refer to the following sections for more information about linker command files and linker directives:

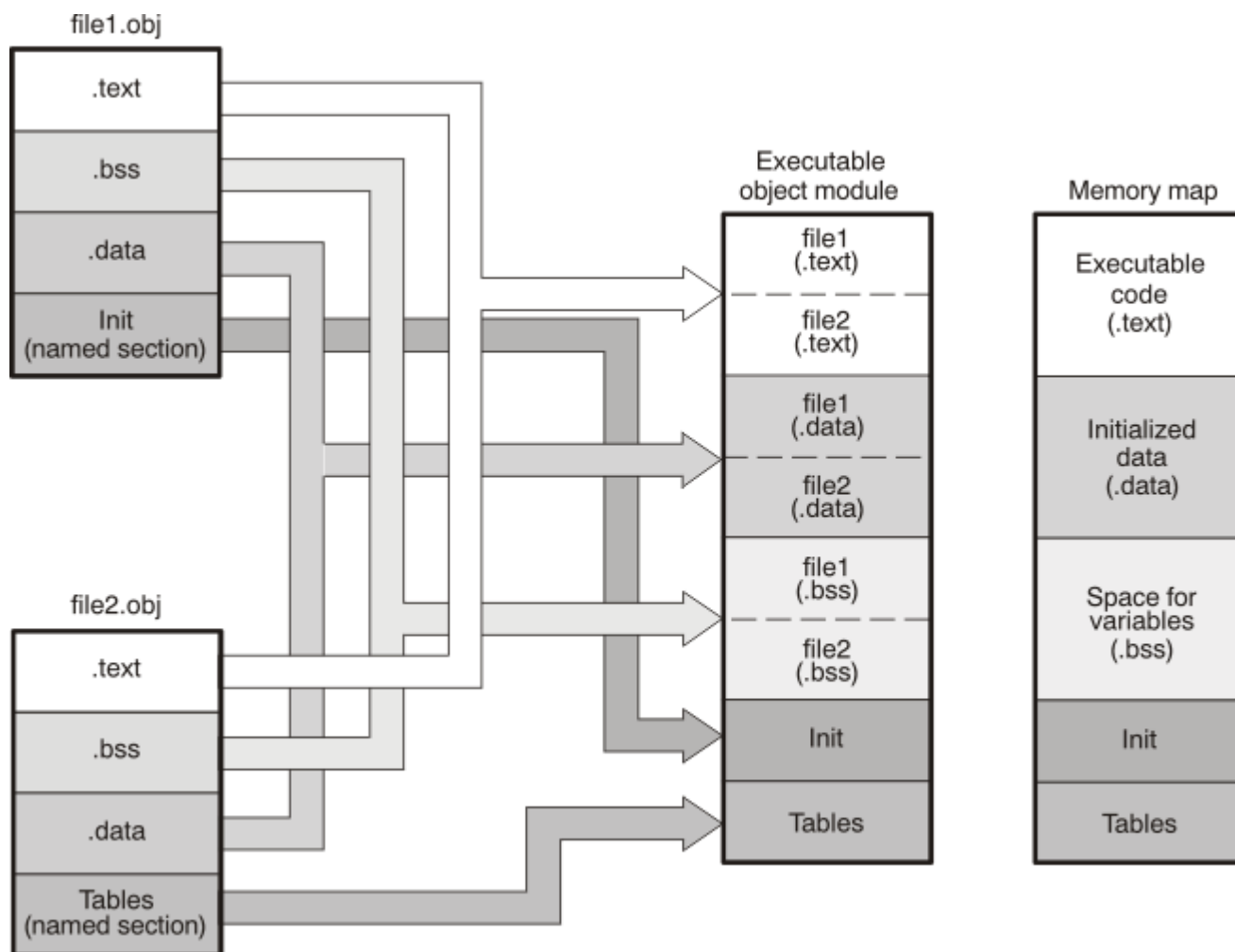
- [Section 12.5, Linker Command Files](#)
- [Section 12.5.4, The MEMORY Directive](#)
- [Section 12.5.5, The SECTIONS Directive](#)
- [Section 12.7, Default Placement Algorithm](#)

8.4.1 Combining Input Sections

Figure 8-2 provides a simplified example of the process of linking two files together.

Note that this is a simplified example, so it does not show all the sections that will be created or the actual sequence of the sections. See [Section 12.7](#) for the actual default memory placement map for C7000.

Figure 8-2. Combining Input Sections to Form an Executable Object Module



In [Figure 8-2](#), file1.obj and file2.obj have been assembled to be used as linker input. Each contains the .text, .data, and default sections; in addition, each contains a user-named section. The executable object module shows the combined sections. The linker combines the .text section from file1.obj and the .text section from file2.obj to form one .text section, then combines the two .data sections and the two sections, and finally places the user-named sections at the end. The memory map shows the combined sections to be placed into memory.

8.4.2 Placing Sections

Figure 8-2 illustrates the linker's default method for combining sections. Sometimes you may not want to use the default setup. For example, you may not want all of the .text sections to be combined into a single .text section. Or you may want a user-named section placed where the .data section would normally be allocated. Most memory maps contain various types of memory (RAM, ROM, EEPROM, FLASH, etc.) in varying amounts; you may want to place a section in a specific type of memory.

For further explanation of section placement within the memory map, see the discussions in Section 12.5.4 and Section 12.5.5. See Section 12.7 for the actual default memory allocation map for C7000.

8.5 Symbols

An object file contains a symbol table that stores information about *symbols* in the object file. The linker uses this table when it performs relocation.

An object file symbol is a named 48-bit integer value, usually representing an address. A symbol can represent such things as the starting address of a function, variable, section, or an absolute integer (such as the size of the stack).

Absolute symbols are symbols that have a numeric value. They may be constants. To the linker, such symbols are unsigned values, but the integer may be treated as signed or unsigned depending on how it is used. The range of legal values for an absolute integer is 0 to $2^{48}-1$ for unsigned treatment and -2^{47} to $2^{47}-1$ for signed treatment.

8.5.1 Local Symbols

Local symbols are visible within a single object file. Each object file may have its own local definition for a particular symbol. References to local symbols in an object file are entirely unrelated to local symbols of the same name in another object file.

By default, a symbol is local.

8.5.2 Weak Symbols

Weak symbols are symbols that may or may not be defined.

The linker processes symbols that are defined with a "weak" binding differently from symbols that are defined with global binding. Instead of including a weak symbol in the object file's symbol table (as it would for a global symbol), the linker only includes a weak symbol in the output of a "final" link if the symbol is required to resolve an otherwise unresolved reference.

This allows the linker to minimize the number of symbols it includes in the output file's symbol table by omitting those that are not needed to resolve references. Reducing the size of the output file's symbol table reduces the time required to link, especially if there are a large number of pre-loaded symbols to link against. This feature is particularly helpful for OpenCL applications.

- **Using the Linker Command File:** To define a weak symbol in a linker command file, use the "weak" operator in an assignment expression to designate that the symbol is eligible for removal from the output file's symbol table if it is not referenced. In a linker command file, an assignment expression outside a MEMORY or SECTIONS directive can be used to define a weak linker-defined symbol. For example, you can define "ext_addr_sym" as follows:

```
weak(ext_addr_sym) = 0x12345678;
```

If the linker command file is used to perform the final link, then "ext_addr_sym" is presented to the linker as a weak symbol; it will not be included in the resulting output file if the symbol is not referenced. See Section 12.6.3.

- **Using C/C++ code:** See information about the WEAK pragma and weak GCC-style variable attribute in the .

If there are multiple definitions of the same symbol, the linker uses certain rules to determine which definition takes precedence. Some definitions may have weak binding and others may have strong binding. "Strong" in this context means that the symbol has *not* been given a weak binding in an assignment statement in a linker command file. The linker uses the following guidelines to determine which definition is used when resolving references to a symbol:

- A strongly bound symbol always takes precedence over a weakly bound symbol.
- If two symbols are both strongly bound or both weakly bound, a symbol defined in a linker command file takes precedence over a symbol defined in an input object file.
- If two symbols are both strongly bound and both are defined in an input object file, the linker provides a symbol redefinition error and halts the link process.

8.6 Loading a Program

The linker creates an executable object file which can be loaded in several ways, depending on your execution environment. These methods include using Code Composer Studio or a hex conversion utility. For details, see [Section 9.1](#).

Program Loading and Running

Even after a program is written, compiled, and linked into an executable object file, there are still many tasks that need to be performed before the program does its job. The program must be loaded onto the target, memory and registers must be initialized, and the program must be set to running.

Some of these tasks need to be built into the program itself. Many of the necessary tasks are handled for you by the compiler and linker, but if you need more control over these tasks, it helps to understand how the pieces are expected to fit together.

This chapter will introduce you to the concepts involved in program loading, initialization, and startup.

This chapter does not cover *dynamic loading*.

Refer to your device documentation for various device-specific aspects of bootstrapping.

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9.1 Loading

A program needs to be placed into the target device's memory before it may be executed. *Loading* is the process of preparing a program for execution by initializing device memory with the program's code and data. A *loader* might be another program on the device, an external agent (for example, a debugger), or the device might initialize itself after power-on, which is known as *bootstrap loading*, or *bootloading*.

The loader is responsible for constructing the *load image* in memory before the program starts. The load image is the program's code and data in memory before execution. What exactly constitutes loading depends on the environment, such as whether an operating system is present. This section describes several loading schemes for bare-metal devices. This section is not exhaustive.

A program may be loaded in the following ways:

- **A debugger running on a connected host workstation.** In a typical embedded development setup, the device is subordinate to a host running a debugger such as Code Composer Studio (CCS). The device is connected with a communication channel such as a JTAG interface. CCS reads the program and writes the load image directly to target memory through the communications interface.
- **Loader running on another CPU.** Using an ELF loader, another CPU on the device (typically an ARM core) loads the executable into memory.
- **Another program running on the device.** The running program can create the load image and transfer control to the loaded program. If an operating system is present, it may have the ability to load and run programs.

9.2 Entry Point

The entry point is the address at which the execution of the program begins. This is the address of the startup routine. The startup routine is responsible for initializing and calling the rest of the program. For a C/C++ program, the startup routine is usually named `_c_int00` (see [Section 9.3.1](#)). After the program is loaded, the value of the entry point is placed in the PC register and the CPU is allowed to run.

The object file has an entry point field. For a C/C++ program, the linker will fill in `_c_int00` by default. You can select a custom entry point; see [Section 12.4.11](#). The device itself cannot read the entry point field from the object file, so it has to be encoded in the program somewhere.

- If you are using a bootloader, the boot table includes an entry point field. When it finishes running, the bootloader branches to the entry point.
- If you are using a hosted debugger, such as CCS, the debugger may explicitly set the program counter (PC) to the value of the entry point.

9.3 Run-Time Initialization

After the load image is in place, the program can run. The subsections that follow describe bootstrap initialization of a C/C++ program.

9.3.1 The `_c_int00` Function

The function `_c_int00` is the *startup routine* (also called the *boot routine*) for C/C++ programs. It performs all the steps necessary for a C/C++ program to initialize itself.

The name `_c_int00` means that it is the interrupt handler for interrupt number 0, RESET, and that it sets up the C environment. Its name need not be exactly `_c_int00`, but the linker sets `_c_int00` as the entry point for C programs by default. The compiler's run-time-support library provides a default implementation of `_c_int00`.

The startup routine is responsible for performing the following actions:

1. Set up the stack by initializing SP
2. Set up the data page pointer DP (for architectures that have one)
3. Set configuration registers
4. Process the `.cinit` table to autoinitialize global variables (when using the `--rom_model` option)
5. Process the `.pinit` table to construct global C++ objects.

6. Call the function main with appropriate arguments
7. Call exit when main returns

9.3.2 RAM Model vs. ROM Model

Choose a startup model based on the needs of your application. The ROM model performs more work during the boot routine. The RAM model performs more work while loading the application.

If your application is likely to need frequent RESETs or is a standalone application, the ROM model may be a better choice, because the boot routine will have all the data it needs to initialize RAM variables. However, for a system with an operating system, it may be better to use the RAM model.

C boot routine copies data from the .cinit section to the run-time location of the variables to be initialized.

9.3.2.1 Autoinitializing Variables at Run Time (--rom_model)

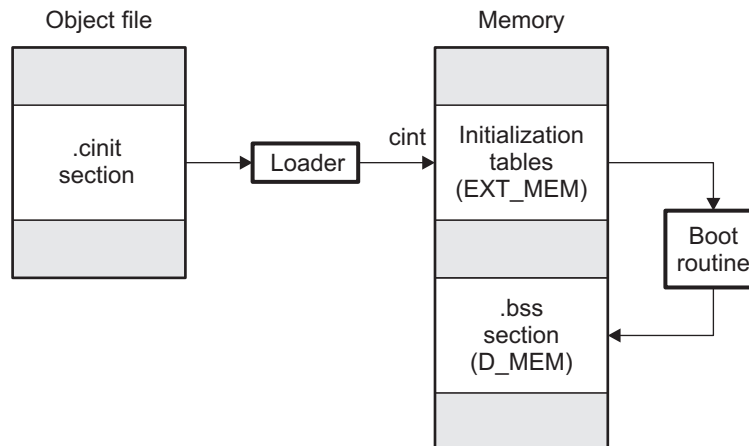
Autoinitializing variables at run time is the default method of autoinitialization. To use this method, invoke the linker with the --rom_model option.

The ROM model allows initialization data to be stored in slow non-volatile memory and copied to fast memory each time the program is reset. Use this method if your application runs from code burned into slow memory or needs to survive a reset.

For the ROM model, the .cinit section is loaded into memory along with all the other initialized sections. The linker defines a special symbol called __TI_CINIT_Base that points to the beginning of the initialization tables in memory. When the program begins running, the C boot routine copies data from the tables (pointed to by .cinit) into the run-time location of the variables.

Figure 9-1 illustrates autoinitialization at run time using the ROM model.

Figure 9-1. Autoinitialization at Run Time



9.3.2.2 Initializing Variables at Load Time (--ram_model)

The RAM model initializes variables at load time. To use this method, invoke the linker with the --ram_model option.

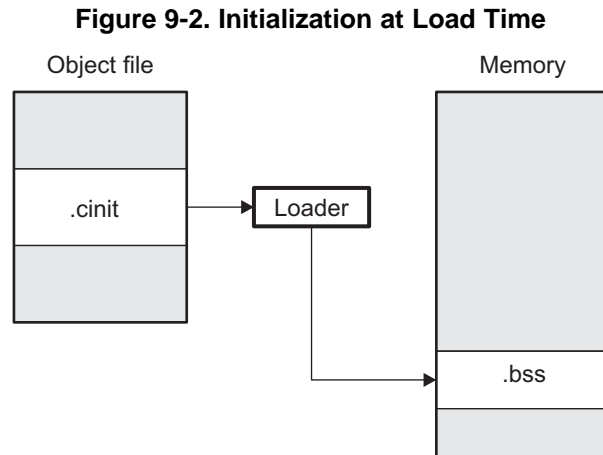
This model may reduce boot time and save memory used by the initialization tables.

When you use the --ram_model linker option, the linker sets the STYP_COPY bit in the .cinit section's header. This tells the loader not to load the .cinit section into memory. (The .cinit section occupies no space in the memory map.)

The linker sets __TI_CINIT_Base equal to __TI_CINIT_Limit to indicate there are no .cinit records.

The loader copies values directly from the .data section to memory.

Figure 9-2 illustrates the initialization of variables at load time.



9.3.2.3 The --rom_model and --ram_model Linker Options

The following list outlines what happens when you invoke the linker with the --ram_model or --rom_model option.

- The symbol `_c_int00` is defined as the program entry point. The `_c_int00` symbol is the start of the C boot routine in `boot.c.obj`. Referencing `_c_int00` ensures that `boot.c.obj` is automatically linked in from the appropriate run-time-support library.
- When you use the RAM model to initialize at load time (--ram_model option):
 - The linker defines a special symbol called `__TI_CINIT_Base` that points to the beginning of the initialization tables in memory. When the program begins running, the C boot routine copies data from the tables (pointed to by `.cinit`) into the run-time location of the variables.
- When you use the ROM model to autoinitialize at run time (--rom_model option):
 - The linker sets `__TI_CINIT_Base` equal to `__TI_CINIT_Limit` to indicate there are no `.cinit` records.

9.3.3 About Linker-Generated Copy Tables

The RTS function `copy_in` can be used at run-time to move code and data around, usually from its load address to its run address. This function reads size and location information from copy tables. The linker automatically generates several kinds of copy tables. Refer to [Section 12.8](#).

You can create and control code overlays with copy tables. See [Section 12.8.4](#) for details and examples.

Copy tables can be used by the linker to implement run-time relocations as described in [Section 9.5](#), however copy tables require a specific table format.

9.3.3.1 BINIT

The BINIT (boot-time initialization) copy table is special in that the target will automatically perform the copying at auto-initialization time. Refer to [Section 12.8.4.2](#) for more about the BINIT copy table name. The BINIT copy table is copied before `.cinit` processing.

9.3.3.2 CINIT

EABI `.cinit` tables are special kinds of copy tables. Refer to [Section 9.3.2.1](#) for more about using the `.cinit` section with the ROM model and [Section 9.3.2.2](#) for more using it with the RAM model.

9.4 Arguments to main

Some programs expect arguments to main (`argc`, `argv`) to be valid. Normally this isn't possible for an embedded program, but the TI runtime does provide a way to do it. The user must allocate an `.args` section of an appropriate size using the `--args` linker option. It is the responsibility of the loader to populate the `.args` section. It is not specified how the loader determines which arguments to pass to the target. The format of the arguments is the same as an array of pointers to `char` on the target.

See [Section 12.4.4](#) for information about allocating memory for argument passing.

9.5 Run-Time Relocation

At times you may want to load code into one area of memory and move it to another area before running it. For example, you may have performance-critical code in an external-memory-based system. The code must be loaded into external memory, but it would run faster in internal memory. Because internal memory is limited, you might swap in different speed-critical functions at different times.

The linker provides a way to handle this. Using the `SECTIONS` directive, you can optionally direct the linker to allocate a section twice: first to set its load address and again to set its run address. Use the `load` keyword for the load address and the `run` keyword for the run address. If a section is assigned two addresses at link time, all labels defined in the section are relocated to refer to the run-time address so that references to the section (such as branches) are correct when the code runs.

If you provide only one allocation (either `load` or `run`) for a section, the section is allocated only once and loads and runs at the same address. If you provide both allocations, the section is actually allocated as if it were two separate sections. The two sections are the same size if the load section is not compressed.

Uninitialized sections (such as `.bss`) are not loaded, so the only significant address is the run address. The linker allocates uninitialized sections only once; if you specify both run and load addresses, the linker warns you and ignores the load address.

For a complete description of run-time relocation, see [Section 12.5.6](#).

9.6 Additional Information

See the following sections and documents for additional information:

[Section 6.7](#), "System Initialization"

[Section 11.3.2](#), "Run-Time Initialization"

[Section 12.4.4](#), "Allocate Memory for Use by the Loader to Pass Arguments (`--arg_size` Option)"

[Section 12.4.11](#), "Define an Entry Point (`--entry_point` Option)"

[Section 12.5.6.1](#), "Specifying Load and Run Addresses"

[Section 12.8](#), "Linker-Generated Copy Tables"

[Section 12.10.1](#), "Run-Time Initialization"

Archiver Description

The C7000 archiver lets you combine several individual files into a single archive file. You can use the archiver to collect a group of object files into an object library. The linker includes in the library the members that resolve external references during the link. The archiver allows you to modify a library by deleting, replacing, extracting, or adding members.

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10.1 Archiver Overview

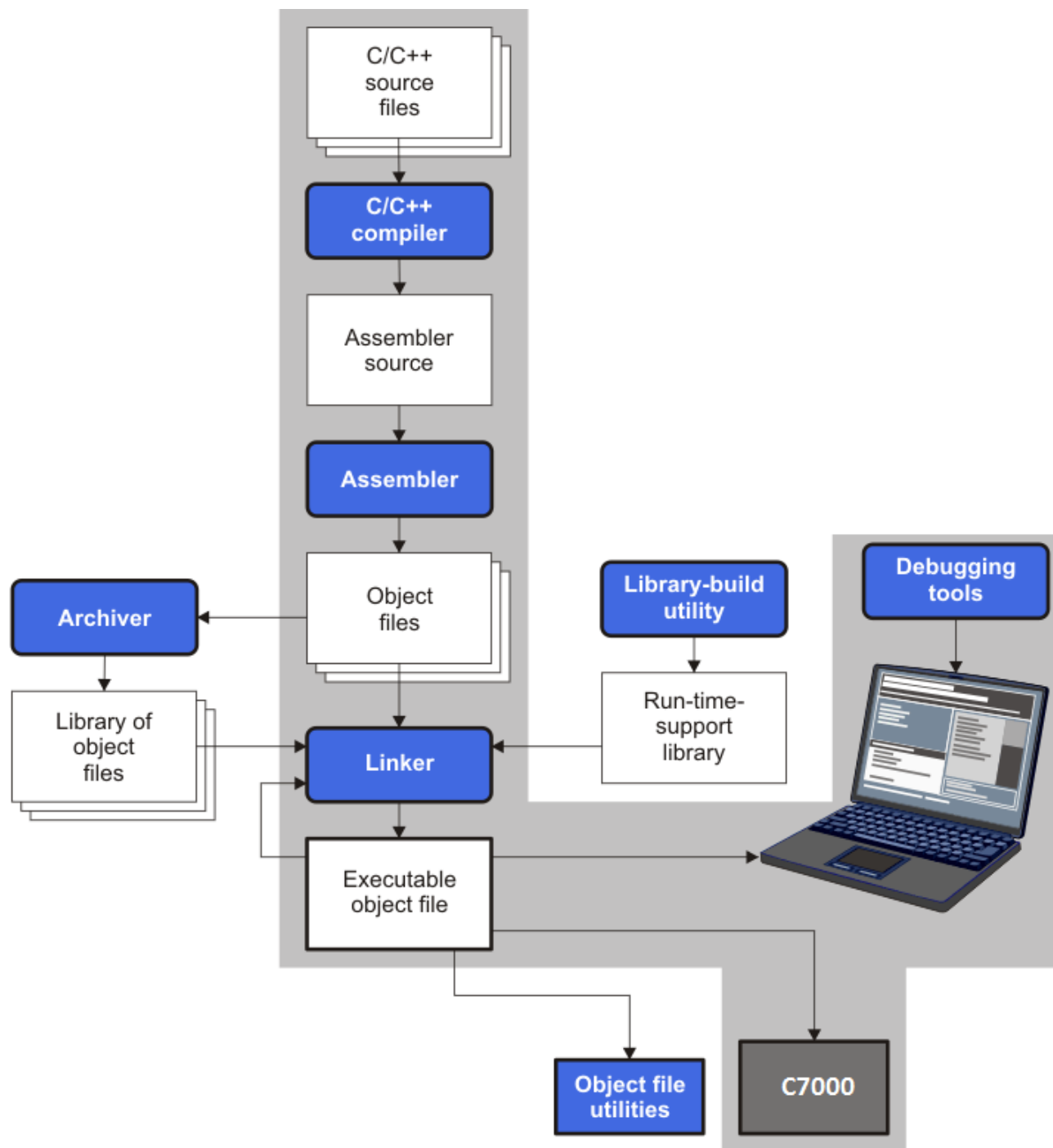
You can build libraries from any type of files. The linker accepts archive libraries as input. It can use libraries that contain individual object files.

One of the most useful applications of the archiver is building libraries of object modules. For example, you can write several arithmetic routines, assemble them, and use the archiver to collect the object files into a single, logical group. You can then specify the object library as linker input. The linker searches the library and includes members that resolve external references.

10.2 The Archiver's Role in the Software Development Flow

Figure 10-1 shows the archiver's role in the software development process. The shaded portion highlights the most common archiver development path.

Figure 10-1. The Archiver in the C7000 Software Development Flow



10.3 Invoking the Archiver

To invoke the archiver, enter:

```
ar7x[-]command [options] libname [filename1 ... filenamen ]
```

ar7x	is the command that invokes the archiver.
[-]command	tells the archiver how to manipulate the existing library members and any specified. A command can be preceded by an optional hyphen. You must use one of the following commands when you invoke the archiver, but you can use only one command per invocation. The archiver commands are as follows: <ul style="list-style-type: none"> @ uses the contents of the specified file instead of command line entries. You can use this command to avoid limitations on command line length imposed by the host operating system. Use a ; at the beginning of a line in the command file to include comments. (See Example 10-1 for an example using an archiver command file.) a adds the specified files to the library. This command does not replace an existing member that has the same name as an added file; it simply <i>appends</i> new members to the end of the archive. d deletes the specified members from the library. r replaces the specified members in the library. If you do not specify filenames, the archiver replaces the library members with files of the same name in the current directory. If the specified file is not found in the library, the archiver adds it instead of replacing it. t prints a table of contents of the library. If you specify filenames, only those files are listed. If you do not specify any filenames, the archiver lists all the members in the specified library. x extracts the specified files. If you do not specify member names, the archiver extracts all library members. When the archiver extracts a member, it simply copies the member into the current directory; it <i>does not</i> remove it from the library.
options	In addition to one of the <i>commands</i> , you can specify options. To use options, combine them with a command; for example, to use the a command and the s option, enter -as or as. The hyphen is optional for archiver options only. These are the archiver options: <ul style="list-style-type: none"> -h provide command-line help -q (quiet) suppresses the banner and status messages. -s prints a list of the global symbols that are defined in the library. (This option is valid only with the a, r, and d commands.) -u replaces library members only if the replacement has a more recent modification date. You must use the r command with the -u option to specify which members to replace. -v (verbose) provides a file-by-file description of the creation of a new library from an old library and its members.
libname	names the archive library to be built or modified. If you do not specify an extension for <i>libname</i> , the archiver uses the default extension <i>.lib</i> .
filenames	names individual files to be manipulated. These files can be existing library members or new files to be added to the library. When you enter a filename, you must enter a complete filename including extension, if applicable.

Naming Library Members

NOTE: It is possible (but not desirable) for a library to contain several members with the same name. If you attempt to delete, replace, or extract a member whose name is the same as another library member, the archiver deletes, replaces, or extracts the first library member with that name.

10.4 Archiver Examples

The following are examples of typical archiver operations:

- If you want to create a library called function.lib that contains the files sine.obj, cos.obj, and flt.obj, enter:

```
ar7x -a function sine.obj cos.obj flt.obj
```

The archiver responds as follows:

```
==> new archive 'function.lib'
==> building new archive 'function.lib'
```

- You can print a table of contents of function.lib with the -t command, enter:

```
ar7x -t function
```

The archiver responds as follows:

SIZE	DATE	FILE NAME
4260	Thu Mar 28 15:38:18 2019	sine.obj
4260	Thu Mar 28 15:38:18 2019	cos.obj
4260	Thu Mar 28 15:38:18 2019	flt.obj

- If you want to add new members to the library, enter:

```
ar7x -as function atan.obj
```

The archiver responds as follows:

```
==> symbol defined: '_sin'
==> symbol defined: '_cos'
==> symbol defined: '_tan'
==> symbol defined: '_atan'
==> building archive 'function.lib'
```

Because this example does not specify an extension for the libname, the archiver adds the files to the library called function.lib. If function.lib does not exist, the archiver creates it. (The -s option tells the archiver to list the global symbols that are defined in the library.)

- If you want to modify a library member, you can extract it, edit it, and replace it. In this example, assume there is a library named sine.obj that contains the members push.asm, pop.asm, and swap.asm.

```
ar7x -x function sine.obj
```

The archiver makes a copy of sine.obj and places it in the current directory; it does not remove sine.obj from the library. Now you can examine or edit the extracted file. To replace the copy of sine.obj in the library with the edited copy, enter:

```
ar7x -r function sine.obj
```

- If you want to use a command file, specify the command filename after the -@ command. For example:

```
ar7x -@modules.cmd
```

The archiver responds as follows:

```
==> building archive 'modules.lib'
```

Example 10-1 is the modules.cmd command file. The r command specifies that the filenames given in the command file replace files of the same name in the modules.lib library. The -u option specifies that these files are replaced only when the current file has a more recent revision date than the file that is in the library.

Example 10-1. Archiver Command File

```
; Command file to replace members of the
; modules library with updated files
; Use r command and u option:
ru
; Specify library name:
modules.lib
; List filenames to be replaced if updated:
align.obj
bss.obj
data.obj
text.obj
sect.obj
clink.obj
copy.obj
double.obj
drnolist.obj
emsg.obj
end.obj
```

10.5 Library Information Archiver Description

[Section 10.1](#) through [Section 10.4](#) explain how to use the archiver to create libraries of object files for use in the linker of one or more applications. You can have multiple versions of the same object file libraries, each built with different sets of build options. For example, you might have different versions of your object file library for big and little endian, for different architecture revisions, or for different ABIs depending on the typical build environments of client applications. However, if you have several versions of a library, it can be cumbersome to keep track of which version of the library needs to be linked in for a particular application.

When several versions of a single library are available, the library information archiver can be used to create an index library of all of the object file library versions. This index library is used in the linker in place of a particular version of your object file library. The linker looks at the build options of the application being linked, and uses the specified index library to determine which version of your object file library to include in the linker. If one or more compatible libraries were found in the index library, the most suitable compatible library is linked in for your application.

10.5.1 Invoking the Library Information Archiver

To invoke the library information archiver, enter:

```
libinfo7x [options] --output=libname libname1 [libname2 ... libnamen]
```

libinfo7x	is the command that invokes the library information archiver.
<i>options</i>	changes the default behavior of the library information archiver. These options are:
--output libname	specifies the name of the index library to create or update. This option is required.
--update	updates any existing information in the index library specified with the --output option instead of creating a new index.
<i>libnames</i>	names individual object file libraries to be manipulated. When you enter a libname, you must enter a complete filename including extension, if applicable.

10.5.2 Library Information Archiver Example

Consider these object file libraries that all have the same members, but are built with different build options:

Object File Library Name	Build Options
mylib_7100_le.lib	--silicon_version=7100
mylib_7100_be.lib	--silicon_version=7100 --big_endian

Using the library information archiver, you can create an index library called mylib.lib from the above libraries:

```
libinfo7x --output mylib.lib mylib_7100_be.lib mylib_7100_le.lib
```

You can now specify mylib.lib as a library for the linker of an application. The linker uses the index library to choose the appropriate version of the library to use. If the --issue_remarks option is specified before the --run_linker option, the linker reports which library was chosen.

- **Example 1** (little endian):

```
c17x -mv7100 --endian=little --issue_remarks main.c -z -l lnk.cmd ./mylib.lib
<Linking>
remark: linking in "mylib_7100_le.lib" in place of "mylib.lib"
```

- **Example 2** (big endian):

```
c17x -mv7100 --endian=big --issue_remarks main.c -z -l lnk.cmd ./mylib.lib
<Linking>
remark: linking in "mylib_7100_be.lib" in place of "mylib.lib"
```

10.5.3 Listing the Contents of an Index Library

The archiver's -t option can be used on an index library to list the archives indexed by an index library:

```
ar7x t mylib.lib
      SIZE      DATE
-----
      119      Wed Feb 03 12:45:22 2018      mylib_7100_be.lib
      119      Wed Feb 03 12:45:22 2018      mylib_7100_le.lib
       0      Wed Sep 30 12:45:22 2018      __TI__$LIBINFO
```

The indexed object file libraries have an additional .libinfo extension in the archiver listing. The __TI__\$LIBINFO member is a special member that designates *mylib.lib* as an index library, rather than a regular library.

If the archiver's -d command is used on an index library to delete a .libinfo member, the linker will no longer choose the corresponding library when the index library is specified.

Using any other archiver option with an index library, or using -d to remove the __TI__\$LIBINFO member, results in undefined behavior, and is not supported.

10.5.4 Requirements

You must follow these requirements to use library index files:

- At least one application object file must appear on the linker command line before the index library.
- Each object file library specified as input to the library information archiver must only contain object file members that are built with the same build options.
- The linker expects the index library and all of the libraries it indexes to be in a single directory.

Linking C/C++ Code

The C/C++ Code Generation Tools provide two methods for linking your programs:

- You can compile individual modules and link them together. This method is especially useful when you have multiple source files.
- You can compile and link in one step. This method is useful when you have a single source module.

This chapter describes how to invoke the linker with each method. It also discusses special requirements of linking C/C++ code, including the run-time-support libraries, specifying the type of initialization, and allocating the program into memory. For a complete description of the linker, see [Chapter 12](#).

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11.1 Invoking the Linker Through the Compiler (-z Option)

This section explains how to invoke the linker after you have compiled and assembled your programs: as a separate step or as part of the compile step.

11.1.1 Invoking the Linker Separately

This is the general syntax for linking C/C++ programs as a separate step:

```
cl7x --run_linker {--rom_model | --ram_model} filenames
      [options] [--output_file= name.out] --library= library [lnk.cmd]
```

cl7x--run_linker	The command that invokes the linker.
--rom_model --ram_model	Options that tell the linker to use special conventions defined by the C/C++ environment. When you use cl7x --run_linker, you must use --rom_model or --ram_model . The --rom_model option uses automatic variable initialization at run time; the --ram_model option uses variable initialization at load time.
<i>filenames</i>	Names of object files, linker command files, or archive libraries. The default extensions for input files are .c.obj (for C source files) and .cpp.obj (for C++ source files). Any other extension must be explicitly specified. The linker can determine whether the input file is an object or ASCII file that contains linker commands. The default output filename is <i>a.out</i> , unless you use the --output_file option to name the output file.
<i>options</i>	Options affect how the linker handles your object files. Linker options can only appear after the --run_linker option on the command line, but otherwise may be in any order. (Options are discussed in detail in Chapter 12 .)
--output_file= name.out	Names the output file.
--library= library	Identifies the appropriate archive library containing C/C++ run-time-support and floating-point math functions, or linker command files. If you are linking C/C++ code, you must use a run-time-support library. You can use the libraries included with the compiler, or you can create your own run-time-support library. If you have specified a run-time-support library in a linker command file, you do not need this parameter. The --library option's short form is -l.
<i>lnk.cmd</i>	Contains options, filenames, directives, or commands for the linker.

NOTE: The default file extensions for object files created by the compiler have been changed. Object files generated from C source files have the .c.obj extension. Object files generated from C++ source files have the .cpp.obj extension.

When you specify a library as linker input, the linker includes and links only those library members that resolve undefined references. The linker uses a default allocation algorithm to allocate your program into memory. You can use the MEMORY and SECTIONS directives in the linker command file to customize the allocation process. For information, see [Chapter 12](#).

You can link a C/C++ program consisting of object files prog1.c.obj, prog2.c.obj, and prog3.cpp.obj, with an executable object file filename of prog.out with the command:

```
cl7x --run_linker --ram_model prog1 prog2 prog3 --output_file=prog.out
      --library=rts7100_le.lib
```

11.1.2 Invoking the Linker as Part of the Compile Step

This is the general syntax for linking C/C++ programs as part of the compile step:

```
cl7x filenames [options] --run_linker {--rom_model | --ram_model} filenames
      [options] [--output_file= name.out] --library= library [lnk.cmd]
```

The **--run_linker** option divides the command line into the compiler options (the options before **--run_linker**) and the linker options (the options following **--run_linker**). The **--run_linker** option must follow all source files and compiler options on the command line.

All arguments that follow **--run_linker** on the command line are passed to the linker. These arguments can be linker command files, additional object files, linker options, or libraries. These arguments are the same as described in [Section 11.1.1](#).

All arguments that precede **--run_linker** on the command line are compiler arguments. These arguments can be C/C++ source files or compiler options. These arguments are described in [Section 3.2](#).

You can compile and link a C/C++ program consisting of object files prog1.c, prog2.c, and prog3.c, with an executable object file filename of prog.out with the command:

```
cl7x prog1.c prog2.c prog3.c --run_linker --ram_model --output_file=prog.out --
library=rts7100_le.lib
```

NOTE: Order of Processing Arguments in the Linker

The order in which the linker processes arguments is important. The compiler passes arguments to the linker in the following order:

1. Object filenames from the command line
 2. Arguments following the **--run_linker** option on the command line
 3. Arguments following the **--run_linker** option from the C7X_C_OPTION environment variable
-

11.1.3 Disabling the Linker (--compile_only Compiler Option)

You can override the **--run_linker** option by using the **--compile_only** compiler option. The **--run_linker** option's short form is **-z** and the **--compile_only** option's short form is **-c**.

The **--compile_only** option is especially helpful if you specify the **--run_linker** option in the C7X_C_OPTION environment variable and want to selectively disable linking with the **--compile_only** option on the command line.

11.2 Linker Code Optimizations

These techniques are used to further optimize your code.

11.2.1 Conditional Linking

With ELF conditional linking, a code or data section will not be included in a link unless at least one symbol in that code or data section is referenced.

You can use the RETAIN pragma ([Section 5.9.32](#)) to force the section that contains a specific symbol to be included in the link. The CLINK pragma ([Section 5.9.3](#)) indicates that the section that contains the definition of this symbol is eligible for removal during conditional linking. You can use the CODE_SECTION ([Section 5.9.6](#)) and DATA_SECTION ([Section 5.9.9](#)) pragmas to force a symbol to be allocated in a particular section. The symbol must be referenced in a statement other than its declaration to force that section to be included in the link.

11.2.2 Generating Function Subsections (`--gen_func_subsections` Compiler Option)

The compiler translates a source module into an object file. It may place all of the functions into a single code section, or it may create multiple code sections. The benefit of multiple code sections is that the linker may omit unused functions from the executable.

When the linker collects code to be placed into an executable file, it cannot split code sections. If the compiler did not use multiple code sections, and any function in a particular module needs to be linked into the executable, then all functions in that module are linked in, even if they are not used.

An example is a library *.c.obj file that contains a signed divide routine and an unsigned divide routine. If the application requires only signed division, then only the signed divide routine is required for linking. If only one code section was used, both the signed and unsigned routines are linked in since they exist in the same *.c.obj file.

The `--gen_func_subsections` compiler option remedies this problem by placing each function in a file in its own subsection. Thus, only the functions that are referenced in the application are linked into the final executable. This can result in an overall code size reduction.

However, be aware that using the `--gen_func_subsections` compiler option can result in overall code size growth if all or nearly all functions are being referenced. This is because any section containing code must be aligned to a 64-byte boundary to support the branching mechanism. When the `--gen_func_subsections` option is not used, all functions in a source file are usually placed in a common section which is aligned. When `--gen_func_subsections` is used, each function defined in a source file is placed in a unique section. Each of the unique sections requires alignment. If all the functions in the file are required for linking, code size may increase due to the additional alignment padding for the individual subsections. Thus, the `--gen_func_subsections` compiler option is advantageous for use with libraries where normally only a limited number of the functions in a file are used in any one executable. The alternative to using the `--gen_func_subsections` option is to place each function in its own file.

11.2.3 Generating Aggregate Data Subsections (`--gen_data_subsections` Compiler Option)

Similarly to code sections described in the previous section, data can either be placed in a single section or multiple sections. The benefit of multiple data sections is that the linker may omit unused data structures from the executable. By default, the `--gen_data_subsections` option is on. This option causes aggregate data—arrays, structs, and unions—to be placed in separate subsections of the data section.

11.3 Controlling the Linking Process

Regardless of the method you choose for invoking the linker, special requirements apply when linking C/C++ programs. You must:

- Include the compiler's run-time-support library
- Specify the type of boot-time initialization
- Determine how you want to allocate your program into memory

This section discusses how these factors are controlled and provides an example of the standard default linker command file. For more information about how to operate the linker, see the linker description in [Chapter 12](#).

11.3.1 Including the Run-Time-Support Library

You must link all C/C++ programs with a run-time-support library. The library contains standard C/C++ functions as well as functions used by the compiler to manage the C/C++ environment. The following sections describe two methods for including the run-time-support library.

11.3.1.1 Automatic Run-Time-Support Library Selection

The linker assumes you are using the C and C++ conventions if either the `--rom_model` or `--ram_model` linker option is specified, or if the link step includes the compile step for a C or C++ file, or if you link against the index library `libc.a`.

If the linker assumes you are using the C and C++ conventions and the entry point for the program (normally `c_int00`) is not resolved by any specified object file or library, the linker attempts to automatically include the most compatible run-time-support library for your program. The run-time-support library chosen by the compiler is searched after any other libraries specified with the `--library` option on the command line or in the linker command file. If `libc.a` is explicitly used, the appropriate run-time-support library is included in the search order where `libc.a` is specified.

You can disable the automatic selection of a run-time-support library by using the `--disable_auto_rts` option.

If the `--issue_remarks` option is specified before the `--run_linker` option during the linker, a remark is generated indicating which run-time support library was linked in. If a different run-time-support library is desired than the one reported by `--issue_remarks`, you must specify the name of the desired run-time-support library using the `--library` option and in your linker command files when necessary.

Example 11-1. Using the `--issue_remarks` Option

```
cl7x --silicon_version=7100 --issue_remarks main.c --run_linker --rom_model

<Linking>
remark: linking in "libc.a"
remark: linking in "rts7100_le.lib" in place of "libc.a"
```

11.3.1.2 Manual Run-Time-Support Library Selection

You can bypass automatic library selection by explicitly specifying the desired run-time-support library to use. Use the `--library` linker option to specify the name of the library. The linker will search the path specified by the `--search_path` option and then the `C7X_C_DIR` environment variable for the named library. You can use the `--library` linker option on the command line or in a command file.

```
cl7x --run_linker {--rom_model | --ram_model} filenames --library= libraryname
```

11.3.1.3 Library Order for Searching for Symbols

Generally, you should specify the run-time-support library as the last name on the command line because the linker searches libraries for unresolved references in the order that files are specified on the command line. If any object files follow a library, references from those object files to that library are not resolved. You can use the `--reread_libs` option to force the linker to reread all libraries until references are resolved. Whenever you specify a library as linker input, the linker includes and links only those library members that resolve undefined references.

By default, if a library introduces an unresolved reference and multiple libraries have a definition for it, then the definition from the same library that introduced the unresolved reference is used. Use the `--priority` option if you want the linker to use the definition from the first library on the command line that contains the definition.

11.3.2 Run-Time Initialization

C/C++ programs require initialization of the run-time environment before execution of the program itself may begin. This initialization is performed by a *bootstrap routine*. This routine is responsible for creating the stack, initializing global variables, and calling the `main()` function. The bootstrap routine should be the entry point for the program, and it typically should be the RESET interrupt handler. The bootstrap routine is responsible for the following tasks:

1. Set up the stack by initializing SP
2. Set up the data page pointer DP (for architectures that have one)
3. Set configuration registers
4. Process the `.cinit` table to autoinitialize global variables (when using the `--rom_model` option)
5. Process the `.pinit` table to construct global C++ objects.
6. Call the `main()` function with appropriate arguments
7. Call `exit()` when `main()` returns

When you compile a C/C++ program and use `--rom_model` or `--ram_model`, the linker automatically looks for a bootstrap routine named `_c_int00`. The run-time support library provides a sample `_c_int00` in `boot.c.obj`, which performs the required tasks. If you use the run-time support's bootstrap routine, you should set `_c_int00` as the entry point.

NOTE: The `_c_int00` Symbol

If you use the `--ram_model` or `--rom_model` link option, `_c_int00` is automatically defined as the entry point for the program. Otherwise, an entry point is not automatically selected and you will receive a linker warning.

11.3.3 Global Object Constructors

Global C++ variables that have constructors and destructors require their constructors to be called during program initialization and their destructors to be called during program termination. The C++ compiler produces a table of constructors to be called at startup.

Constructors for global objects from a single module are invoked in the order declared in the source code, but the relative order of objects from different object files is unspecified.

Global constructors are called after initialization of other global variables and before the `main()` function is called. Global destructors are invoked during the exit run-time support function, similar to functions registered through `atexit`.

[Section 6.7.2.6](#) discusses the format of the global constructor table.

11.3.4 Specifying the Type of Global Variable Initialization

The C/C++ compiler produces data tables for initializing global variables. [Section 6.7.2.4](#) discusses the format of these initialization tables. The initialization tables are used in one of the following ways:

- Global variables are initialized at *run time*. Use the `--rom_model` linker option (see [Section 6.7.2.3](#)).
- Global variables are initialized at *load time*. Use the `--ram_model` linker option (see [Section 6.7.2.5](#)).

When you link a C/C++ program, you must use either the `--rom_model` or `--ram_model` option. These options tell the linker to select initialization at run time or load time. When you compile and link programs, the `--rom_model` option is the default. If used, the `--rom_model` option must follow the `--run_linker` option (see [Section 11.1](#)). For details on linking conventions used with `--rom_model` and `--ram_model`, see [Section 6.7.2.3](#) and [Section 6.7.2.5](#), respectively.

11.3.5 Specifying Where to Allocate Sections in Memory

The compiler produces relocatable blocks of code and data. These blocks, called *sections*, are allocated in memory in a variety of ways to conform to a variety of system configurations. See [Section 6.1.1](#) for a complete description of how the compiler uses these sections.

The compiler creates two basic kinds of sections: initialized and uninitialized. [Table 11-1](#) summarizes the initialized sections. [Table 11-2](#) summarizes the uninitialized sections.

Table 11-1. Initialized Sections Created by the Compiler

Name	Contents
.args	Reserved space for copying command line arguments before the main() function is called by the boot routine. See Section 3.6 .
.binit	Boot time copy tables (See Section 12.8.4.2 for information on BINIT in linker command files.)
.c7xabi.exidx	Index table for exception handling; read-only (see --exceptions option).
.c7xabi.extab	Unwinding instructions for exception handling; read-only (see --exceptions option).
.cinit	The compiler does not generate a .cinit section unless the --rom_mode linker option is specified. If --rom_mode is specified, the linker creates this section, which contains tables for explicitly initialized global and static variables.
.const	Global and static const variables, including string constants and initializers for local variables.
.data	Global and static non-const variables that are explicitly initialized.
.got	Global offset table.
.init_array	Table of constructors to be called at startup.
.name.load	Compressed image of section <i>name</i> ; read-only (See Section 12.8 for information on copy tables.)
.ovly	Copy tables other than boot time (.binit) copy tables. Read-only data.
.TI.crctab	Generated CRC checking tables. Read-only data.

Table 11-2. Uninitialized Sections Created by the Compiler

Name	Contents
.bss	Uninitialized global and static variables
.cio	Buffers for stdio functions from the run-time support library
.stack	
.system	Memory pool (heap) for dynamic memory allocation (malloc, etc)

When you link your program, you must specify where to allocate the sections in memory. In general, initialized sections are linked into ROM or RAM; uninitialized sections are linked into RAM.

The linker provides MEMORY and SECTIONS directives for allocating sections. For more information about allocating sections into memory, see [Section 12.5](#).

11.3.6 A Sample Linker Command File

[Example 11-2](#) shows a typical linker command file that links a C program. The command file in this example is named Ink.cmd and lists several linker options:

--rom_model	Tells the linker to use autoinitialization at run time.
--heap_size	Tells the linker to set the C heap size at 0x2000 bytes.
--stack_size	Tells the linker to set the stack size to 0x0100 bytes.
--library	Tells the linker to use an archive library file, rts7100_le.lib, for input.

To link the program, use the following syntax:

```
cl7x --run_linker object_file(s) --output_file= outfile --map_file= mapfile Ink.cmd
```

The MEMORY and possibly the SECTIONS directives, might require modification to work with your system. See [Section 12.5](#) for more information on these directives.

Example 11-2. Linker Command File

```
--rom_model
--heap_size=0x2000
--stack_size=0x0100
--library=rtss7100_le.lib

MEMORY
{
    VECS:    o = 0x00000000      l = 0x000000400 /* reset & interrupt vectors */
    PMEM:    o = 0x00000400      l = 0x00000FC00 /* intended for initialization */
    BMEM:    o = 0x80000000      l = 0x000010000 /* .bss, .sysmem, .stack, .cinit */
}

SECTIONS
{
    vectors      >      VECS
    .text        >      PMEM
    .data        >      BMEM
    .stack       >      BMEM
    .bss         >      BMEM
    .sysmem      >      BMEM
    .cinit       >      BMEM
    .const       >      BMEM
    .cio         >      BMEM
}
```

Linker Description

The C7000 linker creates a static executable or dynamic object module by combining object modules. This chapter describes the linker options, directives, and statements used to create static executables and dynamic object modules. Object libraries, command files, and other key concepts are discussed as well.

The concept of sections is basic to linker operation; [Chapter 8](#) includes a detailed discussion of sections.

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12.1 Linker Overview

The C7000 linker allows you to allocate output sections efficiently in the memory map. As the linker combines object files, it performs the following tasks:

- Allocates sections into the target system's configured memory
- Relocates symbols and sections to assign them to final addresses
- Resolves undefined external references between input files

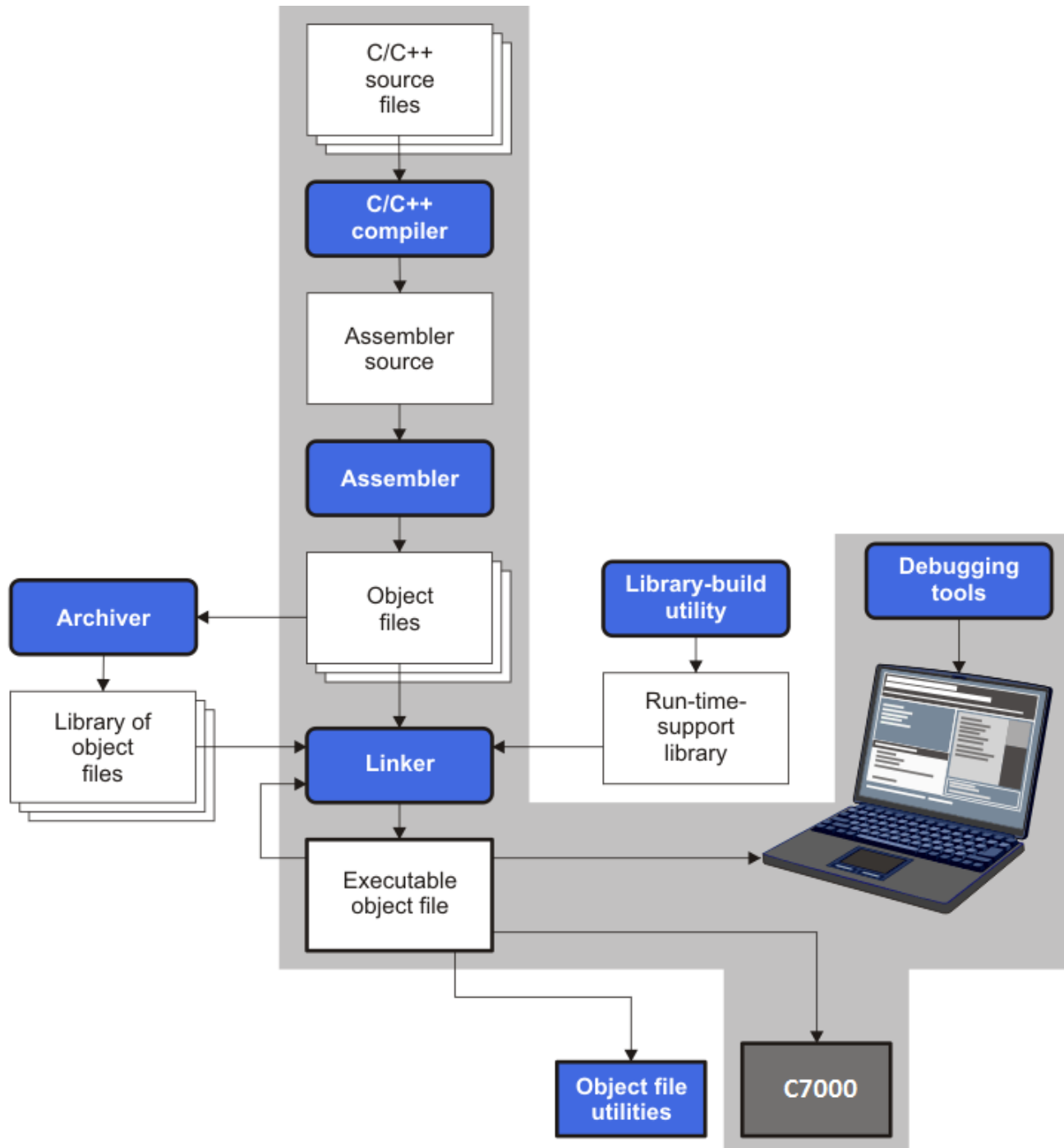
The linker command language controls memory configuration, output section definition, and address binding. The language supports expression assignment and evaluation. You configure system memory by defining and creating a memory model that you design. Two powerful directives, MEMORY and SECTIONS, allow you to:

- Allocate sections into specific areas of memory
- Combine object file sections
- Define or redefine global symbols at link time

12.2 The Linker's Role in the Software Development Flow

Figure 12-1 illustrates the linker's role in the software development process. The linker accepts several types of files as input, including object files, command files, libraries, and partially linked files. The linker creates an executable object module that can be downloaded to one of several development tools or executed by a C7000 device.

Figure 12-1. The Linker in the C7000 Software Development Flow



12.3 Invoking the Linker

The general syntax for invoking the linker is:

```
cl7x --run_linker [options] filename1 .... filenamen
```

cl7x --run_linker	is the command that invokes the linker. The --run_linker option's short form is -Z.
<i>options</i>	can appear anywhere on the command line or in a linker command file. (Options are discussed in Section 12.4 .)
<i>filename₁, filename_n</i>	can be object files, linker command files, or archive libraries. The default extensions for input files are .c.obj (for C source files) and .cpp.obj (for C++ source files). Any other extension must be explicitly specified. The linker can determine whether the input file is an object or ASCII file that contains linker commands. The default output filename is <i>a.out</i> , unless you use the --output_file option to name the output file.

NOTE: The default file extensions for object files created by the compiler have been changed. Object files generated from C source files have the .c.obj extension. Object files generated from C++ source files have the .cpp.obj extension. Object files generated from assembly source files still have the .obj extension.

There are two methods for invoking the linker:

- Specify options and filenames on the command line. This example links two files, file1.c.obj and file2.c.obj, and creates an output module named link.out.
- Put filenames and options in a linker command file. Filenames that are specified inside a linker command file must begin with a letter. For example, assume the file linker.cmd contains the following lines:

```
cl7x --run_linker file1.c.obj file2.c.obj --output_file=link.out
```

```
--output_file=link.out file1.c.obj file2.c.obj
```

Now you can invoke the linker from the command line; specify the command filename as an input file:

```
cl7x --run_linker linker.cmd
```

When you use a command file, you can also specify other options and files on the command line. For example, you could enter:

```
cl7x --run_linker --map_file=link.map linker.cmd file3.c.obj
```

The linker reads and processes a command file as soon as it encounters the filename on the command line, so it links the files in this order: file1.c.obj, file2.c.obj, and file3.c.obj. This example creates an output file called link.out and a map file called link.map.

For information on invoking the linker for C/C++ files, see [Section 12.10](#).

12.4 Linker Options

Linker options control linking operations. They can be placed on the command line or in a command file. Linker options must be preceded by a hyphen (-). Options can be separated from arguments (if they have them) by an optional space.

Table 12-1. Basic Options Summary

Option	Alias	Description	Section
--run_linker	-z	Enables linking	Section 12.3
--output_file	-o	Names the executable output module. The default filename is a.out.	Section 12.4.22
--map_file	-m	Produces a map or listing of the input and output sections, including holes, and places the listing in <i>filename</i>	Section 12.4.17
--stack_size	-stack	Sets C system stack size to <i>size</i> bytes and defines a global symbol that specifies the stack size. Default = 1K bytes	Section 12.4.27
--heap_size	-heap	Sets heap size (for the dynamic memory allocation in C) to <i>size</i> bytes and defines a global symbol that specifies the heap size. Default = 1K bytes	Section 12.4.13

Table 12-2. File Search Path Options Summary

Option	Alias	Description	Section
--library	-l	Names an archive library or link command <i>filename</i> as linker input	Section 12.4.15
--disable_auto_rts		Disables the automatic selection of a run-time-support library	Section 12.4.8
--priority	-priority	Satisfies unresolved references by the first library that contains a definition for that symbol	Section 12.4.15.3
--reread_libs	-x	Forces rereading of libraries, which resolves back references	Section 12.4.15.3
--search_path	-i	Alters library-search algorithms to look in a directory named with <i>pathname</i> before looking in the default location. This option must appear before the --library option.	Section 12.4.15.1

Table 12-3. Command File Preprocessing Options Summary

Option	Alias	Description	Section
--define		Predefines <i>name</i> as a preprocessor macro.	Section 12.4.10
--undefine		Removes the preprocessor macro <i>name</i> .	Section 12.4.10
--disable_pp		Disables preprocessing for command files	Section 12.4.10

Table 12-4. Diagnostic Options Summary

Option	Alias	Description	Section
--diag_error		Categorizes the diagnostic identified by <i>num</i> as an error	Section 12.4.7
--diag_remark		Categorizes the diagnostic identified by <i>num</i> as a remark	Section 12.4.7
--diag_suppress		Suppresses the diagnostic identified by <i>num</i>	Section 12.4.7
--diag_warning		Categorizes the diagnostic identified by <i>num</i> as a warning	Section 12.4.7
--display_error_number		Displays a diagnostic's identifiers along with its text	Section 12.4.7
--emit_references:file[= <i>file</i>]		Emits a file containing section information. The information includes section size, symbols defined, and references to symbols.	Section 12.4.7
--emit_warnings_as_errors	-pdew	Treats warnings as errors	Section 12.4.7
--issue_remarks		Issues remarks (nonserious warnings)	Section 12.4.7
--no_demangle		Disables demangling of symbol names in diagnostics	Section 12.4.19
--no_warnings		Suppresses warning diagnostics (errors are still issued)	Section 12.4.7
--set_error_limit		Sets the error limit to <i>num</i> . The linker abandons linking after this number of errors. (The default is 100.)	Section 12.4.7
--verbose_diagnostics		Provides verbose diagnostics that display the original source with line-wrap	Section 12.4.7
--warn_sections	-w	Displays a message when an undefined output section is created	Section 12.4.32

Table 12-5. Linker Output Options Summary

Option	Alias	Description	Section
--absolute_exe	-a	Produces an absolute, executable module. This is the default; if neither --absolute_exe nor --relocatable is specified, the linker acts as if --absolute_exe were specified.	Section 12.4.3.1
--mapfile_contents		Controls the information that appears in the map file.	Section 12.4.18
--relocatable	-r	Produces a nonexecutable, relocatable output module	Section 12.4.3.2
--rom	-r	Create a ROM object	
--xml_link_info		Generates a well-formed XML <i>file</i> containing detailed information about the result of a link	Section 12.4.33

Table 12-6. Symbol Management Options Summary

Option	Alias	Description	Section
--entry_point	-e	Defines a global symbol that specifies the primary entry point for the output module	Section 12.4.11
--globalize		Changes the symbol linkage to global for symbols that match <i>pattern</i>	Section 12.4.16
--hide		Hides global symbols that match <i>pattern</i>	Section 12.4.14
--localize		Changes the symbol linkage to local for symbols that match <i>pattern</i>	Section 12.4.16
--make_global	-g	Makes <i>symbol</i> global (overrides -h)	Section 12.4.16.1
--make_static	-h	Makes all global symbols static	Section 12.4.16.1
--no_sym_merge	-b	Disables merge of symbolic debugging information	Section 12.4.20
--no_symtable	-s	Strips symbol table information and line number entries from the output module	Section 12.4.21
--retain		Retains a list of sections that otherwise would be discarded	Section 12.4.25
--scan_libraries	-scanlibs	Scans all libraries for duplicate symbol definitions	Section 12.4.26
--symbol_map		Maps symbol references to a symbol definition of a different name	Section 12.4.29
--undef_sym	-u	Places an unresolved external <i>symbol</i> into the output module's symbol table	Section 12.4.31
--unhide		Reveals (un-hides) global symbols that match <i>pattern</i>	Section 12.4.14

Table 12-7. Run-Time Environment Options Summary

Option	Alias	Description	Section
--arg_size	--args	Allocates memory to be used by the loader to pass arguments	Section 12.4.4
--fill_value	-f	Sets default fill values for holes within output sections; <i>fill_value</i> is a 64-bit constant	Section 12.4.12
--ram_model	-cr	Initializes variables at load time	Section 12.4.24
--rom_model	-c	Autoinitializes variables at run time	Section 12.4.24
--trampolines		Generates far call trampolines; on by default	Section 12.4.30

Table 12-8. Miscellaneous Options Summary

Option	Alias	Description	Section
--linker_help	-help	Displays information about syntax and available options	–
--minimize_trampolines		Selects the trampoline minimization algorithm (argument is optional; algorithm is postorder by default)	Section 12.4.30.2
--preferred_order		Prioritizes placement of functions	Section 12.4.23
--strict_compatibility		Performs more conservative and rigorous compatibility checking of input object files	Section 12.4.28
--zero_init		Controls preinitialization of uninitialized variables. Default is on.	Section 12.4.34

12.4.1 Wildcards in File, Section, and Symbol Patterns

The linker allows file, section, and symbol names to be specified using the asterisk (*) and question mark (?) wildcards. Using * matches any number of characters and using ? matches a single character. Using wildcards can make it easier to handle related objects, provided they follow a suitable naming convention.

For example:

```
mp3*.obj      /* matches anything .obj that begins with mp3      */
task?.o*     /* matches task1.obj, task2.c.obj, taskX.o55, etc. */

SECTIONS
{
    .fast_code: { *.obj(*fast*) }          > FAST_MEM
    .vectors   : { vectors.c.obj(.vector:part1:*) > 0xFFFFFFF00
    .str_code  : { rts*.lib<str*.c.obj>(.text) } > S1ROM
}
```

12.4.2 Specifying C/C++ Symbols with Linker Options

The link-time symbol is the same as the C/C++ identifier name. The compiler *does not* prepend an underscore to the beginning of C/C++ identifiers.

For more information on referencing symbol names, see [Section 5.12](#).

For information specifically about C++ symbol naming, see [Chapter 14](#).

See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.4.3 Relocation Capabilities (--absolute_exe and --relocatable Options)

The linker performs relocation, which is the process of adjusting all references to a symbol when the symbol's address changes.

The linker supports two options (--absolute_exe and --relocatable) that allow you to produce an absolute or a relocatable output module.

When the linker encounters a file that contains no relocation or symbol table information, it issues a warning message (but continues executing). Relinking an absolute file can be successful only if each input file contains no information that needs to be relocated (that is, each file has no unresolved references and is bound to the same virtual address that it was bound to when the linker created it).

12.4.3.1 Producing an Absolute Output Module (--absolute_exe option)

When you use the --absolute_exe option without the --relocatable option, the linker produces an *absolute, executable output module*. Absolute files contain *no* relocation information. Executable files contain the following:

- Special symbols defined by the linker (see [Section 12.5.9.4](#))
- An header that describes information such as the program entry point
- No unresolved references

The following example links file1.c.obj and file2.c.obj and creates an absolute output module called a.out:

```
cl7x --run_linker --absolute_exe file1.c.obj file2.c.obj
```

The --absolute_exe and --relocatable Options

NOTE: If you do not use the --absolute_exe or the --relocatable option, the linker acts as if you specified --absolute_exe.

12.4.3.2 Producing a Relocatable Output Module (--relocatable option)

When you use the --relocatable option, the linker retains relocation entries in the output module. If the output module is relocated (at load time) or relinked (by another linker execution), use --relocatable to retain the relocation entries.

The linker produces a file that is not executable when you use the `--relocatable` option without the `--absolute_exe` option. A file that is not executable does not contain special linker symbols or an optional header. The file can contain unresolved references, but these references do not prevent creation of an output module.

This example links `file1.c.obj` and `file2.c.obj` and creates a relocatable output module called `a.out`:

```
cl7x --run_linker --relocatable file1.c.obj file2.c.obj
```

The output file `a.out` can be relinked with other object files or relocated at load time. (Linking a file that will be relinked with other files is called partial linking. For more information, see [Section 12.9](#).)

12.4.3.3 Producing an Executable, Relocatable Output Module (-ar Option)

If you invoke the linker with both the `--absolute_exe` and `--relocatable` options, the linker produces an *executable, relocatable* object module. The output file contains the special linker symbols, an optional header, and all resolved symbol references; however, the relocation information is retained.

This example links `file1.c.obj` and `file2.c.obj` to create an executable, relocatable output module called `xr.out`:

```
cl7x --run_linker -ar file1.c.obj file2.c.obj --output_file=xr.out
```

12.4.4 Allocate Memory for Use by the Loader to Pass Arguments (--arg_size Option)

The `--arg_size` option instructs the linker to allocate memory to be used by the loader to pass arguments from the command line of the loader to the program. The syntax of the `--arg_size` option is:

--arg_size= size

The *size* is the number of bytes to be allocated in target memory for command-line arguments.

By default, the linker creates the `__c_args__` symbol and sets it to -1. When you specify `--arg_size=size`, the following occur:

- The linker creates an uninitialized section named `.args` of *size* bytes.
- The `__c_args__` symbol contains the address of the `.args` section.

The loader and the target boot code use the `.args` section and the `__c_args__` symbol to determine whether and how to pass arguments from the host to the target program. See [Section 3.6](#) for information about the loader.

12.4.5 Compression (--cinit_compression and --copy_compression Option)

By default, the linker does not compress copy table ([Section 9.3.3](#) and [Section 12.8](#)) source data sections. The `--cinit_compression` and `--copy_compression` options specify compression through the linker.

The `--cinit_compression` option specifies the compression type the linker applies to the C autoinitialization copy table source data sections. The default is `lzss`.

Overlays can be managed by using linker-generated copy tables. To save ROM space the linker can compress the data copied by the copy tables. The compressed data is decompressed during copy. The `--copy_compression` option controls the compression of the copy data tables.

The syntax for the options are:

--cinit_compression[=*compression_kind*]

--copy_compression[=*compression_kind*]

The *compression_kind* can be one of the following types:

- **off**. Don't compress the data.
- **rle**. Compress data using Run Length Encoding.
- **lzss**. Compress data using Lempel-Ziv-Storer-Szymanski compression (the default if no *compression_kind* is specified).

See [Section 12.8.5](#) for more information about compression.

12.4.6 Compress DWARF Information (--compress_dwarf Option)

The `--compress_dwarf` option aggressively reduces the size of DWARF information by eliminating duplicate information from input object files.

For ELF object files, which are used with EABI, the `--compress_dwarf` option eliminates duplicate information that could not be removed through the use of ELF COMDAT groups. (See the ELF specification for information on COMDAT groups.)

12.4.7 Control Linker Diagnostics

The linker honors certain C/C++ compiler options to control linker-generated diagnostics. The diagnostic options must be specified before the `--run_linker` option.

--diag_error=num	Categorize the diagnostic identified by <i>num</i> as an error. To find the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate link. Then use <code>--diag_error=num</code> to recategorize the diagnostic as an error. You can only alter the severity of discretionary diagnostics.
--diag_remark=num	Categorize the diagnostic identified by <i>num</i> as a remark. To find the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate link. Then use <code>--diag_remark=num</code> to recategorize the diagnostic as a remark. You can only alter the severity of discretionary diagnostics.
--diag_suppress=num	Suppress the diagnostic identified by <i>num</i> . To find the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate link. Then use <code>--diag_suppress=num</code> to suppress the diagnostic. You can only suppress discretionary diagnostics.
--diag_warning=num	Categorize the diagnostic identified by <i>num</i> as a warning. To find the numeric identifier of a diagnostic message, use the <code>--display_error_number</code> option first in a separate link. Then use <code>--diag_warning=num</code> to recategorize the diagnostic as a warning. You can only alter the severity of discretionary diagnostics.
--display_error_number	Display a diagnostic's numeric identifier along with its text. Use this option in determining which arguments you need to supply to the diagnostic suppression options (<code>--diag_suppress</code> , <code>--diag_error</code> , <code>--diag_remark</code> , and <code>--diag_warning</code>). This option also indicates whether a diagnostic is discretionary. A discretionary diagnostic is one whose severity can be overridden. A discretionary diagnostic includes the suffix <code>-D</code> ; otherwise, no suffix is present. See Section 3.7 for more information on understanding diagnostic messages.
--emit_references:file [= <i>filename</i>]	Emits a file containing section information. The information includes section size, symbols defined, and references to symbols. This information allows you to determine why each section is included in the linked application. The output file is a simple ASCII text file. The <i>filename</i> is used as the base name of a file created. For example, <code>--emit_references:file=myfile</code> generates a file named <code>myfile.txt</code> in the current directory.
--emit_warnings_as_errors	Treat all warnings as errors. This option cannot be used with the <code>--no_warnings</code> option. The <code>--diag_remark</code> option takes precedence over this option. This option takes precedence over the <code>--diag_warning</code> option.
--issue_remarks	Issue remarks (nonserious warnings), which are suppressed by default.
--no_warnings	Suppress warning diagnostics (errors are still issued).
--set_error_limit=num	Set the error limit to <i>num</i> , which can be any decimal value. The linker abandons linking after this number of errors. (The default is 100.)
--verbose_diagnostics	Provide verbose diagnostics that display the original source with line-wrap and indicate the position of the error in the source line

12.4.8 Automatic Library Selection (**--disable_auto_rts Option**)

The `--disable_auto_rts` option disables the automatic selection of a run-time-support (RTS) library. See [Section 11.3.1.1](#) for details on the automatic selection process.

12.4.9 Do Not Remove Unused Sections (**--unused_section_elimination Option**)

In order to minimize the foot print, the ELF linker does not include a section that is not needed to resolve any references in the final executable. Use `--unused_section_elimination=off` to disable this optimization. The syntax for the option is:

--unused_section_elimination[=*on*|*off*]

The linker default behavior is equivalent to `--unused_section_elimination=on`.

12.4.10 Linker Command File Preprocessing (**--disable_pp**, **--define** and **--undefine Options**)

The linker preprocesses linker command files using a standard C preprocessor. Therefore, the command files can contain well-known preprocessing directives such as `#define`, `#include`, and `#if / #endif`.

Three linker options control the preprocessor:

--disable_pp	Disables preprocessing for command files
--define= <i>name</i> [= <i>val</i>]	Predefines <i>name</i> as a preprocessor macro
--undefine= <i>name</i>	Removes the macro <i>name</i>

The compiler has `--define` and `--undefine` options with the same meanings. However, the linker options are distinct; only `--define` and `--undefine` options specified after `--run_linker` are passed to the linker. For example:

```
cl7x --define=FOO=1 main.c --run_linker --define=BAR=2 lnk.cmd
```

The linker sees only the `--define` for BAR; the compiler only sees the `--define` for FOO.

When one command file `#includes` another, preprocessing context is carried from parent to child in the usual way (that is, macros defined in the parent are visible in the child). However, when a command file is invoked other than through `#include`, either on the command line or by the typical way of being named in another command file, preprocessing context is **not** carried into the nested file. The exception to this is `--define` and `--undefine` options, which apply globally from the point they are encountered. For example:

```
--define GLOBAL
#define LOCAL

#include "incfile.cmd"      /* sees GLOBAL and LOCAL */
nestfile.cmd              /* only sees GLOBAL      */
```

Two cautions apply to the use of `--define` and `--undefine` in command files. First, they have global effect as mentioned above. Second, since they are not actually preprocessing directives themselves, they are subject to macro substitution, probably with unintended consequences. This effect can be defeated by quoting the symbol name. For example:

```
--define MYSYM=123
--undefine MYSYM      /* expands to --undefine 123 (!) */
--undefine "MYSYM"    /* ahh, that's better          */
```

The linker uses the same search paths to find `#include` files as it does to find libraries. That is, `#include` files are searched in the following places:

1. If the `#include` file name is in quotes (rather than `<brackets>`), in the directory of the current file
2. In the list of directories specified with `--library` options or environment variables (see [Section 12.4.15](#))

There are two exceptions: relative pathnames (such as `"../name"`) always search the current directory; and absolute pathnames (such as `"/usr/tools/name"`) bypass search paths entirely.

The linker provides the built-in macro definitions listed in [Table 12-9](#). The availability of these macros within the linker is determined by the command-line options used, not the build attributes of the files being linked. If these macros are not set as expected, confirm that your project's command line uses the correct compiler option settings.

Table 12-9. Predefined C7000 Macro Names

Macro Name	Description
<code>__DATE__</code>	Expands to the compilation date in the form <i>mmm dd yyyy</i>
<code>__FILE__</code>	Expands to the current source filename
<code>__TI_COMPILER_VERSION__</code>	Defined to a 7-9 digit integer, depending on if X has 1, 2, or 3 digits. The number does not contain a decimal. For example, version 3.2.1 is represented as 3002001. The leading zeros are dropped to prevent the number being interpreted as an octal.
<code>__TI_EABI__</code>	Defined to 1 if EABI is enabled; otherwise, it is undefined.
<code>__TIME__</code>	Expands to the compilation time in the form <i>"hh:mm:ss"</i>
<code>__C7000__</code>	Always defined
<code>__C7100__</code>	Always defined

12.4.11 Define an Entry Point (`--entry_point` Option)

The memory address at which a program begins executing is called the *entry point*. When a loader loads a program into target memory, the program counter (PC) must be initialized to the entry point; the PC then points to the beginning of the program.

The linker can assign one of four values to the entry point. These values are listed below in the order in which the linker tries to use them. If you use one of the first three values, it must be an external symbol in the symbol table.

- The value specified by the `--entry_point` option. The syntax is:
`--entry_point= global_symbol`
 where *global_symbol* defines the entry point and must be defined as an external symbol of the input files. The external symbol name of C or C++ objects may be different than the name as declared in the source language.
- The value of symbol `_c_int00` (if present). The `_c_int00` symbol *must* be the entry point if you are linking code produced by the C compiler.
- The value of symbol `main` (if present)
- 0 (default value)

This example links `file1.c.obj` and `file2.c.obj`. The symbol `begin` is the entry point; `begin` must be defined as external in `file1` or `file2`.

```
cl7x --run_linker --entry_point=begin file1.c.obj file2.c.obj
```

See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.4.12 Set Default Fill Value (`--fill_value` Option)

The `--fill_value` option fills the holes formed within output sections. The syntax for the option is:

`--fill_value= value`

The argument *value* is a 64-bit constant (up to 16 hexadecimal digits). If you do not use `--fill_value`, the linker uses 0 as the default fill value.

This example fills holes with the hexadecimal value `ABCDABCD`:

```
cl7x --run_linker --fill_value=0xABCDABCDABCDABCD file1.c.obj file2.c.obj
```


12.4.13 Define Heap Size (--heap_size Option)

The C/C++ compiler uses an uninitialized section called for the C run-time memory pool used by malloc(). You can set the size of this memory pool at link time by using the --heap_size option. The syntax for the --heap_size option is:

--heap_size= size

The *size* must be a constant. This example defines a 4K byte heap:

```
c17x --run_linker --heap_size=0x1000 /* defines a 4k heap (.system section)*/
```

The linker creates the section only if there is a section in an input file.

The linker also creates a global symbol, , and assigns it a value equal to the size of the heap. The default size is 1K bytes. See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.4.14 Hiding Symbols

Symbol hiding prevents the symbol from being listed in the output file's symbol table. While localization is used to prevent name space clashes in a link unit (see [Section 12.4.16](#)), symbol hiding is used to obscure symbols which should not be visible outside a link unit. Such symbol's names appear only as empty strings or "no name" in object file readers. The linker supports symbol hiding through the --hide and --unhide options.

The syntax for these options are:

--hide='pattern'

--unhide='pattern'

The *pattern* is a "glob" (a string with optional ? or * wildcards). Use ? to match a single character. Use * to match zero or more characters.

The --hide option hides global symbols with a linkname matching the *pattern*. It hides symbols matching the pattern by changing the name to an empty string. A global symbol that is hidden is also localized.

The --unhide option reveals (un-hides) global symbols that match the *pattern* that are hidden by the --hide option. The --unhide option excludes symbols that match pattern from symbol hiding provided the pattern defined by --unhide is more restrictive than the pattern defined by --hide.

These options have the following properties:

- The --hide and --unhide options can be specified more than once on the command line.
- The order of --hide and --unhide has no significance.
- A symbol is matched by only one pattern defined by either --hide or --unhide.
- A symbol is matched by the most restrictive pattern. Pattern A is considered more restrictive than Pattern B, if Pattern A matches a narrower set than Pattern B.
- It is an error if a symbol matches patterns from --hide and --unhide and one does not supersede the other. Pattern A supersedes pattern B if A can match everything B can and more. If Pattern A supersedes Pattern B, then Pattern B is said to more restrictive than Pattern A.
- These options affect final and partial linking.

In map files these symbols are listed under the Hidden Symbols heading.

12.4.15 Alter the Library Search Algorithm (--library Option, --search_path Option, and C7X_C_DIR Environment Variable)

Usually, when you want to specify a file as linker input, you simply enter the filename; the linker looks for the file in the current directory. For example, suppose the current directory contains the library object.lib. If this library defines symbols that are referenced in the file file1.c.obj, this is how you link the files:

```
cl7x --run_linker file1.c.obj object.lib
```

If you want to use a file that is not in the current directory, use the --library linker option. The --library option's short form is -l. The syntax for this option is:

--library=[pathname] filename

The *filename* is the name of an archive, an object file, or linker command file. You can specify up to 128 search paths.

The --library option is not required when one or more members of an object library are specified for input to an output section. For more information about allocating archive members, see [Section 12.5.5.5](#).

You can augment the linker's directory search algorithm by using the --search_path linker option or the C7X_C_DIR environment variable. The linker searches for object libraries and command files in the following order:

1. It searches directories named with the --search_path linker option. The --search_path option must appear before the --library option on the command line or in a command file.
2. It searches directories named with C7X_C_DIR .
3. If C7X_C_DIR is not set, it searches directories named with the assembler's C7X_A_DIR environment variable.
4. It searches the current directory.

12.4.15.1 Name an Alternate Library Directory (--search_path Option)

The --search_path option names an alternate directory that contains input files. The --search_path option's short form is -I. The syntax for this option is:

--search_path= pathname

The *pathname* names a directory that contains input files.

When the linker is searching for input files named with the --library option, it searches through directories named with --search_path first. Each --search_path option specifies only one directory, but you can have several --search_path options per invocation. When you use the --search_path option to name an alternate directory, it must precede any --library option used on the command line or in a command file.

For example, assume that there are two archive libraries called r.lib and lib2.lib that reside in ld and ld2 directories. The table below shows the directories that r.lib and lib2.lib reside in, how to set environment variable, and how to use both libraries during a link. Select the row for your operating system:

Operating System	Enter
UNIX (Bourne shell)	cl7x --run_linker f1.c.obj f2.c.obj --search_path=/ld --search_path=/ld2
	--library=r.lib --library=lib2.lib
Windows	cl7x --run_linker f1.c.obj f2.c.obj --search_path=\ld --search_path=\ld2
	--library=r.lib --library=lib2.lib

12.4.15.2 Name an Alternate Library Directory (C7X_C_DIR Environment Variable)

An environment variable is a system symbol that you define and assign a string to. The linker uses an environment variable named C7X_C_DIR to name alternate directories that contain object libraries. The command syntaxes for assigning the environment variable are:

Operating System	Enter
UNIX (Bourne shell)	C7X_C_DIR = " <i>pathname₁</i> ; <i>pathname₂</i> ; . . . "; export C7X_C_DIR
Windows	set C7X_C_DIR = <i>pathname₁</i> ; <i>pathname₂</i> ; . . .

The *pathnames* are directories that contain input files. Use the --library linker option on the command line or in a command file to tell the linker which library or linker command file to search for. The pathnames must follow these constraints:

- Pathnames must be separated with a semicolon.
- Spaces or tabs at the beginning or end of a path are ignored. For example the space before and after the semicolon in the following is ignored:

```
set C7X_C_DIR= c:\path\one\to\tools ; c:\path\two\to\tools
```

- Spaces and tabs are allowed within paths to accommodate Windows directories that contain spaces. For example, the pathnames in the following are valid:

```
set C7X_C_DIR=c:\first path\to\tools;d:\second path\to\tools
```

In the example below, assume that two archive libraries called r.lib and lib2.lib reside in ld and ld2 directories. The table below shows how to set the environment variable, and how to use both libraries during a link. Select the row for your operating system:

Operating System	Invocation Command
UNIX (Bourne shell)	C7X_C_DIR="/ld ;/ld2"; export C7X_C_DIR; cl7x --run linker f1.c.obj f2.c.obj --library=r.lib --library=lib2.lib
Windows	C7X_C_DIR=ld;ld2 cl7x --run linker f1.c.obj f2.c.obj --library=r.lib --library=lib2.lib

The environment variable remains set until you reboot the system or reset the variable by entering:

Operating System	Enter
UNIX (Bourne shell)	unset C7X_C_DIR
Windows	set C7X_C_DIR=

The assembler uses an environment variable named C7X_A_DIR to name alternate directories that contain copy/include files. If C7X_C_DIR is not set, the linker searches for object libraries in the directories named with C7X_A_DIR. For more information about object libraries, see [Section 12.6.4](#).

12.4.15.3 Exhaustively Read and Search Libraries (--reread_libs and --priority Options)

There are two ways to exhaustively search for unresolved symbols:

- Reread libraries if you cannot resolve a symbol reference (--reread_libs).
- Search libraries in the order that they are specified (--priority).

The linker normally reads input files, including archive libraries, only once when they are encountered on the command line or in the command file. When an archive is read, any members that resolve references to undefined symbols are included in the link. If an input file later references a symbol defined in a previously read archive library, the reference is not resolved.

With the --reread_libs option, you can force the linker to reread all libraries. The linker rereads libraries until no more references can be resolved. Linking using --reread_libs may be slower, so you should use it only as needed. For example, if a.lib contains a reference to a symbol defined in b.lib, and b.lib contains a reference to a symbol defined in a.lib, you can resolve the mutual dependencies by listing one of the libraries twice, as in:

```
cl7x --run_linker --library=a.lib --library=b.lib --library=a.lib
```

or you can force the linker to do it for you:

```
cl7x --run_linker --reread_libs --library=a.lib --library=b.lib
```

The --priority option provides an alternate search mechanism for libraries. Using --priority causes each unresolved reference to be satisfied by the first library that contains a definition for that symbol. For example:

```
objfile  references A
lib1     defines B
lib2     defines A, B; obj defining A references B
```

Under the existing model, objfile resolves its reference to A in lib2, pulling in a reference to B, which resolves to the B in lib2.

Under --priority, objfile resolves its reference to A in lib2, pulling in a reference to B, but now B is resolved by searching the libraries in order and resolves B to the first definition it finds, namely the one in lib1.

The --priority option is useful for libraries that provide overriding definitions for related sets of functions in other libraries without having to provide a complete version of the whole library.

For example, suppose you want to override versions of malloc and free defined in the rts7100_le.lib without providing a full replacement for rts7100_le.lib. Using --priority and linking your new library before rts7100_le.lib guarantees that all references to malloc and free resolve to the new library.

The --priority option is intended to support linking programs with SYS/BIOS where situations like the one illustrated above occur.

12.4.16 Change Symbol Localization

Symbol localization changes symbol linkage from global to local (static). This is used to obscure global symbols that should not be widely visible, but must be global because they are accessed by several modules in the library. The linker supports symbol localization through the --localize and --globalize linker options.

The syntax for these options are:

--localize='pattern'

--globalize='pattern'

The *pattern* is a "glob" (a string with optional ? or * wildcards). Use ? to match a single character. Use * to match zero or more characters.

The --localize option changes the symbol linkage to local for symbols matching the *pattern*.

The --globalize option changes the symbol linkage to global for symbols matching the *pattern*. The --globalize option only affects symbols that are localized by the --localize option. The --globalize option excludes symbols that match the pattern from symbol localization, provided the pattern defined by --globalize is more restrictive than the pattern defined by --localize.

See [Section 12.4.2](#) for information about using C/C++ identifiers in linker options such as `--localize` and `--globalize`.

These options have the following properties:

- The `--localize` and `--globalize` options can be specified more than once on the command line.
- The order of `--localize` and `--globalize` options has no significance.
- A symbol is matched by only one pattern defined by either `--localize` or `--globalize`.
- A symbol is matched by the most restrictive pattern. Pattern A is considered more restrictive than Pattern B, if Pattern A matches a narrower set than Pattern B.
- It is an error if a symbol matches patterns from `--localize` and `--globalize` and if one does not supersede other. Pattern A supersedes pattern B if A can match everything B can, and some more. If Pattern A supersedes Pattern B, then Pattern B is said to be more restrictive than Pattern A.
- These options affect final and partial linking.

In map files these symbols are listed under the Localized Symbols heading.

12.4.16.1 Make All Global Symbols Static (`--make_static` Option)

The `--make_static` option makes all global symbols static. Static symbols are not visible to externally linked modules. By making global symbols static, global symbols are essentially hidden. This allows external symbols with the same name (in different files) to be treated as unique.

The `--make_static` option effectively nullifies all `.global` assembler directives. All symbols become local to the module in which they are defined, so no external references are possible. For example, assume `file1.c.obj` and `file2.c.obj` both define global symbols called `EXT`. By using the `--make_static` option, you can link these files without conflict. The symbol `EXT` defined in `file1.c.obj` is treated separately from the symbol `EXT` defined in `file2.c.obj`.

```
cl7x --run_linker --make_static file1.c.obj file2.c.obj
```

The `--make_static` option makes all global symbols static. If you have a symbol that you want to remain global and you use the `--make_static` option, you can use the `--make_global` option to declare that symbol to be global. The `--make_global` option overrides the effect of the `--make_static` option for the symbol that you specify. The syntax for the `--make_global` option is:

`--make_global=` *global_symbol*

12.4.17 Create a Map File (--map_file Option)

The syntax for the --map_file option is:

--map_file= filename

The linker map describes:

- Memory configuration
- Input and output section allocation
- Linker-generated copy tables
- Trampolines
- The addresses of external symbols after they have been relocated
- Hidden and localized symbols

The map file contains the name of the output module and the entry point; it can also contain up to three tables:

- A table showing the new memory configuration if any nondefault memory is specified (memory configuration). The table has the following columns; this information is generated on the basis of the information in the MEMORY directive in the linker command file:
 - **Name.** This is the name of the memory range specified with the MEMORY directive.
 - **Origin.** This specifies the starting address of a memory range.
 - **Length.** This specifies the length of a memory range.
 - **Unused.** This specifies the total amount of unused (available) memory in that memory area.
 - **Attributes.** This specifies one to four attributes associated with the named range:
 - R specifies that the memory can be read.
 - W specifies that the memory can be written to.
 - X specifies that the memory can contain executable code.
 - I specifies that the memory can be initialized.

For more information about the MEMORY directive, see [Section 12.5.4](#).

- A table showing the linked addresses of each output section and the input sections that make up the output sections (section placement map). This table has the following columns; this information is generated on the basis of the information in the SECTIONS directive in the linker command file:
 - **Output section.** This is the name of the output section specified with the SECTIONS directive.
 - **Origin.** The first origin listed for each output section is the starting address of that output section. The indented origin value is the starting address of that portion of the output section.
 - **Length.** The first length listed for each output section is the length of that output section. The indented length value is the length of that portion of the output section.
 - **Attributes/input sections.** This lists the input file or value associated with an output section. If the input section could not be allocated, the map file will indicate this with "FAILED TO ALLOCATE".

For more information about the SECTIONS directive, see [Section 12.5.5](#).

- A table showing each external symbol and its address sorted by symbol name.
- A table showing each external symbol and its address sorted by symbol address.

The following example links file1.c.obj and file2.c.obj and creates a map file called map.out:

```
cl7x --run_linker file1.c.obj file2.c.obj --map_file=map.out
```

[Example 12-23](#) shows an example of a map file.

12.4.18 Managing Map File Contents (--mapfile_contents Option)

The --mapfile_contents option assists with managing the content of linker-generated map files. The syntax for the --mapfile_contents option is:

--mapfile_contents= *filter[, filter]*

When the --map_file option is specified, the linker produces a map file containing information about memory usage, placement information about sections that were created during a link, details about linker-generated copy tables, and symbol values.

The --mapfile_contents option provides a mechanism for you to control what information is included in or excluded from a map file. When you specify --mapfile_contents=help from the command line, a help screen listing available filter options is displayed. The following filter options are available:

Attribute	Description	Default State
copytables	Copy tables	On
entry	Entry point	On
load_addr	Display load addresses	Off
memory	Memory ranges	On
modules	Module view	On
sections	Sections	On
sym_defs	Defined symbols per file	Off
sym_dp	Symbols sorted by data page	On
sym_name	Symbols sorted by name	On
sym_runaddr	Symbols sorted by run address	On
all	Enables all attributes	
none	Disables all attributes	

The --mapfile_contents option controls display filter settings by specifying a comma-delimited list of display attributes. When prefixed with the word no, an attribute is disabled instead of enabled. For example:

```
--mapfile_contents=copytables,noentry
--mapfile_contents=all,nocopytables
--mapfile_contents=none,entry
```

By default, those sections that are currently included in the map file when the --map_file option is specified are included. The filters specified in the --mapfile_contents options are processed in the order that they appear in the command line. In the third example above, the first filter, none, clears all map file content. The second filter, entry, then enables information about entry points to be included in the generated map file. That is, when --mapfile_contents=none,entry is specified, the map file contains *only* information about entry points.

The load_addr and sym_defs attributes are both disabled by default.

If you turn on the load_addr filter, the map file includes the load address of symbols that are included in the symbol list in addition to the run address (if the load address is different from the run address).

You can use the sym_defs filter to include information sorted on a file by file basis. You may find it useful to replace the sym_name, sym_dp, and sym_runaddr sections of the map file with the sym_defs section by specifying the following --mapfile_contents option:

```
--mapfile_contents=nosym_name,nosym_dp,nosym_runaddr,sym_defs
```

By default, information about global symbols defined in an application are included in tables sorted by name, data page, and run address. If you use the --mapfile_contents=sym_defs option, static variables are also listed.

12.4.19 Disable Name Demangling (--no_demangle)

By default, the linker uses demangled symbol names in diagnostics. For example:

undefined symbol	first referenced in file
ANewClass::getValue()	test.cpp.obj

The --no_demangle option instead shows the linkname for symbols in diagnostics. For example:

undefined symbol	first referenced in file
_ZN9ANewClass8getValueEv	test.cpp.obj

For information on referencing symbol names, see [Section 5.12](#). For information specifically about C++ symbol naming, see [Chapter 14](#).

12.4.20 Merging of Symbolic Debugging Information

By default, the linker eliminates duplicate entries of symbolic debugging information. Such duplicate information is commonly generated when a C program is compiled for debugging. For example:

```
-[ header.h ]-
typedef struct
{
    <define some structure members>
} XYZ;

-[ f1.c ]-
#include "header.h"
...

-[ f2.c ]-
#include "header.h"
...
```

When these files are compiled for debugging, both f1.c.obj and f2.c.obj have symbolic debugging entries to describe type XYZ. For the final output file, only one set of these entries is necessary. The linker eliminates the duplicate entries automatically.

Use the --no_sym_merge option if you want the linker to keep such duplicate entries in object files. Using the --no_sym_merge option has the effect of the linker running faster and using less host memory during linking, but the resulting executable file may be very large due to duplicated debug information.

12.4.21 Strip Symbolic Information (--no_symtable Option)

The --no_symtable option creates a smaller output module by omitting symbol table information and line number entries. The --no_sym_table option is useful for production applications when you do not want to disclose symbolic information to the consumer.

This example links file1.c.obj and file2.c.obj and creates an output module, stripped of line numbers and symbol table information, named nosym.out:

```
cl7x --run_linker --output_file=nosym.out --no_symtable file1.c.obj file2.c.obj
```

Using the --no_symtable option limits later use of a symbolic debugger.

Stripping Symbolic Information

NOTE: The --no_symtable option is deprecated. To remove symbol table information, use the strip7x utility as described in [Section 13.4](#).

12.4.22 Name an Output Module (`--output_file` Option)

The linker creates an output module when no errors are encountered. If you do not specify a filename for the output module, the linker gives it the default name `a.out`. If you want to write the output module to a different file, use the `--output_file` option. The syntax for the `--output_file` option is:

`--output_file= filename`

The *filename* is the new output module name.

This example links `file1.c.obj` and `file2.c.obj` and creates an output module named `run.out`:

```
cl7x --run_linker --output_file=run.out file1.c.obj file2.c.obj
```

12.4.23 Prioritizing Function Placement (`--preferred_order` Option)

The compiler prioritizes the placement of a function relative to others based on the order in which `--preferred_order` options are encountered during the linker invocation. The syntax is:

`--preferred_order=function specification`

12.4.24 C Language Options (`--ram_model` and `--rom_model` Options)

The `--ram_model` and `--rom_model` options cause the linker to use linking conventions that are required by the C compiler. Both options inform the linker that the program is a C program and requires a boot routine.

- The `--ram_model` option tells the linker to initialize variables at load time.
- The `--rom_model` option tells the linker to autoinitalize variables at run time.

For more information, see [Section 12.10](#), [Section 9.3.2.1](#), and [Section 9.3.2.2](#).

12.4.25 Retain Discarded Sections (`--retain` Option)

When `--unused_section_elimination` is on, the ELF linker does not include a section in the final link if it is not needed in the executable to resolve references. The `--retain` option tells the linker to retain a list of sections that would otherwise not be retained. This option accepts the wildcards `'*'` and `'?'`. When wildcards are used, the argument should be in quotes. The syntax for this option is:

`--retain=sym_or_scn_spec`

The `--retain` option take one of the following forms:

- **`--retain= symbol_spec`**
Specifying the symbol format retains sections that define *symbol_spec*. For example, this code retains sections that define symbols that start with `init`:

```
--retain='init*'
```


You cannot specify `--retain='*'`.
- **`--retain= file_spec[scn_spec[, scn_spec, ...]`**
Specifying the file format retains sections that match one or more *scn_spec* from files matching the *file_spec*. For example, this code retains `.intvec` sections from all input files:

```
--retain='*(.int*)'
```


You can specify `--retain='*(**)'` to retain all sections from all input files. However, this does not prevent sections from library members from being optimized out.
- **`--retain= ar_spec<mem_spec, [mem_spec, ...]>(scn_spec[, scn_spec, ...])`**
Specifying the archive format retains sections matching one or more *scn_spec* from members matching one or more *mem_spec* from archive files matching *ar_spec*. For example, this code retains the `.text` sections from `printf.c.obj` in the `rts7100_le.lib` library:

```
--retain=rts7100_le.lib<printf.c.obj>(.text)
```


If the library is specified with the `--library` option (`--library=rts7100_le.lib`) the library search path is used to search for the library. You cannot specify `'*<*>(*)'`.

12.4.26 Scan All Libraries for Duplicate Symbol Definitions (`--scan_libraries`)

The `--scan_libraries` option scans all libraries during a link looking for duplicate symbol definitions to those symbols that are actually included in the link. The scan does not consider absolute symbols or symbols defined in COMDAT sections. The `--scan_libraries` option helps determine those symbols that were actually chosen by the linker over other existing definitions of the same symbol in a library.

The library scanning feature can be used to check against unintended resolution of a symbol reference to a definition when multiple definitions are available in the libraries.

12.4.27 Define Stack Size (`--stack_size` Option)

The C7000 C/C++ compiler uses an uninitialized section, `.stack`, to allocate space for the run-time stack. You can set the size of this section in bytes at link time with the `--stack_size` option. The syntax for the `--stack_size` option is:

`--stack_size= size`

The *size* must be a constant and is in bytes. This example defines a 4K bytes stack:

```
cl7x --run_linker --stack_size=0x1000 /* defines a 4K heap (.stack section)*/
```

If you specified a different stack size in an input section, the input section stack size is ignored. Any symbols defined in the input section remain valid; only the stack size is different.

When the linker defines the `.stack` section, it also defines a global symbol, `_stack`, and assigns it a value equal to the size of the section. The default software stack size is 1K bytes. See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.4.28 Enforce Strict Compatibility (`--strict_compatibility` Option)

The linker performs more conservative and rigorous compatibility checking of input object files when you specify the `--strict_compatibility` option. Using this option guards against additional potential compatibility issues, but may signal false compatibility errors when linking in object files built with an older toolset, or with object files built with another compiler vendor's toolset. To avoid issues with legacy libraries, the `--strict_compatibility` option is turned off by default.

12.4.29 Mapping of Symbols (`--symbol_map` Option)

Symbol mapping allows a symbol reference to be resolved by a symbol with a different name. Symbol mapping allows functions to be overridden with alternate definitions. This feature can be used to patch in alternate implementations, which provide patches (bug fixes) or alternate functionality. The syntax for the `--symbol_map` option is:

`--symbol_map= refname=defname`

For example, the following code makes the linker resolve any references to `foo` by the definition `foo_patch`:

```
--symbol_map= 'foo=foo_patch'
```

12.4.30 Generate Far Call Trampolines (`--trampolines` Option)

The C7000 device has PC-relative call and PC-relative branch instructions whose range is smaller than the entire address space. When these instructions are used, the destination address must be near enough to the instruction that the difference between the call and the destination fits in the available encoding bits. If the called function is too far away from the calling function, the linker generates an error or generates a trampoline, depending on the setting of the `--trampolines` option (on or off).

The alternative to a PC-relative call is an absolute call, which is often implemented as an indirect call: load the called address into a register, and call that register. This is often undesirable because it takes more instructions (speed- and size-wise) and requires an extra register to contain the address.

By default, the compiler generates calls that may require a trampoline if the destination is too far away. On some architectures, this type of call is called a "near call."

The `--trampolines` option allows you to control the generation of trampolines. When set to "on", this option causes the linker to generate a trampoline code section for each call that is linked out-of-range of its called destination. The trampoline code section contains a sequence of instructions that performs a transparent long branch to the original called address. Each calling instruction that is out-of-range from the called function is redirected to the trampoline.

The syntax for this option is:

`--trampolines[=on|off]`

The default setting is on. For C7000, trampolines are turned on by default.

For example, in a section of C code the bar function calls the foo function. The compiler generates this code for the function:

```
bar:
    ...
    CALL .B1    foo      ; call the function "foo"
    ...
```

If the foo function is placed out-of-range from the call to foo that is inside of bar, then with `--trampolines` the linker changes the original call to foo into a call to foo_trampoline as shown:

```
bar:
    ...
    CALL .B1 $Tramp$L$PI$$myfunc ; call a trampoline for foo
    ...
```

The above code generates a trampoline code section called foo_trampoline, which contains code that executes a long branch to the original called function, foo. For example:

```
$Tramp$L$PI$$myfunc:
    BE .B1 foo ; long branch to foo (with constant extension)
```

Trampolines can be shared among calls to the same called function. The only requirement is that all calls to the called function be linked near the called function's trampoline.

When the linker produces a map file (the `--map_file` option) and it has produced one or more trampolines, then the map file will contain statistics about what trampolines were generated to reach which functions. A list of calls for each trampoline is also provided in the map file.

The Linker Assumes D15 Contains the Stack Pointer

NOTE: Assembly language programmers must be aware that the linker assumes D15 contains the stack pointer. The linker must save and restore values on the stack in trampoline code that it generates. If you do not use D15 as the stack pointer, you should use the linker option that disables trampolines, `--trampolines=off`. Otherwise, trampolines could corrupt memory and overwrite register values.

12.4.30.1 Advantages and Disadvantages of Using Trampolines

The advantage of using trampolines is that you can treat all calls as near calls, which are faster and more efficient. You will only need to modify those calls that don't reach. In addition, there is little need to consider the relative placement of functions that call each other. Cases where calls must go through a trampoline are less common than near calls.

While generating far call trampolines provides a more straightforward solution, trampolines have the disadvantage that they are somewhat slower than directly calling a function. They require both a call and a branch. Additionally, while inline code could be tailored to the environment of the call, trampolines are generated in a more general manner, and may be slightly less efficient than inline code.

An alternative method to creating a trampoline code section for a call that cannot reach its called function is to actually modify the source code for the call. In some cases this can be done without affecting the size of the code. However, in general, this approach is extremely difficult, especially when the size of the code is affected by the transformation.

12.4.30.2 Minimizing the Number of Trampolines Required (--minimize_trampolines Option)

The `--minimize_trampolines` option attempts to place sections so as to minimize the number of far call trampolines required, possibly at the expense of optimal memory packing. The syntax is:

--minimize_trampolines=postorder

The argument selects a heuristic to use. The postorder heuristic attempts to place functions before their callers, so that the PC-relative offset to the callee is known when the caller is placed. By placing the callee first, its address is known when the caller is placed so the linker can definitively know if a trampoline is required.

12.4.30.3 Carrying Trampolines From Load Space to Run Space

It is sometimes useful to load code in one location in memory and run it in another. The linker provides the capability to specify separate load and run allocations for a section. The burden of actually copying the code from the load space to the run space is left to you.

A copy function must be executed before the real function can be executed in its run space. To facilitate this copy function, the assembler provides the `.label` directive, which allows you to define a load-time address. These load-time addresses can then be used to determine the start address and size of the code to be copied. However, this mechanism will *not* work if the code contains a call that requires a trampoline to reach its called function. This is because the trampoline code is generated at link time, after the load-time addresses associated with the `.label` directive have been defined. If the linker detects the definition of a `.label` symbol in an input section that contains a trampoline call, then a warning is generated.

To solve this problem, you can use the `START()`, `END()`, and `SIZE()` operators (see [Section 12.5.9.7](#)). These operators allow you to define symbols to represent the load-time start address and size inside the linker command file. These symbols can be referenced by the copy code, and their values are not resolved until link time, after the trampoline sections have been allocated.

Here is an example of how you could use the `START()` and `SIZE()` operators in association with an output section to copy the trampoline code section along with the code containing the calls that need trampolines:

```
SECTIONS
{
    .foo : load = ROM, run = RAM, start(foo_start), size(foo_size)
        { x.obj(.text) }

    .text: {} > ROM

    .far : { --library=rts.lib(.text) } > FAR_MEM
}
```

A function in `x.c.obj` contains an run-time-support call. The run-time-support library is placed in far memory and so the call is out-of-range. A trampoline section will be added to the `.foo` output section by the linker. The copy code can refer to the symbols `foo_start` and `foo_size` as parameters for the load start address and size of the entire `.foo` output section. This allows the copy code to copy the trampoline section along with the original `x.c.obj` code in `.text` from its load space to its run space.

See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.4.31 Introduce an Unresolved Symbol (--undef_sym Option)

The `--undef_sym` option introduces the linkname for an unresolved symbol into the linker's symbol table. This forces the linker to search a library and include the member that defines the symbol. The linker must encounter the `--undef_sym` option *before* it links in the member that defines the symbol. The syntax for the `--undef_sym` option is:

--undef_sym=symbol

For example, suppose a library named `rts7100_le.lib` contains a member that defines the symbol `symtab`; none of the object files being linked reference `symtab`. However, suppose you plan to relink the output module and you want to include the library member that defines `symtab` in this link. Using the `--undef_sym` option as shown below forces the linker to search `rts7100_le.lib` for the member that defines `symtab` and to link in the member.

```
cl7x --run_linker --undef_sym=symtab file1.c.obj file2.c.obj rts7100_le.lib
```

If you do not use `--undef_sym`, this member is not included, because there is no explicit reference to it in `file1.c.obj` or `file2.c.obj`.

12.4.32 Display a Message When an Undefined Output Section Is Created (`--warn_sections`)

In a linker command file, you can set up a `SECTIONS` directive that describes how input sections are combined into output sections. However, if the linker encounters one or more input sections that do not have a corresponding output section defined in the `SECTIONS` directive, the linker combines the input sections that have the same name into an output section with that name. By default, the linker does not display a message to tell you that this occurred.

You can use the `--warn_sections` option to cause the linker to display a message when it creates a new output section.

For more information about the `SECTIONS` directive, see [Section 12.5.5](#). For more information about the default actions of the linker, see [Section 12.7](#).

12.4.33 Generate XML Link Information File (`--xml_link_info` Option)

The linker supports the generation of an XML link information file through the `--xml_link_info=file` option. This option causes the linker to generate a well-formed XML file containing detailed information about the result of a link. The information included in this file includes all of the information that is currently produced in a linker generated map file. See [Appendix A](#) for specifics on the contents of the generated XML file.

12.4.34 Zero Initialization (`--zero_init` Option)

The C and C++ standards require that global and static variables that are not explicitly initialized must be set to 0 before program execution. The C/C++ compiler supports preinitialization of uninitialized variables by default. To turn this off, specify the linker option `--zero_init=off`.

The syntax for the `--zero_init` option is:

`--zero_init[={on|off}]`

Disabling Zero Initialization Not Recommended

NOTE: In general, this option it is not recommended. If you turn off zero initialization, automatic initialization of uninitialized global and static objects to zero will not occur. You are then expected to initialize these variables to zero in some other manner.

12.5 Linker Command Files

Linker command files allow you to put linker options and directives in a file; this is useful when you invoke the linker often with the same options and directives. Linker command files are also useful because they allow you to use the MEMORY and SECTIONS directives to customize your application. You must use these directives in a command file; you cannot use them on the command line.

Linker command files are ASCII files that contain one or more of the following:

- Input filenames, which specify object files, archive libraries, or other command files. (If a command file calls another command file as input, this statement must be the *last* statement in the calling command file. The linker does not return from called command files.)
- Linker options, which can be used in the command file in the same manner that they are used on the command line
- The MEMORY and SECTIONS linker directives. The MEMORY directive defines the target memory configuration (see [Section 12.5.4](#)). The SECTIONS directive controls how sections are built and allocated (see [Section 12.5.5](#).)
- Assignment statements, which define and assign values to global symbols

To invoke the linker with a command file, enter the `cl7x --run_linker` command and follow it with the name of the command file:

```
cl7x --run_linker command_filename
```

The linker processes input files in the order that it encounters them. If the linker recognizes a file as an object file, it links the file. Otherwise, it assumes that a file is a command file and begins reading and processing commands from it. Command filenames are case sensitive, regardless of the system used.

[Example 12-1](#) shows a sample linker command file called `link.cmd`.

Example 12-1. Linker Command File

```
a.c.obj          /* First input filename      */
b.c.obj          /* Second input filename     */
--output_file=prog.out /* Option to specify output file */
--map_file=prog.map  /* Option to specify map file   */
```

The sample file in [Example 12-1](#) contains only filenames and options. (You can place comments in a command file by delimiting them with `/*` and `*/`.) To invoke the linker with this command file, enter:

```
cl7x --run_linker link.cmd
```

You can place other parameters on the command line when you use a command file:

```
cl7x --run_linker --relocatable link.cmd x.c.obj y.c.obj
```

The linker processes the command file as soon as it encounters the filename, so `a.c.obj` and `b.c.obj` are linked into the output module before `x.c.obj` and `y.c.obj`.

You can specify multiple command files. If, for example, you have a file called `names.lst` that contains filenames and another file called `dir.cmd` that contains linker directives, you could enter:

```
cl7x --run_linker names.lst dir.cmd
```

One command file can call another command file; this type of nesting is limited to 16 levels. If a command file calls another command file as input, this statement must be the *last* statement in the calling command file.

Blanks and blank lines are insignificant in a command file except as delimiters. This also applies to the format of linker directives in a command file. [Example 12-2](#) shows a sample command file that contains linker directives.

Example 12-2. Command File With Linker Directives

```
a.obj b.obj c.obj          /* Input filenames      */
--output_file=prog.out     /* Options          */
--map_file=prog.map

MEMORY                     /* MEMORY directive */
{
    FAST_MEM:  origin = 0x0100    length = 0x0100
    SLOW_MEM:  origin = 0x7000    length = 0x1000
}

SECTIONS                   /* SECTIONS directive */
{
    .text:    > SLOW_MEM
    .data:    > SLOW_MEM
    .bss:     > FAST_MEM
}
```

For more information, see [Section 12.5.4](#) for the MEMORY directive, and [Section 12.5.5](#) for the SECTIONS directive.

12.5.1 Reserved Names in Linker Command Files

The following names (in both uppercase and lowercase) are reserved as keywords for linker directives. Do not use them as symbol or section names in a command file.

In addition, any section names used by the TI tools are reserved from being used as the prefix for other names, unless the section will be a subsection of the section name used by the TI tools. For example, section names may not begin with .debug.

12.5.2 Constants in Linker Command Files

You can specify constants with either of two syntax schemes: the scheme used for specifying decimal, octal, or hexadecimal constants (but not binary constants) used in the assembler or the scheme used for integer constants in C syntax.

Examples:

Format	Decimal	Octal	Hexadecimal
Assembler format	32	40q	020h
C format	32	040	0x20

12.5.3 Accessing Files and Libraries from a Linker Command File

Many applications use custom linker command files (or LCFs) to control the placement of code and data in target memory. For example, you may want to place a specific data object from a specific file into a specific location in target memory. This is simple to do using the available LCF syntax to reference the desired object file or library. However, a problem that many developers run into when they try to do this is a linker generated "file not found" error when accessing an object file or library from inside the LCF that has been specified earlier in the command-line invocation of the linker. Most often, this error occurs because the syntax used to access the file on the linker command-line does not match the syntax that is used to access the same file in the LCF.

Consider a simple example. Imagine that you have an application that requires a table of constants called "app_coeffs" to be defined in a memory area called "DDR". Assume also that the "app_coeffs" data object is defined in a .data section that resides in an object file, app_coeffs.c.obj. The app_coeffs.c.obj file is then included in the object file library app_data.lib. In your LCF, you can control the placement of the "app_coeffs" data object as follows:

```
SECTIONS
{
    ...
    .coeffs: { app_data.lib<app_coeffs.c.obj>(.data) } > DDR
    ...
}
```

Now assume that the app_data.lib object library resides in a sub-directory called "lib" relative to where you are building the application. In order to gain access to app_data.lib from the build command-line, you can use a combination of the -i and -l options to set up a directory search path which the linker can use to find the app_data.lib library:

```
%> cl7x <compile options/files> -z -i ./lib -l app_data.lib mylnk.cmd <link options/files>
```

The -i option adds the lib sub-directory to the directory search path and the -l option instructs the linker to look through the directories in the directory search path to find the app_data.lib library. However, if you do not update the reference to app_data.lib in mylnk.cmd, the linker will fail to find the app_data.lib library and generate a "file not found" error. The reason is that when the linker encounters the reference to app_data.lib inside the SECTIONS directive, there is no -l option preceding the reference. Therefore, the linker tries to open app_data.lib in the current working directory.

In essence, the linker has a few different ways of opening files:

- If there is a path specified, the linker will look for the file in the specified location. For an absolute path, the linker will try to open the file in the specified directory. For a relative path, the linker will follow the specified path starting from the current working directory and try to open the file at that location.
- If there is no path specified, the linker will try to open the file in the current working directory.
- If a -l option precedes the file reference, then the linker will try to find and open the referenced file in one of the directories in the directory search path. The directory search path is set up via -i options and environment variables (like C_DIR and C7X_C_DIR).

As long as a file is referenced in a consistent manner on the command line and throughout any applicable LCFs, the linker will be able to find and open your object files and libraries.

Returning to the earlier example, you can insert a -l option in front of the reference to app_data.lib in mylnk.cmd to ensure that the linker will find and open the app_data.lib library when the application is built:

```
SECTIONS
{
    ...
    .coeffs: { -l app_data.lib<app_coeffs.c.obj>(.data) } > DDR
    ...
}
```

Another benefit to using the -l option when referencing a file from within an LCF is that if the location of the referenced file changes, you can modify the directory search path to incorporate the new location of the file (using -i option on the command line, for example) without having to modify the LCF.

12.5.4 The MEMORY Directive

The linker determines where output sections are allocated into memory; it must have a model of target memory to accomplish this. The MEMORY directive allows you to specify a model of target memory so that you can define the types of memory your system contains and the address ranges they occupy. The linker maintains the model as it allocates output sections and uses it to determine which memory locations can be used for object code.

The memory configurations of C7000 systems differ from application to application. The MEMORY directive allows you to specify a variety of configurations. After you use MEMORY to define a memory model, you can use the SECTIONS directive to allocate output sections into defined memory.

For more information, see [Section 8.4](#).

12.5.4.1 Default Memory Model

If you do not use the MEMORY directive, the linker uses a default memory model that may be suitable for running executables on a generic simulator. Please consult your device documentation to determine what memory ranges are available. This model assumes that the full 48-bit address space (2^{48} locations) is present in the system and available for use. For more information about the default memory model, see [Section 12.7](#).

12.5.4.2 MEMORY Directive Syntax

The MEMORY directive identifies ranges of memory that are physically present in the target system and can be used by a program. Each range has several characteristics:

- Name
- Starting address
- Length
- Optional set of attributes
- Optional fill specification

When you use the MEMORY directive, be sure to identify all memory ranges that are available for the program to access at run time. Memory defined by the MEMORY directive is configured; any memory that you do not explicitly account for with MEMORY is unconfigured. The linker does not place any part of a program into unconfigured memory. You can represent nonexistent memory spaces by simply not including an address range in a MEMORY directive statement.

The MEMORY directive is specified in a command file by the word MEMORY (uppercase), followed by a list of memory range specifications enclosed in braces. The MEMORY directive in [Example 12-3](#) defines a system that has 4K bytes of fast external memory at address 0x0000 0000, 2K bytes of slow external memory at address 0x0000 1000 and 4K bytes of slow external memory at address 0x1000 0000. It also demonstrates the use of memory range expressions as well as start/end/size address operators (see [Section 12.5.4.3](#)).

Example 12-3. The MEMORY Directive

```

/*****
/*      Sample command file with MEMORY directive      */
/*****
file1.c.obj file2.c.obj          /*      Input files      */
--output_file=prog.out          /*      Options        */
#define BUFFER 0

MEMORY
{
    FAST_MEM (RX): origin = 0x00000000      length = 0x00001000 + BUFFER
    SLOW_MEM (RW): origin = end(FAST_MEM) length = 0x00001800 - size(FAST_MEM)
    EXT_MEM  (RX): origin = 0x10000000      length = size(FAST_MEM)

```


The general syntax for the MEMORY directive is:

MEMORY

```
{
    name 1 [( attr )] : origin = expression , length = expression [, fill = constant]
    .
    .
    name n [( attr )] : origin = expression , length = expression [, fill = constant]
}
```

name	names a memory range. A memory name can be one to 64 characters; valid characters include A-Z, a-z, \$, ., and _. The names have no special significance to the linker; they simply identify memory ranges. Memory range names are internal to the linker and are not retained in the output file or in the symbol table. All memory ranges must have unique names and must not overlap.
attr	specifies one to four attributes associated with the named range. Attributes are optional; when used, they must be enclosed in parentheses. Attributes restrict the allocation of output sections into certain memory ranges. If you do not use any attributes, you can allocate any output section into any range with no restrictions. Any memory for which no attributes are specified (including all memory in the default model) has all four attributes. Valid attributes are: <ul style="list-style-type: none"> R specifies that the memory can be read. W specifies that the memory can be written to. X specifies that the memory can contain executable code. I specifies that the memory can be initialized.
origin	specifies the starting address of a memory range; enter as <i>origin</i> , <i>org</i> , or <i>o</i> . The value, specified in bytes, is a 64-bit integer constant expression, which can be decimal, octal, or hexadecimal.
length	specifies the length of a memory range; enter as <i>length</i> , <i>len</i> , or <i>l</i> . The value, specified in bytes, is a 64-bit integer constant expression, which can be decimal, octal, or hexadecimal.
fill	specifies a fill character for the memory range; enter as <i>fill</i> or <i>f</i> . Fills are optional. The value is an integer constant and can be decimal, octal, or hexadecimal. The fill value is used to fill areas of the memory range that are not allocated to a section.

Filling Memory Ranges

NOTE: If you specify fill values for large memory ranges, your output file will be very large because filling a memory range (even with 0s) causes raw data to be generated for all unallocated blocks of memory in the range.

The following example specifies a memory range with the R and W attributes and a fill constant of 0xFFFFFFFFh:

```
MEMORY
{
    RFILE (RW) : o = 0x00000020, l = 0x00001000, f = 0xFFFFFFFF
}
```

You normally use the MEMORY directive in conjunction with the SECTIONS directive to control placement of output sections. For more information about the SECTIONS directive, see [Section 12.5.5](#).

12.5.4.3 Expressions and Address Operators

Memory range origin and length can use expressions of integer constants with the following operators:

Binary operators: * / % + - << >> == = < <= > >= & | && ||

Unary operators: - ~ !

Expressions are evaluated using standard C operator precedence rules.

No checking is done for overflow or underflow, however, expressions are evaluated using a larger integer type.

Preprocess directive #define constants can be used in place of integer constants. Global symbols cannot be used in Memory Directive expressions.

Three address operators reference memory range properties from prior memory range entries:

START(MR)	Returns start address for previously defined memory range MR.
SIZE(MR)	Returns size of previously defined memory range MR.
END(MR)	Returns end address for previously defined memory range MR.

Example 12-4. Origin and Length as Expressions

```

/*****
/*      Sample command file with MEMORY directive      */
/*****
file1.c.obj file2.c.obj          /*      Input files      */
--output_file=prog.out          /*      Options      */
#define ORIGIN 0x00000000
#define BUFFER 0x00000200
#define CACHE  0x0001000

MEMORY
{
    FAST_MEM (RX): origin = ORIGIN + CACHE length = 0x00001000 + BUFFER
    SLOW_MEM (RW): origin = end(FAST_MEM) length = 0x00001800 - size(FAST_MEM)
    EXT_MEM  (RX): origin = 0x10000000    length = size(FAST_MEM) - CACHE

```

12.5.5 The SECTIONS Directive

After you use MEMORY to specify the target system's memory model, you can use SECTIONS to place output sections into specific named memory ranges or into memory that has specific attributes. For example, you could allocate the .text and .data sections into the area named FAST_MEM and allocate the .bss section into the area named SLOW_MEM.

The SECTIONS directive controls your sections in the following ways:

- Describes how input sections are combined into output sections
- Defines output sections in the executable program
- Allows you to control where output sections are placed in memory in relation to each other and to the entire memory space (Note that the memory placement order is *not* simply the sequence in which sections occur in the SECTIONS directive.)
- Permits renaming of output sections

For more information, see [Section 8.4](#). Subsections allow you to manipulate sections with greater precision.

If you do not specify a SECTIONS directive, the linker uses a default algorithm for combining and allocating the sections. [Section 12.7](#) describes this algorithm in detail.

The general syntax for the `SECTIONS` directive is:

SECTIONS

```
{
  name : [property [, property] [, property] . . . ]
  name : [property [, property] [, property] . . . ]
  name : [property [, property] [, property] . . . ]
}
```

Each section specification, beginning with *name*, defines an output section. (An output section is a section in the output file.) Section names can refer to sections, subsections, or archive library members. (See [Section 12.5.5.4](#) for information on multi-level subsections.) After the section name is a list of properties that define the section's contents and how the section is allocated. The properties can be separated by optional commas. Possible properties for a section are as follows:

- **Load allocation** defines where in memory the section is to be loaded. See [Section 9.5](#) and [Section 12.5.6](#).

Syntax: **load** = *allocation* on
 > *allocation*

- **Run allocation** defines where in memory the section is to be run.

Syntax: **run** = *allocation* on
 run > *allocation*

- **Input sections** defines the input sections (object files) that constitute the output section. See [Section 12.5.5.3](#).

Syntax: `{ input_sections }`

- **Section type** defines flags for special section types. See [Section 12.5.8](#).

Syntax: **type = COPY** on
 type = DSECT on

- **Fill value** defines the value used to fill uninitialized holes. See [Section 12.5.10](#).

Syntax: **fill** = *value*

Example 12-5 shows a SECTIONS directive in a sample linker command file.

Example 12-5. The SECTIONS Directive

```

/*****
/* Sample command file with SECTIONS directive */
/*****/
file1.c.obj    file2.c.obj    /* Input files */
--output_file=prog.out      /* Options */

SECTIONS
{
    .text:      load = EXT_MEM, run = 0x00000800
    .const:     load = FAST_MEM
    .bss:       load = SLOW_MEM
    .vectors:   load = 0x00000000
    {
        t1.c.obj(.intvec1)
    }
}

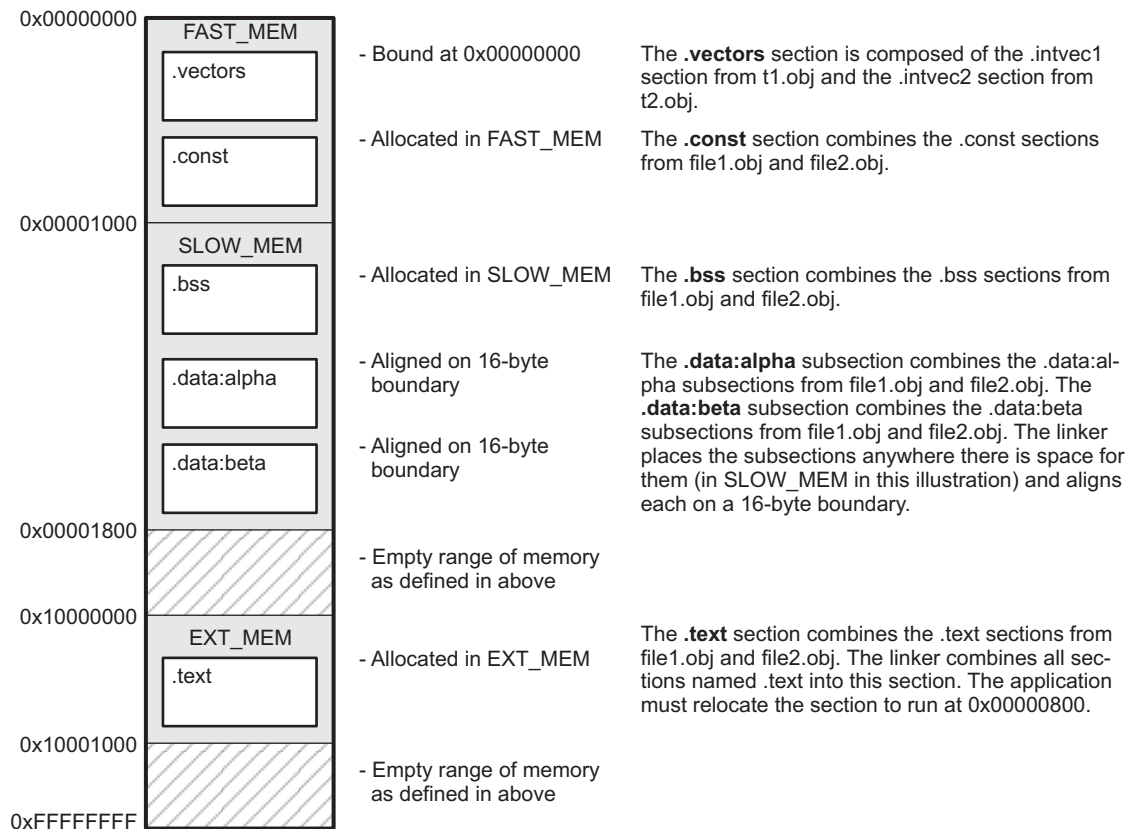
```

Example 12-5. The SECTIONS Directive (continued)

```
t2.c.obj(.intvec2)
endvec = .;
}
.data:alpha: align = 16
.data:beta:  align = 16
}
```

Figure 12-2 shows the output sections defined by the SECTIONS directive in Example 12-5 (.vectors, .text, .const, .bss, .data:alpha, and .data:beta) and shows how these sections are allocated in memory using the MEMORY directive given in Example 12-3.

Figure 12-2. Section Placement Defined by Example 12-5



12.5.5.2 Section Allocation and Placement

The linker assigns each output section two locations in target memory: the location where the section will be loaded and the location where it will be run. Usually, these are the same, and you can think of each section as having only a single address. The process of locating the output section in the target's memory and assigning its address(es) is called placement. For more information about using separate load and run placement, see Section 12.5.6.

If you do not tell the linker how a section is to be allocated, it uses a default algorithm to place the section. Generally, the linker puts sections wherever they fit into configured memory. You can override this default placement for a section by defining it within a SECTIONS directive and providing instructions on how to allocate it.

You control placement by specifying one or more allocation parameters. Each parameter consists of a keyword, an optional equal sign or greater-than sign, and a value optionally enclosed in parentheses. If load and run placement are separate, all parameters following the keyword LOAD apply to load placement, and those following the keyword RUN apply to run placement. The allocation parameters are:

Binding	allocates a section at a specific address. .text: load = 0x1000
Named memory	allocates the section into a range defined in the MEMORY directive with the specified name (like SLOW_MEM) or attributes. .text: load > SLOW_MEM
Alignment	uses the align or palign keyword to specify the section must start on an address boundary. .text: align = 0x100
Blocking	uses the block keyword to specify the section must fit between two address aligned to the blocking factor. If a section is too large, it starts on an address boundary. .text: block(0x100)

For the load (usually the only) allocation, use a greater-than sign and omit the load keyword:

```
.text: > SLOW_MEM
.text: {...} > SLOW_MEM
.text: > 0x4000
```

If more than one parameter is used, you can string them together as follows:

```
.text: > SLOW_MEM align 16
```

Or if you prefer, use parentheses for readability:

```
.text: load = (SLOW_MEM align(16))
```

You can also use an input section specification to identify the sections from input files that are combined to form an output section. See [Section 12.5.5.3](#).

Additional information about controlling the order in which code and data are placed in memory is provided in the [FAQ topic on section placement](#).

12.5.5.2.1 Binding

You can set the starting address for an output section by following the section name with an address:

```
.text: 0x00001000
```

This example specifies that the .text section must begin at location 0x1000. The binding address must be a 64-bit constant.

Output sections can be bound anywhere in configured memory (assuming there is enough space), but they cannot overlap. If there is not enough space to bind a section to a specified address, the linker issues an error message.

Binding is Incompatible With Alignment and Named Memory

NOTE: You cannot bind a section to an address if you use alignment or named memory. If you try to do this, the linker issues an error message.

12.5.5.2.2 Named Memory

You can allocate a section into a memory range that is defined by the MEMORY directive (see [Section 12.5.4](#)). This example names ranges and links sections into them:

```
MEMORY
{
    SLOW_MEM (RIX) : origin = 0x00000000, length = 0x00001000
    FAST_MEM (RWIX) : origin = 0x03000000, length = 0x00000300
}

SECTIONS
{
    .text : > SLOW_MEM
    .data : > FAST_MEM ALIGN(128)
    .bss : > FAST_MEM
}
```

In this example, the linker places .text into the area called SLOW_MEM. The .data and .bss output sections are allocated into FAST_MEM. You can align a section within a named memory range; the .data section is aligned on a 128-byte boundary within the FAST_MEM range.

Similarly, you can link a section into an area of memory that has particular attributes. To do this, specify a set of attributes (enclosed in parentheses) instead of a memory name. Using the same MEMORY directive declaration, you can specify:

```
SECTIONS
{
    .text: > (X)    /* .text --> executable memory      */
    .data: > (RI)   /* .data --> read or init memory    */
    .bss : > (RW)   /* .bss --> read or write memory   */
}
```

In this example, the .text output section can be linked into either the SLOW_MEM or FAST_MEM area because both areas have the X attribute. The .data section can also go into either SLOW_MEM or FAST_MEM because both areas have the R and I attributes. The .bss output section, however, must go into the FAST_MEM area because only FAST_MEM is declared with the W attribute.

You cannot control where in a named memory range a section is allocated, although the linker uses lower memory addresses first and avoids fragmentation when possible. In the preceding examples, assuming no conflicting assignments exist, the .text section starts at address 0. If a section must start on a specific address, use binding instead of named memory.

12.5.5.2.3 Controlling Placement Using The HIGH Location Specifier

The linker allocates output sections from low to high addresses within a designated memory range by default. Alternatively, you can cause the linker to allocate a section from high to low addresses within a memory range by using the HIGH location specifier in the SECTION directive declaration. You might use the HIGH location specifier in order to keep RTS code separate from application code, so that small changes in the application do not cause large changes to the memory map.

For example, given this MEMORY directive:

```
MEMORY
{
    RAM           : origin = 0x0200, length = 0x0800
    FLASH         : origin = 0x1100, length = 0xEE0
    VECTORS       : origin = 0xFFE0, length = 0x001E
    RESET         : origin = 0xFFFE, length = 0x0002
}
```

and an accompanying SECTIONS directive:

```
SECTIONS
{
    .bss          : {} > RAM
    .sysmem       : {} > RAM
    .stack        : {} > RAM (HIGH)
}
```

The HIGH specifier used on the .stack section placement causes the linker to attempt to allocate .stack into the higher addresses within the RAM memory range. The .bss and sections are allocated into the lower addresses within RAM. [Example 12-6](#) illustrates a portion of a map file that shows where the given sections are allocated within RAM for a typical program.

Example 12-6. Linker Placement With the HIGH Specifier

.bss	0	00000200	00000270	UNINITIALIZED
		00000200	0000011a	rtssxxx.lib : defs.c.obj (.bss)
		0000031a	00000088	: trgdrv.c.obj (.bss)
		000003a2	00000078	: lowlev.c.obj (.bss)
		0000041a	00000046	: exit.c.obj (.bss)
		00000460	00000008	: memory.c.obj (.bss)
		00000468	00000004	: _lock.c.obj (.bss)
		0000046c	00000002	: fopen.c.obj (.bss)

Example 12-6. Linker Placement With the HIGH Specifier (continued)

		0000046e	00000002	hello.c.obj (.bss)
.sysmem	0	00000470	00000120	UNINITIALIZED
		00000470	00000004	rtstxxx.lib : memory.c.obj (.sysmem)
.stack	0	000008c0	00000140	UNINITIALIZED
		000008c0	00000002	rtstxxx.lib : boot.c.obj (.stack)

As shown in [Example 12-6](#), the .bss and .sysmem sections are allocated at the lower addresses of RAM (0x0200 - 0x0590) and the .stack section is allocated at address 0x08c0, even though lower addresses are available.

Without using the HIGH specifier, the linker allocation would result in the code shown in [Example 12-7](#)

The HIGH specifier is ignored if it is used with specific address binding or automatic section splitting (>> operator).

Example 12-7. Linker Placement Without HIGH Specifier

.bss	0	00000200	00000270	UNINITIALIZED
		00000200	0000011a	rtstxxx.lib : defs.c.obj (.bss)
		0000031a	00000088	: trgdrv.c.obj (.bss)
		000003a2	00000078	: lowlev.c.obj (.bss)
		0000041a	00000046	: exit.c.obj (.bss)
		00000460	00000008	: memory.c.obj (.bss)
		00000468	00000004	: _lock.c.obj (.bss)
		0000046c	00000002	: fopen.c.obj (.bss)
		0000046e	00000002	hello.c.obj (.bss)
.stack	0	00000470	00000140	UNINITIALIZED
		00000470	00000002	rtstxxx.lib : boot.c.obj (.stack)
.sysmem	0	000005b0	00000120	UNINITIALIZED
		000005b0	00000004	rtstxxx.lib : memory.c.obj (.sysmem)

12.5.5.2.4 Alignment and Blocking

You can tell the linker to place an output section at an address that falls on an n-byte boundary, where n is a power of 2, by using the align keyword. For example, the following code allocates .text so that it falls on a 32-byte boundary:

```
.text: load = align(32)
```

Blocking is a weaker form of alignment that allocates a section anywhere *within* a block of size n. The specified block size must be a power of 2. For example, the following code allocates .bss so that the entire section is contained in a single 128-byte or begins on that boundary:

You can use alignment or blocking alone or in conjunction with a memory area, but alignment and blocking cannot be used together.

12.5.5.2.5 Alignment With Padding

As with align, you can tell the linker to place an output section at an address that falls on an n-byte boundary, where n is a power of 2, by using the palign keyword. In addition, palign ensures that the size of the section is a multiple of its placement alignment restrictions, padding the section size up to such a boundary, as needed.

For example, the following code lines allocate .text on a 2-byte boundary within the PMEM area. The .text section size is guaranteed to be a multiple of 2 bytes. Both statements are equivalent:

```
.text: palign(2) {} > PMEM
.text: palign = 2 {} > PMEM
```

If the linker adds padding to an initialized output section then the padding space is also initialized. By default, padding space is filled with a value of 0 (zero). However, if a fill value is specified for the output section then any padding for the section is also filled with that fill value. For example, consider the following section specification:

```
.mytext: palign(8), fill = 0xffffffff {} > PMEM
```

In this example, the length of the .mytext section is before the palign operator is applied. The contents of .mytext are as follows:

```
addr content
----
0000 0x1234
0002 0x1234
0004 0x1234
```

After the palign operator is applied, the length of .mytext is 8 bytes, and its contents are as follows:

```
addr content
----
0000 0x1234
0002 0x1234
0004 0x1234
0006 0xffff
```

The size of .mytext has been bumped to a multiple of 8 bytes and the padding created by the linker has been filled with 0xff.

The fill value specified in the linker command file is interpreted as a 16-bit constant. If you specify this code:

```
.mytext: palign(8), fill = 0xff {} > PMEM
```

The fill value assumed by the linker is 0x00ff, and .mytext will then have the following contents:

```
addr content
----
0000 0x1234
0002 0x1234
0004 0x1234
0006 0x00ff
```

If the palign operator is applied to an uninitialized section, then the size of the section is bumped to the appropriate boundary, as needed, but any padding created is not initialized.

The palign operator can also take a parameter of *power2*. This parameter tells the linker to add padding to increase the section's size to the next power of two boundary. In addition, the section is aligned on that power of 2 as well. For example, consider the following section specification:

```
.mytext: palign(power2) {} > PMEM
```

Assume that the size of the .mytext section is 120 bytes and PMEM starts at address 0x10020. After applying the palign(power2) operator, the .mytext output section will have the following properties:

name	addr	size	align
.mytext	0x00010080	0x80	128

12.5.5.3 Specifying Input Sections

An input section specification identifies the sections from input files that are combined to form an output section. In general, the linker combines input sections by concatenating them in the order in which they are specified. However, if alignment or blocking is specified for an input section, all of the input sections within the output section are ordered as follows:

- All aligned sections, from largest to smallest
- All blocked sections, from largest to smallest
- All other sections, from largest to smallest

The size of an output section is the sum of the sizes of the input sections that it comprises.

Example 12-8 shows the most common type of section specification; note that no input sections are listed.

Example 12-8. The Most Common Method of Specifying Section Contents

```
SECTIONS
{
    .text:
    .data:
    .bss:
}
```

In [Example 12-8](#), the linker takes all the .text sections from the input files and combines them into the .text output section. The linker concatenates the .text input sections in the order that it encounters them in the input files. The linker performs similar operations with the .data and .bss sections. You can use this type of specification for any output section.

You can explicitly specify the input sections that form an output section. Each input section is identified by its filename and section name. If the filename is hyphenated (or contains special characters), enclose it within quotes:

```
SECTIONS
{
    .text :          /* Build .text output section          */
    {
        f1.c.obj(.text)      /* Link .text section from f1.c.obj      */
        f2.c.obj(sec1)      /* Link sec1 section from f2.c.obj      */
        "f3-new.c.obj"      /* Link ALL sections from f3-new.c.obj  */
        f4.c.obj"(.text,sec2) /* Link .text and sec2 from f4.c.obj    */
    }
}
```

It is not necessary for input sections to have the same name as each other or as the output section they become part of. If a file is listed with no sections, *all* of its sections are included in the output section. If any additional input sections have the same name as an output section but are not explicitly specified by the SECTIONS directive, they are automatically linked in at the end of the output section. For example, if the linker found more .text sections in the preceding example and these .text sections *were not* specified anywhere in the SECTIONS directive, the linker would concatenate these extra sections after f4.c.obj(sec2).

The specifications in [Example 12-8](#) are actually a shorthand method for the following:

```
SECTIONS
{
    .text: { *(.text) }
    .data: { *(.data) }
    .bss:  { *(.bss)  }
}
```

The specification **(.text)* means *the unallocated .text sections from all input files*. This format is useful if:

- You want the output section to contain all input sections that have a specified name, but the output section name is different from the input sections' name.
- You want the linker to allocate the input sections before it processes additional input sections or commands within the braces.

The following example illustrates the two purposes above:

```
SECTIONS
{
    .text : {
        abc.c.obj(xqt)
        *(.text)
    }
    .data : {
        *(.data)
        fil.c.obj(table)
    }
}
```


In this example, the .text output section contains a named section xqt from file abc.c.obj, which is followed by all the .text input sections. The .data section contains all the .data input sections, followed by a named section table from the file fil.c.obj. This method includes all the unallocated sections. For example, if one of the .text input sections was already included in another output section when the linker encountered *(.text), the linker could not include that first .text input section in the second output section.

Each input section acts as a prefix and gathers longer-named sections. For example, the pattern *(.data) matches .dataspecial. This mechanism enables the use of subsections, which are described in the following section.

12.5.5.4 Using Multi-Level Subsections

Subsections can be identified with the base section name and one or more subsection names separated by colons. For example, A:B and A:B:C name subsections of the base section A. In certain places in a linker command file specifying a base name, such as A, selects the section A as well as any subsections of A, such as A:B or A:C:D.

A name such as A:B can specify a (sub)section of that name as well as any (multi-level) subsections beginning with that name, such as A:B:C, A:B:OTHER, etc. All subsections of A:B are also subsections of A. A and A:B are supersections of A:B:C. Among a group of supersections of a subsection, the nearest supersection is the supersection with the longest name. Thus, among {A, A:B} the nearest supersection of A:B:C:D is A:B. With multiple levels of subsections, the constraints are the following:

1. When specifying **input** sections within a file (or library unit) the section name selects an input section of the same name and any subsections of that name.
2. Input sections that are not explicitly allocated are allocated in an existing **output** section of the same name or in the nearest existing supersection of such an output section. An exception to this rule is that during a partial link (specified by the --relocatable linker option) a subsection is allocated only to an existing output section of the same name.
3. If no such output section described in 2) is defined, the input section is put in a **newly created output** section with the same name as the base name of the input section

Consider linking input sections with the following names:

europe:north:norway	europe:central:france	europe:south:spain
europe:north:sweden	europe:central:germany	europe:south:italy
europe:north:finland	europe:central:denmark	europe:south:malta
europe:north:iceland		

This SECTIONS specification allocates the input sections as indicated in the comments:

```
SECTIONS {
    nordic: {*(europe:north)
              *(europe:central:denmark)} /* the nordic countries */
    central: {*(europe:central)}          /* france, germany */
    therest: {*(europe)}                  /* spain, italy, malta */
}
```

This SECTIONS specification allocates the input sections as indicated in the comments:

```
SECTIONS {
    islands: {*(europe:south:malta)
              *(europe:north:iceland)} /* malta, iceland */
    europe:north:finland : {}           /* finland */
    europe:north          : {}           /* norway, sweden */
    europe:central         : {}           /* germany, denmark */
    europe:central:france: {}           /* france */

    /* (italy, spain) go into a linker-generated output section "europe" */
}
```

Upward Compatibility of Multi-Level Subsections

NOTE: Existing linker commands that use the existing single-level subsection features and which do not contain section names containing multiple colon characters continue to behave as before. However, if section names in a linker command file or in the input sections supplied to the linker contain multiple colon characters, some change in behavior could be possible. You should carefully consider the impact of the rules for multiple levels to see if it affects a particular system link.

12.5.5.5 Specifying Library or Archive Members as Input to Output Sections

You can specify one or more members of an object library or archive for input to an output section. Consider this SECTIONS directive:

Example 12-9. Archive Members to Output Sections

```
SECTIONS
{
    boot    >      BOOT1
    {
        -l rtsXX.lib<boot.c.obj> (.text)
        -l rtsXX.lib<exit.c.obj strcpy.c.obj> (.text)
    }

    .rts    >      BOOT2
    {
        -l rtsXX.lib (.text)
    }

    .text   >      RAM
    {
        * (.text)
    }
}
```

In [Example 12-9](#), the .text sections of boot.c.obj, exit.c.obj, and strcpy.c.obj are extracted from the run-time-support library and placed in the .boot output section. The remainder of the run-time-support library object that is referenced is allocated to the .rts output section. Finally, the remainder of all other .text sections are to be placed in section .text.

An archive member or a list of members is specified by surrounding the member name(s) with angle brackets < and > after the library name. Any object files separated by commas or spaces from the specified archive file are legal within the angle brackets.

The --library option (which normally implies a library path search be made for the named file following the option) listed before each library in [Example 12-9](#) is optional when listing specific archive members inside < >. Using < > implies that you are referring to a library.

To collect a set of the input sections from a library in one place, use the --library option within the SECTIONS directive. For example, the following collects all the .text sections from rts7100_le.lib into the .rtstest section:

```
SECTIONS
{
    .rtstest { -l rts7100_le.lib(.text) } > RAM
}
```

SECTIONS Directive Effect on --priority

NOTE: Specifying a library in a SECTIONS directive causes that library to be entered in the list of libraries that the linker searches to resolve references. If you use the --priority option, the first library specified in the command file will be searched first.

12.5.5.6 Allocation Using Multiple Memory Ranges

The linker allows you to specify an explicit list of memory ranges into which an output section can be allocated. Consider the following example:

```
MEMORY
{
    P_MEM1 : origin = 0x02000, length = 0x01000
    P_MEM2 : origin = 0x04000, length = 0x01000
    P_MEM3 : origin = 0x06000, length = 0x01000
    P_MEM4 : origin = 0x08000, length = 0x01000
}
SECTIONS
{
    .text : { } > P_MEM1 | P_MEM2 | P_MEM4
}
```

The | operator is used to specify the multiple memory ranges. The .text output section is allocated as a whole into the first memory range in which it fits. The memory ranges are accessed in the order specified. In this example, the linker first tries to allocate the section in P_MEM1. If that attempt fails, the linker tries to place the section into P_MEM2, and so on. If the output section is not successfully allocated in any of the named memory ranges, the linker issues an error message.

With this type of SECTIONS directive specification, the linker can seamlessly handle an output section that grows beyond the available space of the memory range in which it is originally allocated. Instead of modifying the linker command file, you can let the linker move the section into one of the other areas.

12.5.5.7 Automatic Splitting of Output Sections Among Non-Contiguous Memory Ranges

The linker can split output sections among multiple memory ranges for efficient allocation. Use the >> operator to indicate that an output section can be split, if necessary, into the specified memory ranges:

```
MEMORY
{
    P_MEM1 : origin = 0x2000, length = 0x1000
    P_MEM2 : origin = 0x4000, length = 0x1000
    P_MEM3 : origin = 0x6000, length = 0x1000
    P_MEM4 : origin = 0x8000, length = 0x1000
}
SECTIONS
{
    .text: { *(.text) } >> P_MEM1 | P_MEM2 | P_MEM3 | P_MEM4
}
```

In this example, the >> operator indicates that the .text output section can be split among any of the listed memory areas. If the .text section grows beyond the available memory in P_MEM1, it is split on an input section boundary, and the remainder of the output section is allocated to P_MEM2 | P_MEM3 | P_MEM4.

The | operator is used to specify the list of multiple memory ranges.

You can also use the >> operator to indicate that an output section can be split within a single memory range. This functionality is useful when several output sections must be allocated into the same memory range, but the restrictions of one output section cause the memory range to be partitioned. Consider the following example:

```
MEMORY
{
    RAM : origin = 0x1000, length = 0x8000
}
SECTIONS
{
    .special: { f1.c.obj(.text) } load = 0x4000
    .text: { *(.text) } >> RAM
}
```

The .special output section is allocated near the middle of the RAM memory range. This leaves two unused areas in RAM: from 0x1000 to 0x4000, and from the end of f1.c.obj(.text) to 0x8000. The specification for the .text section allows the linker to split the .text section around the .special section and use the available space in RAM on either side of .special.

The >> operator can also be used to split an output section among all memory ranges that match a specified attribute combination. For example:

```
MEMORY
{
    P_MEM1 (RWX) : origin = 0x1000, length = 0x2000
    P_MEM2 (RWI) : origin = 0x4000, length = 0x1000
}

SECTIONS
{
    .text: { *(.text) } >> (RW)
}
```

The linker attempts to allocate all or part of the output section into any memory range whose attributes match the attributes specified in the SECTIONS directive.

This SECTIONS directive has the same effect as:

```
SECTIONS
{
    .text: { *(.text) } >> P_MEM1 | P_MEM2
}
```

Certain sections should not be split:

- Certain sections created by the compiler, including
 - The .cinit section, which contains the autoinitialization table for C/C++ programs
 - The .pinit section, which contains the list of global constructors for C++ programs
 - The .bss section, which defines global variables
- An output section with an input section specification that includes an expression to be evaluated. The expression may define a symbol that is used in the program to manage the output section at run time.
- An output section that has a START(), END(), OR SIZE() operator applied to it. These operators provide information about a section's load or run address, and size. Splitting the section may compromise the integrity of the operation.
- The run allocation of a UNION. (Splitting the load allocation of a UNION is allowed.)

If you use the >> operator on any of these sections, the linker issues a warning and ignores the operator.

12.5.6 Placing a Section at Different Load and Run Addresses

At times, you may want to load code into one area of memory and run it in another. For example, you may have performance-critical code in slow external memory. The code must be loaded into slow external memory, but it would run faster in fast external memory.

The linker provides a simple way to accomplish this. You can use the SECTIONS directive to direct the linker to allocate a section twice: once to set its load address and again to set its run address. For example:

```
.fir: load = SLOW_MEM, run = FAST_MEM
```

Use the *load* keyword for the load address and the *run* keyword for the run address.

See [Section 9.5](#) for an overview on run-time relocation.

The application must copy the section from its load address to its run address; this does *not* happen automatically when you specify a separate run address. (The TABLE operator instructs the linker to produce a copy table; see [Section 12.8.4.1](#).)

12.5.6.1 Specifying Load and Run Addresses

The load address determines where a loader places the raw data for the section. Any references to the section (such as labels in it) refer to its run address.

If you provide only one allocation (either load or run) for a section, the section is allocated only once and loads and runs at the same address. If you provide both allocations, the section is allocated as if it were two sections of the same size. This means that both allocations occupy space in the memory map and cannot overlay each other or other sections. (The `UNION` directive provides a way to overlay sections; see [Section 12.5.7.2](#).)

If either the load or run address has additional parameters, such as alignment or blocking, list them after the appropriate keyword. Everything related to allocation after the keyword `load` affects the load address until the keyword `run` is seen, after which, everything affects the run address. The load and run allocations are completely independent, so any qualification of one (such as alignment) has no effect on the other. You can also specify run first, then load. Use parentheses to improve readability.

The examples that follow specify load and run addresses.

In this example, `align` applies only to load:

```
.data: load = SLOW_MEM, align = 32, run = FAST_MEM
```

The following example uses parentheses, but has effects that are identical to the previous example:

```
.data: load = (SLOW_MEM align 32), run = FAST_MEM
```

The following example aligns `FAST_MEM` to 32 bits for run allocations and aligns all load allocations to 16 bits:

```
.data: run = FAST_MEM, align 32, load = align 16
```

For more information on run-time relocation see [Section 9.5](#).

Uninitialized sections (such as `.bss`) are not loaded, so their only significant address is the run address. The linker allocates uninitialized sections only once: if you specify both run and load addresses, the linker warns you and ignores the load address. Otherwise, if you specify only one address, the linker treats it as a run address, regardless of whether you call it load or run.

This example specifies load and run addresses for an uninitialized section:

```
.bss: load = 0x1000, run = FAST_MEM
```

A warning is issued, load is ignored, and space is allocated in `FAST_MEM`. All of the following examples have the same effect. The `.bss` section is allocated in `FAST_MEM`.

```
.dbss: load = FAST_MEM
.bss: run = FAST_MEM
.bss: > FAST_MEM
```

12.5.7 Using GROUP and UNION Statements

Two `SECTIONS` statements allow you to organize or conserve memory: `GROUP` and `UNION`. Grouping sections causes the linker to allocate them contiguously in memory. Unioning sections causes the linker to allocate them to the same run address.

12.5.7.1 Grouping Output Sections Together

The `SECTIONS` directive's `GROUP` option forces several output sections to be allocated contiguously and in the order listed, unless the `UNORDERED` operator is used. For example, assume that a section named `term_rec` contains a termination record for a table in the `.data` section. You can force the linker to allocate `.data` and `term_rec` together:

Example 12-10. Allocate Sections Together

```
SECTIONS
{
    .text          /* Normal output section */
    .bss           /* Normal output section */
}
```

Example 12-10. Allocate Sections Together (continued)

```
GROUP 0x00001000 : /* Specify a group of sections */
{
    .data          /* First section in the group */
    term_rec       /* Allocated immediately after .data */
}
}
```

You can use binding, alignment, or named memory to allocate a GROUP in the same manner as a single output section. In the preceding example, the GROUP is bound to address 0x1000. This means that .data is allocated at 0x1000, and term_rec follows it in memory.

You Cannot Specify Addresses for Sections Within a GROUP

NOTE: When you use the GROUP option, binding, alignment, or allocation into named memory can be specified for the group only. You cannot use binding, named memory, or alignment for sections within a group.

12.5.7.2 Overlaying Sections With the UNION Statement

For some applications, you may want to allocate more than one section that occupies the same address during run time. For example, you may have several routines you want in fast external memory at different stages of execution. Or you may want several data objects that are not active at the same time to share a block of memory. The UNION statement within the SECTIONS directive provides a way to allocate several sections at the same run-time address.

In [Example 12-11](#), the .bss sections from file1.c.obj and file2.c.obj are allocated at the same address in FAST_MEM. In the memory map, the union occupies as much space as its largest component. The components of a union remain independent sections; they are simply allocated together as a unit.

Example 12-11. The UNION Statement

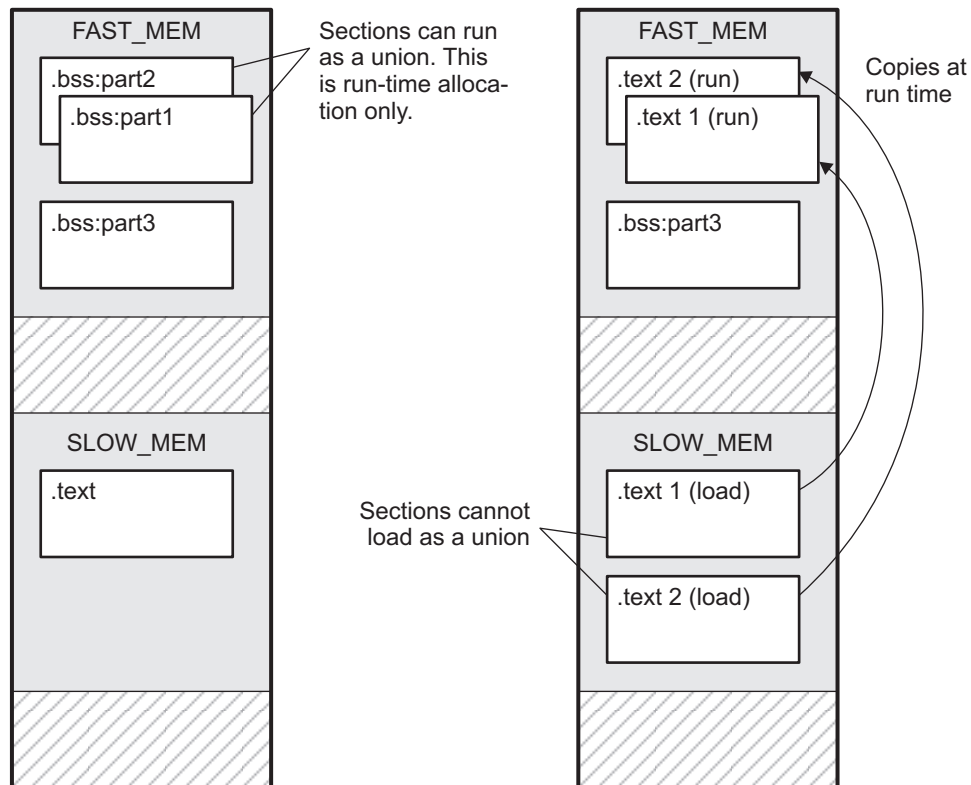
```
SECTIONS
{
    .text: load = SLOW_MEM
    UNION: run = FAST_MEM
    {
        .bss:part1: { file1.c.obj(.bss) }
        .bss:part2: { file2.c.obj(.bss) }
    }
    .bss:part3: run = FAST_MEM { globals.c.obj(.bss) }
}
```

Allocation of a section as part of a union affects only its *run* address. Under no circumstances can sections be overlaid for loading. If an initialized section is a union member (an initialized section, such as .text, has raw data), its load allocation *must* be separately specified. See [Example 12-12](#). (There is an exception to this rule when combining an initialized section with uninitialized sections; see [Section 12.5.7.3](#).)

Example 12-12. Separate Load Addresses for UNION Sections

```
UNION run = FAST_MEM
{
    .text:part1: load = SLOW_MEM, { file1.c.obj(.text) }
    .text:part2: load = SLOW_MEM, { file2.c.obj(.text) }
}
```

Figure 12-3. Memory Allocation Shown in Example 12-11 and Example 12-12



Since the .text sections contain raw data, they cannot *load* as a union, although they can be *run* as a union. Therefore, each requires its own load address. If you fail to provide a load allocation for an initialized section within a UNION, the linker issues a warning and allocates load space anywhere it can in configured memory.

Uninitialized sections are not loaded and do not require load addresses.

The UNION statement applies only to allocation of run addresses, so it is meaningless to specify a load address for the union itself. For purposes of allocation, the union is treated as an uninitialized section: any one allocation specified is considered a run address, and if both run and load addresses are specified, the linker issues a warning and ignores the load address.

12.5.7.3 Using Memory for Multiple Purposes

One way to reduce an application's memory requirement is to use the same range of memory for multiple purposes. You can first use a range of memory for system initialization and startup. Once that phase is complete, the same memory can be repurposed as a collection of uninitialized data variables or a heap. To implement this scheme, use the following variation of the UNION statement to allow one section to be initialized and the remaining sections to be uninitialized.

Generally, an initialized section (one with raw data, such as .text) in a union must have its load allocation specified separately. However, one and only one initialized section in a union can be allocated at the union's run address. By listing it in the UNION statement with no load allocation at all, it will use the union's run address as its own load address.

For example:

```
UNION run = FAST_MEM
{ .cinit .bss }
```

In this example, the .cinit section is an initialized section. It will be loaded into FAST_MEM at the run address of the union. In contrast, .bss is an uninitialized section. Its run address will also be that of the union.

12.5.7.4 Nesting UNIONS and GROUPs

The linker allows arbitrary nesting of GROUP and UNION statements with the SECTIONS directive. By nesting GROUP and UNION statements, you can express hierarchical overlays and groupings of sections. [Example 12-13](#) shows how two overlays can be grouped together.

Example 12-13. Nesting GROUP and UNION Statements

```
SECTIONS
{
  GROUP 0x1000 : run = FAST_MEM
  {
    UNION:
    {
      mysect1: load = SLOW_MEM
      mysect2: load = SLOW_MEM
    }
    UNION:
    {
      mysect3: load = SLOW_MEM
      mysect4: load = SLOW_MEM
    }
  }
}
```

For this example, the linker performs the following allocations:

- The four sections (mysect1, mysect2, mysect3, mysect4) are assigned unique, non-overlapping load addresses. This assignment is determined by the particular load allocations given for each section.
- Sections mysect1 and mysect2 are assigned the same run address in FAST_MEM.
- Sections mysect3 and mysect4 are assigned the same run address in FAST_MEM.
- The run addresses of mysect1/mysect2 and mysect3/mysect4 are allocated contiguously, as directed by the GROUP statement (subject to alignment and blocking restrictions).

To refer to groups and unions, linker diagnostic messages use the notation:

GROUP_*n* UNION_*n*

where *n* is a sequential number (beginning at 1) that represents the lexical ordering of the group or union in the linker control file without regard to nesting. Groups and unions each have their own counter.

12.5.7.5 Checking the Consistency of Allocators

The linker checks the consistency of load and run allocations specified for unions, groups, and sections. The following rules are used:

- Run allocations are only allowed for top-level sections, groups, or unions (sections, groups, or unions that are not nested under any other groups or unions). The linker uses the run address of the top-level structure to compute the run addresses of the components within groups and unions.
- The linker does not accept a load allocation for UNIONS.
- The linker does not accept a load allocation for uninitialized sections.
- In most cases, you must provide a load allocation for an initialized section. However, the linker does not accept a load allocation for an initialized section that is located within a group that already defines a load allocator.
- As a shortcut, you can specify a load allocation for an entire group, to determine the load allocations for every initialized section or subgroup nested within the group. However, a load allocation is accepted for an entire group only if all of the following conditions are true:
 - The group is initialized (that is, it has at least one initialized member).
 - The group is not nested inside another group that has a load allocator.
 - The group does not contain a union containing initialized sections.

- If the group contains a union with initialized sections, it is necessary to specify the load allocation for each initialized section nested within the group. Consider the following example:

```
SECTIONS
{
  GROUP: load = SLOW_MEM, run = SLOW_MEM
  {
    .text1:
    UNION:
    {
      .text2:
      .text3:
    }
  }
}
```

The load allocator given for the group does not uniquely specify the load allocation for the elements within the union: .text2 and .text3. In this case, the linker issues a diagnostic message to request that these load allocations be specified explicitly.

12.5.7.6 Naming UNIONS and GROUPs

You can give a name to a UNION or GROUP by entering the name in parentheses after the declaration. For example:

```
GROUP(BSS_SYSMEM_STACK_GROUP)
{
  .bss      :{}
  .sysmem   :{}
  .stack    :{}
} load=D_MEM, run=D_MEM
```

The name you defined is used in diagnostics for easy identification of the problem LCF area. For example:

warning: LOAD placement ignored for "BSS_SYSMEM_STACK_GROUP": object is uninitialized

```
UNION(TEXT_CINIT_UNION)
{
  .const :{}load=D_MEM, table(table1)
  .pinit :{}load=D_MEM, table(table1)
}run=P_MEM
```

warning:table(table1) operator ignored: table(table1) has already been applied to a section in the "UNION(TEXT_CINIT_UNION)" in which ".pinit" is a descendant

12.5.8 Special Section Types (DSECT, COPY, NOLOAD, and NOINIT)

You can assign the following special types to output sections: DSECT, COPY, NOLOAD, and NOINIT. These types affect the way that the program is treated when it is linked and loaded. You can assign a type to a section by placing the type after the section definition. For example:

```
SECTIONS
{
  sec1: load = 0x00002000, type = DSECT {f1.c.obj}
  sec2: load = 0x00004000, type = COPY {f2.c.obj}
  sec3: load = 0x00006000, type = NOLOAD {f3.c.obj}
  sec4: load = 0x00008000, type = NOINIT {f4.c.obj}
}
```

- The DSECT type creates a dummy section with the following characteristics:
 - It is not included in the output section memory allocation. It takes up no memory and is not included in the memory map listing.
 - It can overlay other output sections, other DSECTs, and unconfigured memory.
 - Global symbols defined in a dummy section are relocated normally. They appear in the output module's symbol table with the same value they would have if the DSECT had actually been loaded. These symbols can be referenced by other input sections.
 - Undefined external symbols found in a DSECT cause specified archive libraries to be searched.

- The section's contents, relocation information, and line number information are not placed in the output module.

In the preceding example, none of the sections from f1.c.obj are allocated, but all the symbols are relocated as though the sections were linked at address 0x2000. The other sections can refer to any of the global symbols in sec1.

- A COPY section is similar to a DSECT section, except that its contents and associated information are written to the output module. The .cinit section that contains initialization tables for the C7000 C/C++ compiler has this attribute under the run-time initialization model.
- A NOLOAD section differs from a normal output section in one respect: the section's contents, relocation information, and line number information are not placed in the output module. The linker allocates space for the section, and it appears in the memory map listing.
- A NOINIT section is not C auto-initialized by the linker. It is your responsibility to initialize this section as needed.

12.5.9 Assigning Symbols at Link Time

Linker assignment statements allow you to define external (global) symbols and assign values to them at link time. You can use this feature to initialize a variable or pointer to an allocation-dependent value. See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.5.9.1 Syntax of Assignment Statements

The syntax of assignment statements in the linker is similar to that of assignment statements in the C language:

<i>symbol</i>	=	<i>expression</i> ;	assigns the value of expression to symbol
<i>symbol</i>	+=	<i>expression</i> ;	adds the value of expression to symbol
<i>symbol</i>	-=	<i>expression</i> ;	subtracts the value of expression from symbol
<i>symbol</i>	*=	<i>expression</i> ;	multiplies symbol by expression
<i>symbol</i>	/=	<i>expression</i> ;	divides symbol by expression

The symbol should be defined externally. If it is not, the linker defines a new symbol and enters it into the symbol table. The expression must follow the rules defined in [Section 12.5.9.3](#). Assignment statements *must* terminate with a semicolon.

The linker processes assignment statements *after* it allocates all the output sections. Therefore, if an expression contains a symbol, the address used for that symbol reflects the symbol's address in the executable output file.

For example, suppose a program reads data from one of two tables identified by two external symbols, Table1 and Table2. The program uses the symbol cur_tab as the address of the current table. The cur_tab symbol must point to either Table1 or Table2. You can use a linker assignment statement to assign cur_tab at link time:

```
prog.c.obj          /* Input file */
cur_tab = Table1;   /* Assign cur_tab to one of the tables */
```

12.5.9.2 Assigning the SPC to a Symbol

A special symbol, denoted by a dot (.), represents the current value of the section program counter (SPC) during allocation. The SPC keeps track of the current location within a section. The . symbol can be used only in assignment statements within a SECTIONS directive because . is meaningful only during allocation and SECTIONS controls the allocation process. (See [Section 12.5.5](#).)

The . symbol refers to the current run address, not the current load address, of the section.

A special type of assignment assigns a value to the . symbol. This adjusts the SPC within an output section and creates a hole between two input sections. Any value assigned to . to create a hole is relative to the beginning of the section, not to the address actually represented by the . symbol. Holes and assignments to . are described in [Section 12.5.10](#).

12.5.9.3 Assignment Expressions

These rules apply to linker expressions:

- Expressions can contain global symbols, constants, and the C language operators listed in [Table 12-10](#).
- All numbers are treated as long (64-bit) integers.
- Constants are identified by the linker in the same way as by the assembler. That is, numbers are recognized as decimal unless they have a suffix (H or h for hexadecimal and Q or q for octal). C language prefixes are also recognized (0 for octal and 0x for hex). Hexadecimal constants must begin with a digit. No binary constants are allowed.
- Symbols within an expression have only the value of the symbol's *address*. No type-checking is performed.
- Linker expressions can be absolute or relocatable. If an expression contains *any* relocatable symbols (and 0 or more constants or absolute symbols), it is relocatable. Otherwise, the expression is absolute. If a symbol is assigned the value of a relocatable expression, it is relocatable; if it is assigned the value of an absolute expression, it is absolute.

The linker supports the C language operators listed in [Table 12-10](#) in order of precedence. Operators in the same group have the same precedence. Besides the operators listed in [Table 12-10](#), the linker also has an align operator that allows a symbol to be aligned on an n-byte boundary within an output section (n is a power of 2). For example, the following expression aligns the SPC within the current section on the next 16-byte boundary. Because the align operator is a function of the current SPC, it can be used only in the same context as `.`—that is, within a `SECTIONS` directive.

```
. = align(16);
```

Table 12-10. Groups of Operators Used in Expressions (Precedence)

Group 1 (Highest Precedence)		Group 6			
!	Logical NOT	&	Bitwise AND		
~	Bitwise NOT				
-	Negation				
Group 2		Group 7			
*	Multiplication		Bitwise OR		
/	Division				
%	Modulus				
Group 3		Group 8			
+	Addition	&&	Logical AND		
-	Subtraction				
Group 4		Group 9			
>>	Arithmetic right shift		Logical OR		
<<	Arithmetic left shift				
Group 5		Group 10 (Lowest Precedence)			
==	Equal to	=	Assignment		
!=	Not equal to	+ =	A + = B	is equivalent to	A = A + B
>	Greater than	- =	A - = B	is equivalent to	A = A - B
<	Less than	* =	A * = B	is equivalent to	A = A * B
<=	Less than or equal to	/ =	A / = B	is equivalent to	A = A / B
>=	Greater than or equal to				

12.5.9.4 Symbols Automatically Defined by the Linker

The linker automatically defines the following symbols for C/C++ support when the `--ram_model` or `--rom_model` option is used.

<code>__TI_STACK_SIZE</code>	is assigned the size of the <code>.stack</code> section.
<code>__TI_STACK_END</code>	is assigned the end of the <code>.stack</code> section.
<code>__TI_SYSMEM_SIZE</code>	is assigned the size of the <code>.sysmem</code> section.
<code>__TI_STATIC_BASE</code>	is assigned the value to be loaded into the data pointer register (DP) at boot time. This is typically the start of the first section containing a definition of a symbol that is referenced via near-DP addressing.

See [Section 12.6.1](#) for information about referring to linker symbols in C/C++ code.

12.5.9.5 Assigning Exact Start, End, and Size Values of a Section to a Symbol

The code generation tools currently support the ability to load program code in one area of (slow) memory and run it in another (faster) area. This is done by specifying separate load and run addresses for an output section or group in the linker command file. Then execute a sequence of instructions that moves the program code from its load area to its run area before it is needed.

There are several responsibilities that a programmer must take on when setting up a system with this feature. One of these responsibilities is to determine the size and run-time address of the program code to be moved. The current mechanisms to do this involve use of the `.label` directives in the copying code.

This method of specifying the size and load address of the program code has limitations. While it works fine for an individual input section that is contained entirely within one source file, this method becomes more complicated if the program code is spread over several source files or if the programmer wants to copy an entire output section from load space to run space.

Another problem with this method is that it does not account for the possibility that the section being moved may have an associated far call trampoline section that needs to be moved with it.

12.5.9.6 Why the Dot Operator Does Not Always Work

The dot operator (`.`) is used to define symbols at link-time with a particular address inside of an output section. It is interpreted like a PC. Whatever the current offset within the current section is, that is the value associated with the dot. Consider an output section specification within a `SECTIONS` directive:

```
outsect:
{
    s1.c.obj(.text)
    end_of_s1 = .;
    start_of_s2 = .;
    s2.c.obj(.text)
    end_of_s2 = .;
}
```

This statement creates three symbols:

- `end_of_s1`—the end address of `.text` in `s1.c.obj`
- `start_of_s2`—the start address of `.text` in `s2.c.obj`
- `end_of_s2`—the end address of `.text` in `s2.c.obj`

Suppose there is padding between `s1.c.obj` and `s2.c.obj` created as a result of alignment. Then `start_of_s2` is not really the start address of the `.text` section in `s2.c.obj`, but it is the address before the padding needed to align the `.text` section in `s2.c.obj`. This is due to the linker's interpretation of the dot operator as the current PC. It is also true because the dot operator is evaluated independently of the input sections around it.

Another potential problem in the above example is that `end_of_s2` may not account for any padding that was required at the end of the output section. You cannot reliably use `end_of_s2` as the end address of the output section. One way to get around this problem is to create a dummy section immediately after the output section in question. For example:

```
GROUP
{
    outsect:
    {
        start_of_outsect = .;
        ...
    }
    dummy: { size_of_outsect = . - start_of_outsect; }
}
```

12.5.9.7 Address and Dimension Operators

Six operators allow you to define symbols for load-time and run-time addresses and sizes:

LOAD_START(sym)	Defines <i>sym</i> with the load-time start address of related allocation unit
START(sym)	
LOAD_END(sym)	Defines <i>sym</i> with the load-time end address of related allocation unit
END(sym)	
LOAD_SIZE(sym)	Defines <i>sym</i> with the load-time size of related allocation unit
SIZE(sym)	
RUN_START(sym)	Defines <i>sym</i> with the run-time start address of related allocation unit
RUN_END(sym)	Defines <i>sym</i> with the run-time end address of related allocation unit
RUN_SIZE(sym)	Defines <i>sym</i> with the run-time size of related allocation unit

Linker Command File Operator Equivalencies --

NOTE: LOAD_START() and START() are equivalent, as are LOAD_END()/END() and LOAD_SIZE()/SIZE(). The LOAD names are recommended for clarity.

These address and dimension operators can be associated with several different kinds of allocation units, including input items, output sections, GROUPs, and UNIONs. The following sections provide some examples of how the operators can be used in each case.

These symbols defined by the linker can be accessed at runtime using the `_symval` operator, which is essentially a cast operation. For example, suppose your linker command file contains the following:

```
.text: RUN_START(text_run_start), RUN_SIZE(text_run_size) { *(.text) }
```

Your C program can access these symbols as follows:

```
extern char text_run_start, text_run_size;

printf(".text load start is %lx\n", _symval(&text_run_start));
printf(".text load size is %lx\n", _symval(&text_run_size));
```

See [Section 12.6.1](#) for more information about referring to linker symbols in C/C++ code.

12.5.9.7.1 Input Items

Consider an output section specification within a SECTIONS directive:

```
outsect:
{
    s1.c.obj(.text)
    end_of_s1 = .;
    start_of_s2 = .;
    s2.c.obj(.text)
    end_of_s2 = .;
}
```

This can be rewritten using the START and END operators as follows:

```
outsect:
{
```

```
s1.c.obj(.text) { END(end_of_s1) }
s2.c.obj(.text) { START(start_of_s2), END(end_of_s2) }
}
```

The values of `end_of_s1` and `end_of_s2` will be the same as if you had used the dot operator in the original example, but `start_of_s2` would be defined after any necessary padding that needs to be added between the two `.text` sections. Remember that the dot operator would cause `start_of_s2` to be defined before any necessary padding is inserted between the two input sections.

The syntax for using these operators in association with input sections calls for braces `{ }` to enclose the operator list. The operators in the list are applied to the input item that occurs immediately before the list.

12.5.9.7.2 Output Section

The `START`, `END`, and `SIZE` operators can also be associated with an output section. Here is an example:

```
outsect: START(start_of_outsect), SIZE(size_of_outsect)
{
    <list of input items>
}
```

In this case, the `SIZE` operator defines `size_of_outsect` to incorporate any padding that is required in the output section to conform to any alignment requirements that are imposed.

The syntax for specifying the operators with an output section does not require braces to enclose the operator list. The operator list is simply included as part of the allocation specification for an output section.

12.5.9.7.3 GROUPs

Here is another use of the `START` and `SIZE` operators in the context of a `GROUP` specification:

```
GROUP
{
    outsect1: { ... }
    outsect2: { ... }
} load = ROM, run = RAM, START(group_start), SIZE(group_size);
```

This can be useful if the whole `GROUP` is to be loaded in one location and run in another. The copying code can use `group_start` and `group_size` as parameters for where to copy from and how much is to be copied.

12.5.9.7.4 UNIONS

The `RUN_SIZE` and `LOAD_SIZE` operators provide a mechanism to distinguish between the size of a `UNION`'s load space and the size of the space where its constituents are going to be copied before they are run. Here is an example:

```
UNION: run = RAM, LOAD_START(union_load_addr),
      LOAD_SIZE(union_ld_sz), RUN_SIZE(union_run_sz)
{
    .text1: load = ROM, SIZE(text1_size) { f1.c.obj(.text) }
    .text2: load = ROM, SIZE(text2_size) { f2.c.obj(.text) }
}
```

Here `union_ld_sz` is going to be equal to the sum of the sizes of all output sections placed in the union. The `union_run_sz` value is equivalent to the largest output section in the union. Both of these symbols incorporate any padding due to blocking or alignment requirements.

12.5.10 Creating and Filling Holes

The linker provides you with the ability to create areas *within output sections* that have nothing linked into them. These areas are called *holes*. In special cases, uninitialized sections can also be treated as holes. This section describes how the linker handles holes and how you can fill holes (and uninitialized sections) with values.

12.5.10.1 Initialized and Uninitialized Sections

There are two rules to remember about the contents of output sections. An output section contains either:

- Raw data for the *entire* section
- No raw data

A section that has raw data is referred to as *initialized*. This means that the object file contains the actual memory image contents of the section. When the section is loaded, this image is loaded into memory at the section's specified starting address. The .text and .data sections *always* have raw data if anything was assembled into them.

By default, the .bss section and sections defined with the .usect directive have no raw data (they are *uninitialized*). They occupy space in the memory map but have no actual contents. Uninitialized sections typically reserve space in fast external memory for variables. In the object file, an uninitialized section has a normal section header and can have symbols defined in it; no memory image, however, is stored in the section.

12.5.10.2 Creating Holes

You can create a hole in an initialized output section. A hole is created when you force the linker to leave extra space between input sections within an output section. When such a hole is created, *the linker must supply raw data for the hole*.

Holes can be created only *within* output sections. Space can exist *between* output sections, but such space is not a hole. To fill the space between output sections, see [Section 12.5.4.2](#).

To create a hole in an output section, you must use a special type of linker assignment statement within an output section definition. The assignment statement modifies the SPC (denoted by .) by adding to it, assigning a greater value to it, or aligning it on an address boundary. The operators, expressions, and syntaxes of assignment statements are described in [Section 12.5.9](#).

The following example uses assignment statements to create holes in output sections:

```
SECTIONS
{
    outsect:
    {
        file1.c.obj(.text)
        . += 0x0100      /* Create a hole with size 0x0100 */
        file2.c.obj(.text)
        . = align(16); /* Create a hole to align the SPC */
        file3.c.obj(.text)
    }
}
```

The output section outsect is built as follows:

1. The .text section from file1.c.obj is linked in.
2. The linker creates a 256-byte hole.
3. The .text section from file2.c.obj is linked in after the hole.
4. The linker creates another hole by aligning the SPC on a 16-byte boundary.
5. Finally, the .text section from file3.c.obj is linked in.

All values assigned to the . symbol within a section refer to the *relative address within the section*. The linker handles assignments to the . symbol as if the section started at address 0 (even if you have specified a binding address). Consider the statement . = align(16) in the example. This statement effectively aligns the file3.c.obj .text section to start on a 16-byte boundary within outsect. If outsect is ultimately allocated to start on an address that is not aligned, the file3.c.obj .text section will not be aligned either.

The . symbol refers to the current run address, not the current load address, of the section.

Expressions that decrement the . symbol are illegal. For example, it is invalid to use the -= operator in an assignment to the . symbol. The most common operators used in assignments to the . symbol are += and align.

If an output section contains all input sections of a certain type (such as .text), you can use the following statements to create a hole at the beginning or end of the output section.

```
.text: { . += 0x0100; }      /* Hole at the beginning */
.data: { *(.data)
        . += 0x0100; }      /* Hole at the end          */
```

Another way to create a hole in an output section is to combine an uninitialized section with an initialized section to form a single output section. *In this case, the linker treats the uninitialized section as a hole and supplies data for it.* The following example illustrates this method:

```
SECTIONS
{
    outsect:
    {
        file1.c.obj(.text)
        file1.c.obj(.bss)          /* This becomes a hole */
    }
}
```

Because the .text section has raw data, all of outsect must also contain raw data. Therefore, the uninitialized .bss section becomes a hole.

Uninitialized sections become holes only when they are combined with initialized sections. If several uninitialized sections are linked together, the resulting output section is also uninitialized.

12.5.10.3 Filling Holes

When a hole exists in an initialized output section, the linker must supply raw data to fill it. The linker fills holes with a 64-bit fill value that is replicated through memory until it fills the hole. The linker determines the fill value as follows:

1. If the hole is formed by combining an uninitialized section with an initialized section, you can specify a fill value for the uninitialized section. Follow the section name with an = sign and a 64-bit constant. For example:

```
SECTIONS
{
    outsect:
    {
        file1.c.obj(.text)
        file2.c.obj(.bss)= 0xFF00FF00 /* Fill this hole with 0xFF00FF00 */
    }
}
```

2. You can also specify a fill value for all the holes in an output section by supplying the fill value after the section definition:

```
SECTIONS
{
    outsect:fill = 0xFF00FF00 /* Fills holes with 0xFF00FF00 */
    {
        . += 0x0010; /* This creates a hole */
        file1.c.obj(.text)
        file1.c.obj(.bss) /* This creates another hole */
    }
}
```

3. If you do not specify an initialization value for a hole, the linker fills the hole with the value specified with the --fill_value option (see [Section 12.4.12](#)). For example, suppose the command file link.cmd contains the following SECTIONS directive:

```
SECTIONS { .text: { . = 0x0100; } /* Create a 100 word hole */ }
```

Now invoke the linker with the --fill_value option:

```
cl7x --run_linker --fill_value=0xFFFFFFFFFFFFFFFF link.cmd
```

This fills the hole with 0xFFFFFFFF.

4. If you do not invoke the linker with the --fill_value option or otherwise specify a fill value, the linker fills holes with 0s.

Whenever a hole is created and filled in an initialized output section, the hole is identified in the link map along with the value the linker uses to fill it.

12.5.10.4 Explicit Initialization of Uninitialized Sections

You can force the linker to initialize an uninitialized section by specifying an explicit fill value for it in the SECTIONS directive. This causes the entire section to have raw data (the fill value). For example:

```
SECTIONS
{
    .bss: fill = 0x1234123412341234 /* Fills .bss with 0x1234123412341234 */
}
```

Filling Sections

NOTE: Because filling a section (even with 0s) causes raw data to be generated for the entire section in the output file, your output file will be very large if you specify fill values for large sections or holes.

12.6 Linker Symbols

This section provides information about using and resolving linker symbols.

12.6.1 Using Linker Symbols in C/C++ Applications

Linker symbols have a name and a value. The value is a 48-bit address contained in a 64-bit unsigned long.

The most common kind of symbol is generated by the compiler for each function and variable. The value represents the target address where that function or variable is located. When you refer to the symbol by name in the linker command file, you get that 48-bit value.

However, in C and C++ names mean something different. If you have a variable named `x` that contains the value `Y`, and you use the name `"x"` in your C program, you are actually referring to the contents of variable `x`. If `"x"` is used on the right-hand side of an expression, the compiler fetches the value `Y`. To realize this variable, the compiler generates a linker symbol named `x` with the value `&x`. Even though the C/C++ variable and the linker symbol have the same name, they don't represent the same thing. In C, `x` is a variable name with the address `&x` and content `Y`. For linker symbols, `x` is an address, and that address contains the value `Y`.

Because of this difference, there are some tricks to referring to linker symbols in C code. The basic technique is to cause the compiler to create a "fake" C variable or function and take its address. The details differ depending on the type of linker symbol.

Linker symbols that represent a function address: In C code, declare the function as an extern function. Then, refer to the value of the linker symbol using the same name. This works because function pointers "decay" to their address value when used without adornment. For example:

```
extern void _c_int00(void);

printf("_c_int00 %lx\n", (unsigned long) &_c_int00);
```

Suppose your linker command file defines the following linker symbol:

```
func_sym=other_sym+100;
```

Your C application can refer to this symbol as follows:

```
extern void func_sym(void);

printf("func_sym %lx\n", (unsigned long) &func_sym);
```

Linker symbols that represent a data address or an arbitrary address: In C code, declare the variable as an extern variable. Then, refer to the value of the linker symbol using the `&` operator. Because the variable is at a valid data address, we know that a data pointer can represent the value. Suppose your linker command file defines the following linker symbols:

```
data_sym=.data+100;
xyz=12345
```

Your C application can refer to these symbols as follows:

```
extern char data_sym;
extern int xyz;

printf("data_sym %p\n", &data_sym);

int another_var = &xyz;
```

On C7000 devices, all symbol references are handled in a position-independent manner through a PC-relative offset. However, linker-defined symbols may have a value that does not resolve to a valid symbol address or resolves to an address that is beyond the +/- 2 GB reach of normal PC-relative addressing. When accessing such symbols, you must use the `_symval()` intrinsic to force the use of absolute addressing. Such addressing prevents the compiler from generating PC-relative offsets/relocations for symbols that don't actually correspond to addresses or to addresses that are beyond the +/- 2 GB reach of PC-relative addressing.

Therefore, if the data symbol in the above example is more than +/- 2 GB from where it is used, you must use the `_symval()` operator to force an absolute addressing mechanism, because the PC-relative addressing mechanism won't reach:

```
printf("data_sym %p\n", _symval(&data_sym));
```

12.6.2 Using `_symval()` vs. Weak Symbol References

On C7000 devices, all symbol references are handled in a position-independent manner through a PC-relative offset. However, linker-defined symbols may have a value that does not resolve to a valid symbol address. When accessing such symbols, you must use the `_symval()` intrinsic to force the use of absolute addressing as described in the previous section.

If a symbol may resolve to either a valid address or a single non-address value, you are encouraged to use weak symbol references. A weak symbol reference may be unresolved at link time, in which case the address is treated as 0. Therefore, for weak references, application code must test to make sure `&var` is not zero before attempting to read the contents. Using weak symbol references preserves the position independence of the system, while allowing for cases in which the symbol may resolve to a non-address value (in this case, "0" if the symbol is unresolved at link time).

12.6.3 Declaring Weak Symbols

In a linker command file, an assignment expression outside a `MEMORY` or `SECTIONS` directive can be used to define a linker-defined symbol. To define a weak symbol in a linker command file, use the "weak" operator in an assignment expression to designate that the symbol is eligible for removal from the output file's symbol table if it is not referenced. For example, you can define "ext_addr_sym" as follows:

```
weak(ext_addr_sym) = 0x12345678;
```

When the linker command file is used to perform the final link, then "ext_addr_sym" is presented to the linker as a weak absolute symbol; it will not be included in the resulting output file if the symbol is not referenced.

See [Section 8.5.2](#) for details about how weak symbols are handled by the linker.

12.6.4 Resolving Symbols with Object Libraries

An object library is a partitioned archive file that contains object files as members. Usually, a group of related modules are grouped together into a library. When you specify an object library as linker input, the linker includes any members of the library that define existing unresolved symbol references. You can use the archiver to build and maintain libraries. [Section 10.1](#) contains more information about the archiver.

Using object libraries can reduce link time and the size of the executable module. Normally, if an object file that contains a function is specified at link time, the file is linked whether the function is used or not; however, if that same function is placed in an archive library, the file is included only if the function is referenced.

The order in which libraries are specified is important, because the linker includes only those members that resolve symbols that are undefined at the time the library is searched. The same library can be specified as often as necessary; it is searched each time it is included. Alternatively, you can use the `--reread_libs` option to reread libraries until no more references can be resolved (see [Section 12.4.15.3](#)). A library has a table that lists all external symbols defined in the library; the linker searches through the table until it determines that it cannot use the library to resolve any more references.

The following examples link several files and libraries, using these assumptions:

- Input files `f1.c.obj` and `f2.c.obj` both reference an external function named `clrscr`.
- Input file `f1.c.obj` references the symbol `origin`.
- Input file `f2.c.obj` references the symbol `fillclr`.
- Member 0 of library `libc.lib` contains a definition of `origin`.
- Member 3 of library `liba.lib` contains a definition of `fillclr`.
- Member 1 of both libraries defines `clrscr`.

If you enter:

```
cl7x --run_linker f1.c.obj f2.c.obj liba.lib libc.lib
```

then:

- Member 1 of `liba.lib` satisfies the `f1.c.obj` and `f2.c.obj` references to `clrscr` because the library is searched and the definition of `clrscr` is found.

- Member 0 of libc.lib satisfies the reference to *origin*.
- Member 3 of liba.lib satisfies the reference to *fillclr*.

If, however, you enter:

```
c17x --run_linker f1.c.obj f2.c.obj libc.lib liba.lib
```

then the references to *clrscr* are satisfied by member 1 of libc.lib.

If none of the linked files reference symbols defined in a library, you can use the `--undef_sym` option to force the linker to include a library member. (See [Section 12.4.31](#).) The next example creates an undefined symbol *rout1* in the linker's global symbol table:

```
c17x --run_linker --undef_sym=rout1 libc.lib
```

If any member of libc.lib defines *rout1*, the linker includes that member.

Library members are allocated according to the SECTIONS directive default allocation algorithm; see [Section 12.5.5](#).

[Section 12.4.15](#) describes methods for specifying directories that contain object libraries.

12.7 Default Placement Algorithm

The MEMORY and SECTIONS directives provide flexible methods for building, combining, and allocating sections. However, any memory locations or sections you choose *not* to specify must still be handled by the linker. The linker uses algorithms to build and allocate sections in coordination with any specifications you do supply.

If you do not use the MEMORY and SECTIONS directives, the linker allocates sections starting at a memory address near zero. It begins by placing .text sections and then places the various data sections after that.

See [Section 8.4.1](#) for information about default memory allocation.

All .text input sections are concatenated to form a .text output section in the executable output file, and all .data input sections are combined to form a .data output section.

If you use a SECTIONS directive, allocation is performed according to the rules specified by the SECTIONS directive and the general algorithm described next in [Section 12.7.1](#).

12.7.1 How the Allocation Algorithm Creates Output Sections

An output section can be formed in one of two ways:

Method 1 As the result of a SECTIONS directive definition

Method 2 By combining input sections with the same name into an output section that is not defined in a SECTIONS directive

If an output section is formed as a result of a SECTIONS directive, this definition completely determines the section's contents. (See [Section 12.5.5](#) for examples of how to define an output section's content.)

If an output section is formed by combining input sections not specified by a SECTIONS directive, the linker combines all such input sections that have the same name into an output section with that name. For example, suppose the files f1.c.obj and f2.c.obj both contain named sections called *Vectors* and that the SECTIONS directive does not define an output section for them. The linker combines the two *Vectors* sections from the input files into a single output section named *Vectors*, allocates it into memory, and includes it in the output file.

By default, the linker does not display a message when it creates an output section that is not defined in the SECTIONS directive. You can use the `--warn_sections` linker option (see [Section 12.4.32](#)) to cause the linker to display a message when it creates a new output section.

After the linker determines the composition of all output sections, it must allocate them into configured memory. The MEMORY directive specifies which portions of memory are configured. If there is no MEMORY directive, the linker uses the default configuration. (See [Section 12.5.4](#) for more information on configuring memory.)

12.7.2 Reducing Memory Fragmentation

The linker's allocation algorithm attempts to minimize memory fragmentation. This allows memory to be used more efficiently and increases the probability that your program will fit into memory. The algorithm comprises these steps:

1. Each output section for which you supply a specific binding address is placed in memory at that address.
2. Each output section that is included in a specific, named memory range or that has memory attribute restrictions is allocated. Each output section is placed into the first available space within the named area, considering alignment where necessary.
3. Any remaining sections are allocated in the order in which they are defined. Sections not defined in a SECTIONS directive are allocated in the order in which they are encountered. Each output section is placed into the first available memory space, considering alignment where necessary.

If you want to control the order in which code and data are placed in memory, see the [FAQ topic on section placement](#).

12.8 Using Linker-Generated Copy Tables

The linker supports extensions to the linker command file syntax that enable the following:

- Make it easier for you to copy objects from load-space to run-space at boot time
- Make it easier for you to manage memory overlays at run time
- Allow you to split GROUPs and output sections that have separate load and run addresses

For an introduction to copy tables and their use, see [Section 9.3.3](#).

12.8.1 Using Copy Tables for Boot Loading

In some embedded applications, there is a need to copy or download code and/or data from one location to another at boot time before the application actually begins its main execution thread. For example, an application may have its code and/or data in FLASH memory and need to copy it into on-chip memory before the application begins execution.

One way to develop such an application is to create a copy table that contains three elements for each block of code or data that needs to be moved from FLASH to on-chip memory at boot time:

- The load address
- The run address
- The size

The process you follow to develop such an application might look like this:

1. Build the application to produce a .map file that contains the load and run addresses of each section that has a separate load and run placement.
2. Edit the copy table (used by the boot loader) to correct the load and run addresses as well as the size of each block of code or data that needs to be moved at boot time.
3. Build the application again, incorporating the updated copy table.
4. Run the application.

This process puts a heavy burden on you to maintain the copy table (by hand, no less). Each time a piece of code or data is added or removed from the application, you must repeat the process in order to keep the contents of the copy table up to date.

12.8.2 Using Built-in Link Operators in Copy Tables

You can avoid some of this maintenance burden by using the `LOAD_START()`, `RUN_START()`, and `SIZE()` operators that are already part of the linker command file syntax. For example, instead of building the application to generate a `.map` file, the linker command file can be annotated:

```
SECTIONS
{
    .flashcode: { app_tasks.c.obj(.text) }
        load = FLASH, run = PMEM,
        LOAD_START(_flash_code_ld_start),
        RUN_START(_flash_code_rn_start),
        SIZE(_flash_code_size)
    ...
}
```

In this example, the `LOAD_START()`, `RUN_START()`, and `SIZE()` operators instruct the linker to create three symbols:

Symbol	Description
<code>_flash_code_ld_start</code>	Load address of <code>.flashcode</code> section
<code>_flash_code_rn_start</code>	Run address of <code>.flashcode</code> section
<code>_flash_code_size</code>	Size of <code>.flashcode</code> section

These symbols can then be referenced from the copy table. The actual data in the copy table will be updated automatically each time the application is linked. This approach removes step 1 of the process described in [Section 12.8.1](#).

While maintenance of the copy table is reduced markedly, you must still carry the burden of keeping the copy table contents in sync with the symbols that are defined in the linker command file. Ideally, the linker would generate the boot copy table automatically. This would avoid having to build the application twice *and* free you from having to explicitly manage the contents of the boot copy table.

For more information on the `LOAD_START()`, `RUN_START()`, and `SIZE()` operators, see [Section 12.5.9.7](#).

12.8.3 Overlay Management Example

Consider an application that contains a memory overlay that must be managed at run time. The memory overlay is defined using a `UNION` in the linker command file as illustrated in [Example 12-14](#):

Example 12-14. Using a `UNION` for Memory Overlay

```
SECTIONS
{
    ...
    UNION
    {
        GROUP
        {
            .task1: { task1.c.obj(.text) }
            .task2: { task2.c.obj(.text) }

        } load = ROM, LOAD_START(_task12_load_start), SIZE(_task12_size)

        GROUP
        {
            .task3: { task3.c.obj(.text) }
            .task4: { task4.c.obj(.text) }

        } load = ROM, LOAD_START(_task34_load_start), SIZE(_task_34_size)
    } run = RAM, RUN_START(_task_run_start)
    ...
}
```

The application must manage the contents of the memory overlay at run time. That is, whenever any services from .task1 or .task2 are needed, the application must first ensure that .task1 and .task2 are resident in the memory overlay. Similarly for .task3 and .task4.

To affect a copy of .task1 and .task2 from ROM to RAM at run time, the application must first gain access to the load address of the tasks (_task12_load_start), the run address (_task_run_start), and the size (_task12_size). Then this information is used to perform the actual code copy.

12.8.4 Generating Copy Tables With the table() Operator

The linker supports extensions to the linker command file syntax that enable you to do the following:

- Identify any object components that may need to be copied from load space to run space at some point during the run of an application
- Instruct the linker to automatically generate a copy table that contains (at least) the load address, run address, and size of the component that needs to be copied
- Instruct the linker to generate a symbol specified by you that provides the address of a linker-generated copy table. For instance, [Example 12-14](#) can be written as shown in [Example 12-15](#):

Example 12-15. Produce Address for Linker Generated Copy Table

```
SECTIONS
{
    ...

    UNION
    {
        GROUP
        {
            .task1: { task1.c.obj(.text) }
            .task2: { task2.c.obj(.text) }

        } load = ROM, table(_task12_copy_table)

        GROUP
        {
            .task3: { task3.c.obj(.text) }
            .task4: { task4.c.obj(.text) }

        } load = ROM, table(_task34_copy_table)

    } run = RAM
    ...
}
```

Using the SECTIONS directive from [Example 12-15](#) in the linker command file, the linker generates two copy tables named: _task12_copy_table and _task34_copy_table. Each copy table provides the load address, run address, and size of the GROUP that is associated with the copy table. This information is accessible from application source code using the linker-generated symbols, _task12_copy_table and _task34_copy_table, which provide the addresses of the two copy tables, respectively.

Using this method, you need not worry about the creation or maintenance of a copy table. You can reference the address of any copy table generated by the linker in C/C++, passing that value to a general purpose copy routine, which will process the copy table and affect the actual copy.

12.8.4.1 The table() Operator

You can use the `table()` operator to instruct the linker to produce a copy table. A `table()` operator can be applied to an output section, a GROUP, or a UNION member. The copy table generated for a particular `table()` specification can be accessed through a symbol specified by you that is provided as an argument to the `table()` operator. The linker creates a symbol with this name and assigns it the address of the copy table as the value of the symbol. The copy table can then be accessed from the application using the linker-generated symbol.

Each `table()` specification you apply to members of a given UNION must contain a unique name. If a `table()` operator is applied to a GROUP, then none of that GROUP's members may be marked with a `table()` specification. The linker detects violations of these rules and reports them as warnings, ignoring each offending use of the `table()` specification. The linker does not generate a copy table for erroneous `table()` operator specifications.

Copy tables can be generated automatically; see [Section 12.8.4](#). The table operator can be used with compression; see [Section 12.8.5](#).

12.8.4.2 Boot-Time Copy Tables

The linker supports a special copy table name, BINIT (or binit), that you can use to create a boot-time copy table. This table is handled before the `.cinit` section is used to initialize variables at startup. For example, the linker command file for the boot-loaded application described in [Section 12.8.2](#) can be rewritten as follows:

```
SECTIONS
{
    .flashcode: { app_tasks.c.obj(.text) }
    load = FLASH, run = PMEM,
        table(BINIT)
    ...
}
```

For this example, the linker creates a copy table that can be accessed through a special linker-generated symbol, `__binit__`, which contains the list of all object components that need to be copied from their load location to their run location at boot-time. If a linker command file does not contain any uses of `table(BINIT)`, then the `__binit__` symbol is given a value of -1 to indicate that a boot-time copy table does not exist for a particular application.

You can apply the `table(BINIT)` specification to an output section, GROUP, or UNION member. If used in the context of a UNION, only one member of the UNION can be designated with `table(BINIT)`. If applied to a GROUP, then none of that GROUP's members may be marked with `table(BINIT)`. The linker detects violations of these rules and reports them as warnings, ignoring each offending use of the `table(BINIT)` specification.

12.8.4.3 Using the table() Operator to Manage Object Components

If you have several pieces of code that need to be managed together, then you can apply the same `table()` operator to several different object components. In addition, if you want to manage a particular object component in multiple ways, you can apply more than one `table()` operator to it. Consider the linker command file excerpt in [Example 12-16](#):

Example 12-16. Linker Command File to Manage Object Components

```
SECTIONS
{
    UNION
    {
        .first: { a1.c.obj(.text), b1.c.obj(.text), c1.c.obj(.text) }
            load = EMEM, run = PMEM, table(BINIT), table(_first_ctbl)

        .second: { a2.c.obj(.text), b2.c.obj(.text) }
            load = EMEM, run = PMEM, table(_second_ctbl)
    }

    .extra: load = EMEM, run = PMEM, table(BINIT)
    ...
}
```

In this example, the output sections `.first` and `.extra` are copied from external memory (EMEM) into program memory (PMEM) at boot time while processing the BINIT copy table. After the application has started executing its main thread, it can then manage the contents of the overlay using the two overlay copy tables named: `_first_ctbl` and `_second_ctbl`.

12.8.4.4 Linker-Generated Copy Table Sections and Symbols

The linker creates and allocates a separate input section for each copy table that it generates. Each copy table symbol is defined with the address value of the input section that contains the corresponding copy table.

The linker generates a unique name for each overlay copy table input section. For example, `table(_first_ctbl)` would place the copy table for the `.first` section into an input section called `.ovly:_first_ctbl`. The linker creates a single input section, `.binit`, to contain the entire boot-time copy table.

[Example 12-17](#) illustrates how you can control the placement of the linker-generated copy table sections using the input section names in the linker command file.

Example 12-17. Controlling the Placement of the Linker-Generated Copy Table Sections

```
SECTIONS
{
    UNION
    {
        .first: { a1.c.obj(.text), b1.c.obj(.text), c1.c.obj(.text) }
            load = EMEM, run = PMEM, table(BINIT), table(_first_ctbl)

        .second: { a2.c.obj(.text), b2.c.obj(.text) }
            load = EMEM, run = PMEM, table(_second_ctbl)
    }

    .extra: load = EMEM, run = PMEM, table(BINIT)
    ...
    .ovly: { } > BMEM
    .binit: { } > BMEM
}
```

For the linker command file in [Example 12-17](#), the boot-time copy table is generated into a `.binit` input section, which is collected into the `.binit` output section, which is mapped to an address in the BMEM memory area. The `_first_ctbl` is generated into the `.ovly:_first_ctbl` input section and the `_second_ctbl` is generated into the `.ovly:_second_ctbl` input section. Since the base names of these input sections match the name of the `.ovly` output section, the input sections are collected into the `.ovly` output section, which is then mapped to an address in the BMEM memory area.

If you do not provide explicit placement instructions for the linker-generated copy table sections, they are allocated according to the linker's default placement algorithm.

The linker does not allow other types of input sections to be combined with a copy table input section in the same output section. The linker does not allow a copy table section that was created from a partial link session to be used as input to a succeeding link session.

12.8.4.5 Splitting Object Components and Overlay Management

It is possible to split sections that have separate load and run placement instructions. The linker can access both the load address and run address of every piece of a split object component. Using the `table()` operator, you can tell the linker to generate this information into a copy table. The linker gives each piece of the split object component a `COPY_RECORD` entry in the copy table object.

For example, consider an application which has seven tasks. Tasks 1 through 3 are overlaid with tasks 4 through 7 (using a `UNION` directive). The load placement of all of the tasks is split among four different memory areas (LMEM1, LMEM2, LMEM3, and LMEM4). The overlay is defined as part of memory area PMEM. You must move each set of tasks into the overlay at run time before any services from the set are used.

You can use `table()` operators in combination with splitting operators, `>>`, to create copy tables that have all the information needed to move either group of tasks into the memory overlay as shown in [Example 12-18](#).

Example 12-18. Creating a Copy Table to Access a Split Object Component

```
SECTIONS
{
    UNION
    {
        .task1to3: { *(.task1), *(.task2), *(.task3) }
                load >> LMEM1 | LMEM2 | LMEM4, table(_task13_ctbl)

        GROUP
        {
            .task4: { *(.task4) }
            .task5: { *(.task5) }
            .task6: { *(.task6) }
            .task7: { *(.task7) }

        } load >> LMEM1 | LMEM3 | LMEM4, table(_task47_ctbl)

    } run = PMEM
    ...
    .ovly: > LMEM4
}
```

[Example 12-19](#) illustrates a possible driver for such an application.

Example 12-19. Split Object Component Driver

```
#include <cpy_tbl.h>

extern COPY_TABLE task13_ctbl;
extern COPY_TABLE task47_ctbl;

extern void task1(void);
...
extern void task7(void);

main()
{
    ...
    copy_in(&task13_ctbl);
    task1();
    task2();
    task3();
    ...

    copy_in(&task47_ctbl);
    task4();
    task5();
    task6();
    task7();
    ...
}
```

The contents of the .task1to3 section are split in the section's load space and contiguous in its run space. The linker-generated copy table, _task13_ctbl, contains a separate COPY_RECORD for each piece of the split section .task1to3. When the address of _task13_ctbl is passed to copy_in(), each piece of .task1to3 is copied from its load location into the run location.

The contents of the GROUP containing tasks 4 through 7 are also split in load space. The linker performs the GROUP split by applying the split operator to each member of the GROUP in order. The copy table for the GROUP then contains a COPY_RECORD entry for every piece of every member of the GROUP. These pieces are copied into the memory overlay when the _task47_ctbl is processed by copy_in().

The split operator can be applied to an output section, GROUP, or the load placement of a UNION or UNION member. The linker does not permit a split operator to be applied to the run placement of either a UNION or of a UNION member. The linker detects such violations, emits a warning, and ignores the offending split operator usage.

12.8.5 Compression

When automatically generating copy tables, the linker provides a way to compress the load-space data. This can reduce the read-only memory foot print. This compressed data can be decompressed while copying the data from load space to run space.

You can specify compression in two ways:

- The linker command line option `--copy_compression=compression_kind` can be used to apply the specified compression to any output section that has a `table()` operator applied to it.
- The `table()` operator accepts an optional compression parameter. The syntax is: .

table(name , compression= compression_kind)

The *compression_kind* can be one of the following types:

- **off**. Don't compress the data.
- **rle**. Compress data using Run Length Encoding.
- **lzss**. Compress data using Lempel-Ziv-Storer-Szymanski compression.

A `table()` operator without the compression keyword uses the compression kind specified using the command line option `--copy_compression`. If no *compression_kind* was specified with the command-line option, the default is LZSS compression.

When you choose compression, it is not guaranteed that the linker will compress the load data. The linker compresses load data only when such compression reduces the overall size of the load space. In some cases even if the compression results in smaller load section size the linker does not compress the data if the decompression routine offsets for the savings.

For example, assume RLE compression reduces the size of section1 by 30 bytes. Also assume the RLE decompression routine takes up 40 bytes in load space. By choosing to compress section1 the load space is increased by 10 bytes. Therefore, the linker will not compress section1. On the other hand, if there is another section (say section2) that can benefit by more than 10 bytes from applying the same compression then both sections can be compressed and the overall load space is reduced. In such cases the linker compresses both the sections.

You cannot force the linker to compress the data when doing so does not result in savings.

You cannot compress the decompression routines or any member of a GROUP containing .cinit.

12.8.5.1 Compressed Copy Table Format

The copy table format is the same irrespective of the *compression_kind*. The size field of the copy record is overloaded to support compression. [Figure 12-4](#) illustrates the compressed copy table layout.

Figure 12-4. Compressed Copy Table

Rec size	Rec cnt		
Load address		Run address	Size (0 if load data is compressed)

In [Figure 12-4](#), if the size in the copy record is non-zero it represents the size of the data to be copied, and also means that the size of the load data is the same as the run data. When the size is 0, it means that the load data is compressed.

12.8.5.2 Compressed Section Representation in the Object File

The linker creates a separate input section to hold the compressed data. Consider the following table() operation in the linker command file.

```
SECTIONS
{
    .task1: load = ROM, run = RAM, table(_task1_table)
}
```

The output object file has one output section named `.task1` which has different load and run addresses. This is possible because the load space and run space have identical data when the section is not compressed.

Alternatively, consider the following:

```
SECTIONS
{
    .task1: load = ROM, run = RAM, table(_task1_table, compression=rle)
}
```

If the linker compresses the `.task1` section then the load space data and the run space data are different. The linker creates the following two sections:

- **.task1** : This section is uninitialized. This output section represents the run space image of section `task1`.
- **.task1.load** : This section is initialized. This output section represents the load space image of the section `task1`. This section usually is considerably smaller in size than `.task1` output section.

The linker allocates load space for the `.task1.load` input section in the memory area that was specified for load placement for the `.task1` section. There is only a single load section to represent the load placement of `.task1` - `.task1.load`. If the `.task1` data had not been compressed, there would be two allocations for the `.task1` input section: one for its load placement and another for its run placement.

12.8.5.3 Compressed Data Layout

The compressed load data has the following layout:

-bit index	Compressed data
------------	-----------------

The first bits of the load data are the handler index. This handler index is used to index into a handler table to get the address of a handler function that knows how to decode the data that follows. The handler table is a list of 48-bit function pointers as shown in [Figure 12-5](#).

Figure 12-5. Handler Table

`_TI_Handler_Table_Base:`

48-bit handler address 1
⋮
48-bit handler address N

`_TI_Handler_Table_Limit:`

The linker creates a separate output section for the load and run space. For example, if `.task1.load` is compressed using RLE, the handler index points to an entry in the handler table that has the address of the run-time-support routine `__TI_decompress_rle()`.

12.8.5.4 Run-Time Decompression

During run time you call the run-time-support routine `copy_in()` to copy the data from load space to run space. The address of the copy table is passed to this routine. First the routine reads the record count. Then it repeats the following steps for each record:

1. Read load address, run address and size from record.
2. If size is zero go to step 5.
3. Call `memcpy` passing the run address, load address and size.
4. Go to step 1 if there are more records to read.
5. Read the first from the load address.
6. Read the handler address from `(&__TI_Handler_Base)[index]`.
7. Call the handler and pass load address + 1 and run address.
8. Go to step 1 if there are more records to read.

The routines to handle the decompression of load data are provided in the run-time-support library.

12.8.5.5 Compression Algorithms

The following subsections provide information about decompression algorithms for the RLE and LZSS formats. To see example decompression algorithms, refer to the following functions in the Run-Time Support library:

- **RLE:** The `__TI_decompress_rle()` function in the `copy_decompress_rle.c` file.
- **LZSS:** The `__TI_decompress_lzss()` function in the `copy_decompress_lzss.c` file.

Run Length Encoding (RLE):

-bit index	Initialization data compressed using run length encoding
------------	--

The data following the -bit index is compressed using run length encoded (RLE) format. C7000 uses a simple run length encoding that can be decompressed using the following algorithm. See `copy_decompress_rle.c` for details.

1. Read the first , Delimiter (D).
2. Read the next (B).
3. If $B \neq D$, copy B to the output buffer and go to step 2.
4. Read the next (L).
 - a. If $L == 0$, then length is either a value or we've reached the end of the data, read the next (L).
 - b. Else if $L > 0$ and $L < 4$, copy D to the output buffer L times. Go to step 2.
 - c. Else, length is -bit value (L).
5. Read the next (C); C is the repeat character.
6. Write C to the output buffer L times; go to step 2.
7. End of processing.

The C7000 run-time support library has a routine `__TI_decompress_rle()` to decompress data compressed using RLE. The first argument to this function is the address pointing to the after the -bit index. The second argument is the run address from the C auto initialization record.

Lempel-Ziv-Storer-Szymanski Compression (LZSS):

-bit index	Data compressed using LZSS
------------	----------------------------

The data following the 8-bit index is compressed using LZSS compression. The C7000 run-time-support library has the routine `__TI_decompress_lzss()` to decompress the data compressed using LZSS. The first argument to this function is the address pointing to the after the -bit Index, and the second argument is the run address from the C auto initialization record.

See `copy_decompress_lzss.c` for details on the LZSS algorithm.

12.8.6 Copy Table Contents

To use a copy table generated by the linker, you must know the contents of the copy table. This information is included in a run-time-support library header file, `cpy_tbl.h`, which contains a C source representation of the copy table data structure that is generated by the linker.

Example 12-20. C7000 `cpy_tbl.h` File

```

/*****
/* cpy_tbl.h
/*
/* Copyright (c) 2003 Texas Instruments Incorporated
/* http://www.ti.com/
/*
/* Specification of copy table data structures which can be automatically
/* generated by the linker (using the table() operator in the LCF).
*****/

#ifndef _CPY_TBL
#define _CPY_TBL

#include <stdint.h>

#ifdef __cplusplus
extern "C" {
#endif /* __cplusplus */

/*****
/* Copy Record Data Structure
*****/
typedef struct copy_record
{
    uint64_t load_addr;
    uint64_t run_addr;
    uint32_t size;
} __attribute__((__packed__)) COPY_RECORD;

/*****
/* Copy Table Data Structure
*****/
typedef struct copy_table
{
    uint16_t rec_size;
    uint16_t num_recs;
    COPY_RECORD recs[1];
} COPY_TABLE;

/*****
/* Prototype for general purpose copy routine.
*****/
extern void copy_in(COPY_TABLE *tp);

#ifdef __cplusplus
} /* extern "C" */
#endif /* __cplusplus */

#endif /* !_CPY_TBL */

```

For each object component that is marked for a copy, the linker creates a `COPY_RECORD` object for it. Each `COPY_RECORD` contains at least the following information for the object component:

- The load address
- The run address
- The size

The linker collects all COPY_RECORDs that are associated with the same copy table into a COPY_TABLE object. The COPY_TABLE object contains the size of a given COPY_RECORD, the number of COPY_RECORDs in the table, and the array of COPY_RECORDs in the table. For instance, in the BINIT example in [Section 12.8.4.2](#), the .first and .extra output sections will each have their own COPY_RECORD entries in the BINIT copy table. The BINIT copy table will then look like this:

```
COPY_TABLE __binit__ = { 12, 2,
                        { <load address of .first>,
                          <run address of .first>,
                          <size of .first> },
                        { <load address of .extra>,
                          <run address of .extra>,
                          <size of .extra> } };
```

12.8.7 General Purpose Copy Routine

The cpy_tbl.h file in [Example 12-20](#) also contains a prototype for a general-purpose copy routine, copy_in(), which is provided as part of the run-time-support library. The copy_in() routine takes a single argument: the address of a linker-generated copy table. The routine then processes the copy table data object and performs the copy of each object component specified in the copy table.

The copy_in() function definition is provided in the cpy_tbl.c run-time-support source file shown in [Example 12-21](#).

Example 12-21. Run-Time-Support cpy_tbl.c File

```

/*****
/* cpy_tbl.c
/*
/* Copyright (c) 2011 Texas Instruments Incorporated
/*
/* General purpose copy routine. Given the address of a link-generated
/* COPY_TABLE data structure, effect the copy of all object components
/* that are designated for copy via the corresponding LCF table() operator.
/*
/*
/*****

#include <cpy_tbl.h>
#include <string.h>

typedef void (*handler_fptr)(const unsigned char *in, unsigned char *out);

/*****
/* COPY_IN()
/*****
void copy_in(COPY_TABLE *tp)
{
    unsigned short I;

    for (I = 0; I < tp->num_recs; I++)
    {
        COPY_RECORD crp = tp->recs[i];
        unsigned char *ld_addr = (unsigned char *)crp.load_addr;
        unsigned char *rn_addr = (unsigned char *)crp.run_addr;

        if (crp.size)
        {
            /*-----*/
            /* Copy record has a non-zero size so the data is not compressed.
            /* Just copy the data.
            /*-----*/
            memcpy(rn_addr, ld_addr, crp.size);
        }
    }
}
```

Example 12-21. Run-Time-Support cpy_tbl.c File (continued)

```

#ifdef __TI_EABI__
    else if (HANDLER_TABLE)
    {
        /*-----*/
        /* Copy record has size zero so the data is compressed. The first */
        /* byte of the load data has the handler index. Use this index with */
        /* the handler table to get the handler for this data. Then call */
        /* the handler by passing the load and run address. */
        /*-----*/
        unsigned char index = *((unsigned char *)ld_addr++);
        handler_fptr hndl = (handler_fptr)(&HANDLER_TABLE)[index];
        (*hndl)((const unsigned char *)ld_addr, (unsigned char *)rn_addr);
    }
#endif
}
}

```

12.9 Partial (Incremental) Linking

An output file that has been linked can be linked again with additional modules. This is known as *partial linking* or *incremental linking*. Partial linking allows you to partition large applications, link each part separately, and then link all the parts together to create the final executable program.

Follow these guidelines for producing a file that you will relink:

- The intermediate files produced by the linker *must* have relocation information. Use the `--relocatable` option when you link the file the first time. (See [Section 12.4.3.2](#).)
- Intermediate files *must* have symbolic information. By default, the linker retains symbolic information in its output. Do not use the `--no_sym_table` option if you plan to relink a file, because `--no_sym_table` strips symbolic information from the output module. (See [Section 12.4.21](#).)
- Intermediate link operations should be concerned only with the formation of output sections and not with allocation. All allocation, binding, and MEMORY directives should be performed in the final link. Since the ELF object file format is used, input sections are not combined into output sections during a partial link unless a matching SECTIONS directive is specified in the link step command file.
- If the intermediate files have global symbols that have the same name as global symbols in other files and you want them to be treated as static (visible only within the intermediate file), you must link the files with the `--make_static` option (see [Section 12.4.16.1](#)).
- If you are linking C code, do not use `--ram_model` or `--rom_model` until the final linker. Every time you invoke the linker with the `--ram_model` or `--rom_model` option, the linker attempts to create an entry point. (See [Section 12.4.24](#), [Section 9.3.2.1](#), and [Section 9.3.2.2](#).)

The following example shows how you can use partial linking:

Step 1: Link the file `file1.com`; use the `--relocatable` option to retain relocation information in the output file `tempout1.out`.

```
cl7x --run_linker --relocatable --output_file=tempout1 file1.com
```

`file1.com` contains:

```

SECTIONS
{
    ssl: {
        fl.c.obj
        f2.c.obj
        .
        .
        .
        fn.c.obj
    }
}

```

Step 2: Link the file file2.com; use the --relocatable option to retain relocation information in the output file tempout2.out. file2.com contains:

```
SECTIONS
{
    ss2: {
        g1.c.obj
        g2.c.obj
        .
        .
        .
        gn.c.obj
    }
}
```

Step 3: Link tempout1.out and tempout2.out.

```
cl7x --run_linker --map_file=final.map --
output_file=final.out tempout1.out tempout2.out
```

12.10 Linking C/C++ Code

The C/C++ compiler produces assembly language source code that can be assembled and linked. For example, a C program consisting of modules prog1, prog2, etc., can be assembled and then linked to produce an executable file called prog.out:

```
cl7x --run_linker --rom_model --
output_file prog.out prog1.c.obj prog2.c.obj ... rts7100_le.lib
```

The --rom_model option tells the linker to use special conventions that are defined by the C/C++ environment.

The archive libraries shipped by TI contain C/C++ run-time-support functions.

C, C++, and mixed C and C++ programs can use the same run-time-support library. Run-time-support functions and variables that can be called and referenced from both C and C++ will have the same linkage.

12.10.1 Run-Time Initialization

All C/C++ programs must be linked with code to initialize and execute the program, called a *bootstrap* routine, also known as the *boot.c.obj* object module. The symbol `_c_int00` is defined as the program entry point and is the start of the C boot routine in *boot.c.obj*; referencing `_c_int00` ensures that *boot.c.obj* is automatically linked in from the run-time-support library. When a program begins running, it executes *boot.c.obj* first. The *boot.c.obj* symbol contains code and data for initializing the run-time environment and performs the following tasks:

- Sets up the system stack and configuration registers
- Processes the run-time *.cinit* initialization table and autoinitializes global variables (when the linker is invoked with the --rom_model option)
- Disables interrupts and calls `_main`

The run-time-support object libraries contain *boot.c.obj*. You can:

- Use the archiver to extract *boot.c.obj* from the library and then link the module in directly.
- Include the appropriate run-time-support library as an input file (the linker automatically extracts *boot.c.obj* when you use the --ram_model or --rom_model option).

12.10.2 Object Libraries and Run-Time Support

[Chapter 7](#) describes additional run-time-support functions that are included in *rts.src*. If your program uses any of these functions, you must link the appropriate run-time-support library with your object files.

You can also create your own object libraries and link them. The linker includes and links only those library members that resolve undefined references.

12.10.3 Setting the Size of the Stack and Heap Sections

The C/C++ language uses two uninitialized sections called `.sysmem` and `.stack` for the memory pool used by the `malloc()` functions and the run-time stacks, respectively. You can set the size of these by using the `--heap_size` or `--stack_size` option and specifying the size of the section as a constant immediately after the option. If the options are not used, the default size of the heap is 1K bytes and the default size of the stack is 1K bytes.

See [Section 12.4.13](#) for setting heap sizes [Section 12.4.27](#) for setting stack sizes.

12.10.4 Initializing and AutoInitializing Variables at Run Time

Autoinitializing variables at run time is the default method of autoinitialization. To use this method, invoke the linker with the `--rom_model` option. See [Section 9.3.2.1](#) for details.

Initialization of variables at load time enhances performance by reducing boot time and by saving the memory used by the initialization tables. To use this method, invoke the linker with the `--ram_model` option. See for details.

See [Section 9.3.2.3](#) for information about the steps that are performed when you invoke the linker with the `--ram_model` or `--rom_model` option.

12.11 Linker Example

This example links three object files named `demo.c.obj`, `filter.c.obj`, and `tables.obj` and creates a program called `demo.out`.

Assume that target memory has the following program memory configuration:

Address Range	Contents
0x00000020 to 0x00210000	PMEM
0x00400000 to 0x01400000	EXT0
0x01400000 to 0x01800000	EXT1
0x02000000 to 0x03000000	EXT2
0x03000000 to 0x04000000	EXT3
0x40000000 to 0x82000000	BMEM

The output sections are constructed in the following manner:

- Executable code, contained in the `.text` sections of `demo.c.obj`, `filters.c.obj`, as well as executable code from the RTS library, are linked into program memory PMEM.
- Two data objects are defined in `tables.c.obj`. Each is placed in its own output section: `.tableA` and `.tableB`. When the program is loaded, both the `.tableA` and `.tableB` output sections are linked into separate locations in the BMEM area. However, run-time access to these tables refers to the run-time location indicated by the symbol "filter_matrix", which is defined as the start address of the UNION containing both `.tableA` and `.tableB`. This location is linked into the EXT1 memory area. At run-time, the application is responsible for copying either `.tableA` or `.tableB` from its load location in BMEM to its run location in EXT1 before attempting to access data from the table that was copied. The linker supports the copy table mechanisms described in [Section 12.8](#) to help facilitate this action.
- For architectures that support and use DP-relative addressing, all data objects that are accessed using DP-relative addressing are collected into a group consisting of the `.bss` output sections. This group is linked into the BMEM memory area.
- Since the `demo.out` program uses command line arguments that must be specified when `demo.out` is loaded and run, the application must reserve space for passing command-line arguments to the program in the `.args` section. The amount of space allocated for the `.args` section is indicated in the '`--args 0x1000`' option near the top of the linker command file. The `.args` output section is then linked into the BMEM memory area. Support for processing command-line arguments is provided in the boot routine contained in the RTS library that will be linked into the `demo.out` program.

- The size of the software stack is indicated by the "--stack 0x6000" option near the top of the linker command file. Likewise, the size of the heap, from which memory can be dynamically allocated at run-time, is indicated via the "--heap 0x3000" option near the top of the linker command file. Both the .stack and .system (which contains the heap) output sections are linked into the BMEM memory area.

Example 12-22 shows the linker command file for this example. Example 12-23 shows the map file.

Example 12-22. Linker Command File, mylnk.cmd

```

/*****
*** Specify Linker Options ***
*****/
/* --ram_model: load-time initialization */
-cr
--heap 0x3000
--stack 0x6000
--args 0x1000

--output_file=demo.out          /* Name the output file */
--map_file=demo.map             /* Create an output map file */

--undefined_sym=filter_table_A /* Introduce an undefined symbol */
--undefined_sym=filter_table_B /* Introduce an undefined symbol */

/*****
*** Specify the Input Files ***
*****/
demo.c.obj
tables.obj
filter.c.obj

/*****
*** Specify Runtime Support Library to be linked in ***
*****/
-l libc.a

/*****
*** Specify the Memory Configuration ***
*****/
MEMORY
{
    PMEM: o = 00000020h l = 0020ffe0h
    EXT0: o = 00400000h l = 01000000h
    EXT1: o = 01400000h l = 00400000h
    EXT2: o = 02000000h l = 01000000h
    EXT3: o = 03000000h l = 01000000h
    BMEM: o = 40000000h l = 02000000h
}

/*****
*** Specify the Output Sections ***
*****/
SECTIONS
{
    .text : > PMEM

    UNION
    {
        .tableA: { tables.obj(tableA) } load > BMEM, table(tableA_cpy)
        .tableB: { tables.obj(tableB) } load > BMEM, table(tableB_cpy)
    } RUN = EXT1, RUN_START(filter_matrix)

    GROUP
    {
        .rodata:
        .bss:
    }
}

```

Example 12-22. Linker Command File, mylnk.cmd (continued)

```

} > EXT2

.stack: > BMEM
.args : > BMEM
.cinit: > BMEM
.cio:   > BMEM
.const: > BMEM
.data:  > BMEM
.systemem: > BMEM
}

/*****
*** End of Command File          ***
*****/

```

Invoke the linker by entering the following command:

```
cl7x --run_linker mylnk.cmd
```

This creates the map file shown in [Example 12-23](#) and an output file called demo.out that can be run on a C7000.

Example 12-23. Output Map File, demo.map

```

OUTPUT FILE NAME:    <demo.out>
ENTRY POINT SYMBOL:  "_c_int00"  address: 000000007ec0

```

MEMORY CONFIGURATION

name	origin	length	used	unused	attr	fill
PMEM	000000000020	0020ffe0	00008170	00207e70	RWIX	
EXT0	000000400000	01000000	00000000	01000000	RWIX	
EXT1	000001400000	00400000	00000080	003fff80	RWIX	
EXT2	000002000000	01000000	000000b0	00ffff50	RWIX	
EXT3	000003000000	01000000	00000000	01000000	RWIX	
BMEM	000040000000	02000000	0000a6e4	01ff591c	RWIX	

SEGMENT ALLOCATION MAP

run origin	load origin	length	init length	attrs	members
000000000040	000000000040	00008170	00008170	r-x	
000000000040	000000000040	00008140	00008140	r-x	.text
000000008180	000000008180	00000030	00000030	r--	.ovly
000001400000	00004000a5e4	00000080	00000080	rw-	
000001400000	00004000a5e4	00000080	00000080	rw-	.tableA
000001400000	00004000a664	00000080	00000080	rw-	
000001400000	00004000a664	00000080	00000080	rw-	.tableB
000002000000	000002000000	000000b0	00000000	rw-	
000002000000	000002000000	000000b0	00000000	rw-	.bss
000040000000	000040000000	00009000	00000000	rw-	
000040000000	000040000000	00006000	00000000	rw-	.stack
000040006000	000040006000	00003000	00000000	rw-	.systemem
000040009000	000040009000	00001384	00001384	rw-	
000040009000	000040009000	00001000	00001000	rw-	.args
00004000a000	00004000a000	00000384	00000384	rw-	.data
00004000a384	00004000a384	00000140	00000140	r--	
00004000a384	00004000a384	00000140	00000140	r--	.const
00004000a4c4	00004000a4c4	00000120	00000000	rw-	
00004000a4c4	00004000a4c4	00000120	00000000	rw-	.cio

Example 12-23. Output Map File, demo.map (continued)

SECTION ALLOCATION MAP				
output section	page	origin	length	attributes/ input sections
-----	----	-----	-----	-----
.text	0	000000000040	00008140	
		000000000040	00002400	rts7100_le.lib : _printfi.c.obj (.text:__TI_printfi)
		000000002440	00000900	: _printfi.c.obj (.text:pconv_a)
		000000002d40	00000800	: _printfi.c.obj (.text:pconv_g)
		000000003540	00000680	: _printfi.c.obj (.text:pconv_e)
		000000003bc0	000003c0	: memory.c.obj (.text:aligned_alloc)
		000000003f80	00000380	: frcddivd.c.obj (.text:__TI_frcdivd)
		000000004300	00000340	: _printfi.c.obj (.text:pconv_f)
		000000004640	00000300	: _printfi.c.obj (.text:fcvt)
		000000004940	00000300	: fputs.c.obj (.text:fputs)
...				
.rodata	0	000002000000	00000000	UNINITIALIZED
.bss	0	000002000000	000000b0	UNINITIALIZED
		000002000000	000000a0	(.common:__TI_tmpnams)
		0000020000a0	00000008	rts7100_le.lib : memory.c.obj (.bss)
		0000020000a8	00000008	(.common:parmbuf)
.stack	0	000040000000	00006000	UNINITIALIZED
		000040000000	00000010	rts7100_le.lib : boot.c.obj (.stack)
		000040000010	00005ff0	--HOLE--
.sysmem	0	000040006000	00003000	UNINITIALIZED
		000040006000	00000010	rts7100_le.lib : memory.c.obj (.sysmem)
		000040006010	00002ff0	--HOLE--
.args	0	000040009000	00001000	
		000040009000	00001000	--HOLE-- [fill = 0]
.data	0	00004000a000	00000384	
		00004000a000	000001e0	rts7100_le.lib : defs.c.obj (.data:_ftable)
		00004000a1e0	000000d8	: host_device.c.obj (.data:_device)
		00004000a2b8	000000a0	: host_device.c.obj (.data:_stream)
		00004000a358	00000010	: exit.c.obj (.data)
		00004000a368	00000008	: _lock.c.obj (.data:_lock)
		00004000a370	00000008	: _lock.c.obj (.data:_unlock)
		00004000a378	00000004	: defs.c.obj (.data)
		00004000a37c	00000004	: errno.c.obj (.data)
		00004000a380	00000004	: memory.c.obj (.data)
.const	0	00004000a384	00000140	
		00004000a384	00000101	rts7100_le.lib : ctype.c.obj (.const:.string:_ctypes_)
		00004000a485	00000003	--HOLE-- [fill = 0]
		00004000a488	00000024	: _printfi.c.obj (.const:.string)
		00004000a4ac	00000018	demo.c.obj (.const:.string)
.tableA	0	00004000a5e4	00000080	RUN ADDR = 000001400000
		00004000a5e4	00000080	tables.obj (tableA)
.tableB	0	00004000a664	00000080	RUN ADDR = 000001400000
		00004000a664	00000080	tables.obj (tableB)
.cinit	0	000040000000	00000000	UNINITIALIZED
.cio	0	00004000a4c4	00000120	UNINITIALIZED
		00004000a4c4	00000120	rts7100_le.lib : trgmsg.c.obj (.cio)

Example 12-23. Output Map File, demo.map (continued)

```
.ovly      0      000000008180      000000030
              000000008180      00000018      (.ovly:tableA_cpy)
              000000008198      00000018      (.ovly:tableB_cpy)
...
LINKER GENERATED COPY TABLES

tableA_cpy @ 00008180 records: 1, size/record: 20, table size: 24
    .tableA: load addr=00004000a5e4, load size=00000080, run addr=000001400000,
    run size=00000080, compression=none
tableB_cpy @ 00008198 records: 1, size/record: 20, table size: 24
    .tableB: load addr=00004000a664, load size=00000080, run addr=000001400000,
    run size=00000080, compression=none

GLOBAL SYMBOLS: SORTED ALPHABETICALLY BY Name

address      name
-----
000000008040 C$$EXIT
000000006eb0 C$$IO$$
0000000069c0 HOSTclose
000000006100 HOSTlseek
000000005f80 HOSTopen
...
000000008180 tableA_cpy
000000008198 tableB_cpy
000000007cc0 unlink
000000007d40 wcslen
000000007dc0 write
...
[96 symbols]
```


Object File Utilities

This chapter describes how to invoke the following utilities:

- The **object file display utility** prints the contents of object files, executable files, and/or archive libraries in both text and XML formats.
- The **disassembler** accepts object files and executable files as input and produces an assembly listing as output. This listing shows assembly instructions, their opcodes, and the section program counter values.
- The **name utility** prints a list of names defined and referenced in an object file, executable files, and/or archive libraries.
- The **strip utility** removes symbol table and debugging information from object and executable files.

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13.1 Invoking the Object File Display Utility

The object file display utility, *ofd7x*, prints the contents of object files (.obj), executable files (.out), and/or archive libraries (.lib) in both text and XML formats. Hidden symbols are listed as *no name*, while localized symbols are listed like any other local symbol.

To invoke the object file display utility, enter the following:

ofd7x [*options*] *input filename* [*input filename*]

ofd7x	is the command that invokes the object file display utility.
<i>input filename</i>	names the object file (.obj), executable file (.out), or archive library (.lib) source file. The filename must contain an extension.
<i>options</i>	identify the object file display utility options that you want to use. Options are not case sensitive and can appear anywhere on the command line following the command. Precede each option with a hyphen.
--call_graph	Prints function stack usage and callee information in XML format. While the XML output may be accessed by a developer, this option was primarily designed to be used by tools such as Code Composer Studio to display an application's worst case stack usage.
--dwarf_display=attributes	Controls the DWARF display filter settings by specifying a comma-delimited list of <i>attributes</i> . When prefixed with no, an attribute is disabled instead of enabled. Examples: --dwarf_display=nodabbrev,nodline --dwarf_display=all,nodabbrev --dwarf_display=none,dinfo,types The ordering of attributes is important (see --obj_display). The list of available display attributes can be obtained by invoking ofd7x --dwarf_display=help.
--dwarf	Appends DWARF debug information to program output.
--help	Displays help
--output=filename	Sends program output to <i>filename</i> rather than to the screen.
--obj_display attributes	Controls the object file display filter settings by specifying a comma-delimited list of <i>attributes</i> . When prefixed with no, an attribute is disabled instead of enabled. Examples: --obj_display=rawdata,nostrings --obj_display=all,norawdata --obj_display=none,header The ordering of attributes is important. For instance, in "--obj_display=none,header", ofd7x disables all output, then re-enables file header information. If the attributes are specified in the reverse order, (header,none), the file header is enabled, the all output is disabled, including the file header. Thus, nothing is printed to the screen for the given files. The list of available display attributes can be obtained by invoking ofd7x --obj_display=help.
--verbose	Prints verbose text output.
--xml	Displays output in XML format.
--xml_indent=num	Sets the number of spaces to indent nested XML tags.

If an archive file is given as input to the object file display utility, each object file member of the archive is processed as if it was passed on the command line. The object file members are processed in the order in which they appear in the archive file.

If the object file display utility is invoked without any options, it displays information about the contents of the input files on the console screen.

Object File Display Format

NOTE: The object file display utility produces data in a text format by default. This data is not intended to be used as input to programs for further processing of the information. XML format should be used for mechanical processing.

13.2 Invoking the Disassembler

The disassembler, *dis7x*, examines the output of the assembler or linker. This utility accepts an object file or executable file as input and writes the disassembled object code to standard output or a specified file.

To invoke the disassembler, enter the following:

dis7x [*options*] *input filename*[.] [*output filename*]

dis7x	is the command that invokes the disassembler.
options	identifies the name utility options you want to use. Options are not case sensitive and can appear anywhere on the command line following the invocation. Precede each option with a hyphen (-). The name utility options are as follows:
--all (-1)	disassembles all sections, processes .cinit sections
--noaddr (-a)	disables the printing of branch destination addresses along with labels.
--bytes (-b)	displays data as bytes instead of words.
-c	dumps the object file information.
--nodata (-d)	disables display of data sections.
--hex (-e)	displays integer values in hexadecimal.
--help (-h)	shows the current help screen.
--data_as_text (-i)	disassembles .data sections as instructions.
--text_as_data (-l)	disassembles data sections as text.
--loadtime_addr (-L)	displays both load and run addresses if they are different.
--single_opcode (-o)##	disassembles single word ## or 0x## then exits.
--quiet (-q)	(quiet mode) suppresses the banner and all progress information.
--realquiet (-qq)	(super quiet mode) suppresses all headers.
--suppress (-s)	suppresses printing of address and data words.
--notext (-t)	suppresses the display of text sections in the listing.
--silicon_version (-v)	displays family of the target.
--copy_tables (-y)	displays copy tables and the sections copied. The table information is dumped first, then each record followed by its load and run data.
input filename[.ext]	This is the name of the input file. If the optional extension is not specified, the file is searched for in this order: <ul style="list-style-type: none"> 1. <i>infile</i> 2. <i>infile.out</i>, an executable file 3. <i>infile.obj</i>, an object file
output filename	is the name of the optional output file to which the disassembly will be written. If an output filename is not specified, the disassembly is written to standard output.

13.3 Invoking the Name Utility

The name utility, *nm7x*, prints the list of names defined and referenced in an object file, executable file, or archive library. It also prints the symbol value and an indication of the kind of symbol. Hidden symbols are listed as ". To invoke the name utility, enter the following:

nm7x [-options] [input filenames]

nm7x	is the command that invokes the name utility.
<i>input filename</i>	is an object file (.obj), executable file (.out), or archive library (.lib).
<i>options</i>	identifies the name utility options you want to use. Options are not case sensitive and can appear anywhere on the command line following the invocation. Precede each option with a hyphen (-). The name utility options are as follows:
--all (-a)	prints all symbols.
--prep_fname (-f)	prepends file name to each symbol.
--global (-g)	prints only global symbols.
--help (-h)	shows the current help screen.
--format:long (-l)	produces a detailed listing of the symbol information.
--sort:value (-n)	sorts symbols numerically rather than alphabetically.
--output (-o) file	outputs to the given file.
--sort:none (-p)	causes the name utility to not sort any symbols.
--quiet (-q)	(quiet mode) suppresses the banner and all progress information.
--sort:reverse (-r)	sorts symbols in reverse order.
--dynamic (-s)	lists symbols in the dynamic symbol table for an ELF object module.
--undefined (-u)	only prints undefined symbols.

13.4 Invoking the Strip Utility

The strip utility, *strip7x*, removes symbol table and debugging information from object and executable files. To invoke the strip utility, enter the following:

strip7x [-p] input filename [input filename]

strip7x	is the command that invokes the strip utility.
<i>input filename</i>	is an object file (.obj) or an executable file (.out).
<i>options</i>	identifies the strip utility options you want to use. Options are not case sensitive and can appear anywhere on the command line following the invocation. Precede each option with a hyphen (-). The strip utility option is as follows:
--help (-h)	displays help information.
--outfile (-o) filename	writes the stripped output to filename.
--postlink (-p)	removes all information not required for execution. This option causes more information to be removed than the default behavior, but the object file is left in a state that cannot be linked. This option should be used only with static executable or dynamic object module files.
--rom	Strip readonly sections and segments.

When the strip utility is invoked without the -o option, the input object files are replaced with the stripped version.

C++ Name Demangler

The C++ compiler implements function overloading, operator overloading, and type-safe linking by encoding a function's prototype and namespace in its link-level name. The process of encoding the prototype into the linkname is often referred to as name mangling. When you inspect mangled names, such as in assembly files, disassembler output, or compiler or linker diagnostic messages, it can be difficult to associate a mangled name with its corresponding name in the C++ source code. The C++ name demangler is a debugging aid that translates each mangled name it detects to its original name found in the C++ source code.

These topics tell you how to invoke and use the C++ name demangler. The C++ name demangler reads in input, looking for mangled names. All unmangled text is copied to output unaltered. All mangled names are demangled before being copied to output.

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14.1 Invoking the C++ Name Demangler

The syntax for invoking the C++ name demangler is:

```
dem7x [options] [filenames]
```

dem7x	Command that invokes the C++ name demangler.
options	Options affect how the name demangler behaves. Options can appear anywhere on the command line.
filenames	Text input files, such as the assembly file output by the compiler, the assembler listing file, the disassembly file, and the linker map file. If no filenames are specified on the command line, dem7x uses standard input.

By default, the C++ name demangler outputs to standard output. You can use the -o file option if you want to output to a file.

The following options apply only to the C++ name demangler:

--debug (--d)	Prints debug messages.
--diag_wrap[=on,off]	Sets diagnostic messages to wrap at 79 columns (on, which is the default) or not (off).
--help (-h)	Prints a help screen that provides an online summary of the C++ name demangler options.
--output= file (-o)	Outputs to the specified file rather than to standard out.
--quiet (-q)	Reduces the number of messages generated during execution.

14.2 Sample Usage of the C++ Name Demangler

The examples in this section illustrate the demangling process. [Example 14-1](#) shows a sample C++ program. In this example, the linknames of all the functions are mangled; that is, their signature information is encoded into their names.

Example 14-1. C++ Code for calories_in_a_banana

```
class banana {
public:
    int calories(void);

    banana();

    ~banana();
};

int calories_in_a_banana(void)
{
    banana x;

    return x.calories();
}
```

Executing the C++ name demangler demangles all names that it believes to be mangled. Enter:

```
dem7x calories_in_a_banana.asm
```

The result is shown in [Example 14-2](#). The linknames `_ZN6bananaC1Ev`, `_ZN6banana8caloriesEv`, and `_ZN6bananaD1Ev` are demangled.

Example 14-2. Result After Running the C++ Name Demangler

```

||calories_in_a_banana()||:
; ** -----*

MVC      .S1      RP,A9          ; [A_S1]
||      STD      .D1      A8,*SP(8)      ; [A_D1]
||      STD      .D2X     A9,*SP++(-24)   ; [A_D2]

CALL     .B1      ||banana::banana()|| ; [A_B] |9|
||      ADDD     .D1      SP,0x10,A4      ; [A_D1] |9|

$C$RL0:   ; CALL OCCURS (||banana::banana()||) arg:{A4} ret:{} ; [] |9|

CALL     .B1      ||banana::calories()|| ; [A_B] |10|
||      ADDD     .D1      SP,0x10,A4      ; [A_D1] |10|

$C$RL1:   ; CALL OCCURS (||banana::calories()||) arg:{A4} ret:{A4} ; [] |10|

CALL     .B1      ||banana::~~banana()|| ; [A_B] |10|
||      ADDD     .D1      SP,0x10,A4      ; [A_D1] |10|
||      MV       .D2      A4,A8          ; [A_D2] |10|

$C$RL2:   ; CALL OCCURS (||banana::~~banana()||) arg:{A4} ret:{} ; [] |10|
MV       .D1      A8,A4                ; [A_D1] |10|
MVC      .S1      A9,RP                ; [A_S1] BARRIER

LDD      .D1      *SP(24),A9           ; [A_D1]
||      LDD      .D2      *SP(32),A8     ; [A_D2]

RET      .B1      ; [A_B]
||      ADDD     .D1      SP,0x18,SP      ; [A_D1]

; RETURN OCCURS {RP} ; []

```

XML Link Information File Description

The C7000 linker supports the generation of an XML link information file via the `--xml_link_info file` option. This option causes the linker to generate a well-formed XML file containing detailed information about the result of a link. The information included in this file includes all of the information that is currently produced in a linker-generated map file.

As the linker evolves, the XML link information file may be extended to include additional information that could be useful for static analysis of linker results.

This appendix enumerates all of the elements that are generated by the linker into the XML link information file.

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A.1 XML Information File Element Types

These element types will be generated by the linker:

- **Container elements** represent an object that contains other elements that describe the object. Container elements have an id attribute that makes them accessible from other elements.
- **String elements** contain a string representation of their value.
- **Constant elements** contain a 64-bit unsigned long representation of their value (with a 0x prefix).
- **Reference elements** are empty elements that contain an idref attribute that specifies a link to another container element.

In [Section A.2](#), the element type is specified for each element in parentheses following the element description. For instance, the <link_time> element lists the time of the link execution (string).

A.2 Document Elements

The root element, or the document element, is **<link_info>**. All other elements contained in the XML link information file are children of the <link_info> element. The following sections describe the elements that an XML information file can contain.

A.2.1 Header Elements

The first elements in the XML link information file provide general information about the linker and the link session:

- The **<banner>** element lists the name of the executable and the version information (string).
- The **<copyright>** element lists the TI copyright information (string).
- The **<link_time>** is a timestamp representation of the link time (unsigned 32-bit int).
- The **<output_file>** element lists the name of the linked output file generated (string).
- The **<entry_point>** element specifies the program entry point, as determined by the linker (container) with two entries:
 - The **<name>** is the entry point symbol name, if any (string).
 - The **<address>** is the entry point address (constant).

Example A-1. Header Element for the hi.out Output File

```
<banner>TMS320Cxx Linker          Version x.xx (Jan 6 2008)</banner>
<copyright>Copyright (c) 1996-2008 Texas Instruments Incorporated</copyright>
<link_time>0x43dfd8a4</link_time>
<output_file>hi.out</output_file>
<entry_point>
  <name>_c_int00</name>
  <address>0xaf80</address>
</entry_point>
```

A.2.2 Input File List

The next section of the XML link information file is the input file list, which is delimited with a **<input_file_list>** container element. The **<input_file_list>** can contain any number of **<input_file>** elements.

Each **<input_file>** instance specifies the input file involved in the link. Each **<input_file>** has an **id** attribute that can be referenced by other elements, such as an **<object_component>**. An **<input_file>** is a container element enclosing the following elements:

- The **<path>** element names a directory path, if applicable (string).
- The **<kind>** element specifies a file type, either archive or object (string).
- The **<file>** element specifies an archive name or filename (string).
- The **<name>** element specifies an object file name, or archive member name (string).

Example A-2. Input File List for the hi.out Output File

```
<input_file_list>
  <input_file id="fl-1">
    <kind>object</kind>
    <file>hi.obj</file>
    <name>hi.obj</name>
  </input_file>
  <input_file id="fl-2">
    <path>/tools/lib/</path>
    <kind>archive</kind>
    <file>rtsxxx.lib</file>
    <name>boot.obj</name>
  </input_file>
  <input_file id="fl-3">
    <path>/tools/lib/</path>
    <kind>archive</kind>
    <file>rtsxxx.lib</file>
    <name>exit.obj</name>
  </input_file>
  <input_file id="fl-4">
    <path>/tools/lib/</path>
    <kind>archive</kind>
    <file>rtsxxx.lib</file>
    <name>printf.obj</name>
  </input_file>
  ...
</input_file_list>
```

A.2.3 Object Component List

The next section of the XML link information file contains a specification of all of the object components that are involved in the link. An example of an object component is an input section. In general, an object component is the smallest piece of object that can be manipulated by the linker.

The **<object_component_list>** is a container element enclosing any number of **<object_component>** elements.

Each **<object_component>** specifies a single object component. Each **<object_component>** has an **id** attribute so that it can be referenced directly from other elements, such as a **<logical_group>**. An **<object_component>** is a container element enclosing the following elements:

- The **<name>** element names the object component (string).
- The **<load_address>** element specifies the load-time address of the object component (constant).
- The **<run_address>** element specifies the run-time address of the object component (constant).
- The **<size>** element specifies the size of the object component (constant).
- The **<input_file_ref>** element specifies the source file where the object component originated (reference).

Example A-3. Object Component List for the fl-4 Input File

```
<object_component id="oc-20">
  <name>.text</name>
  <load_address>0xac00</load_address>
  <run_address>0xac00</run_address>
  <size>0xc0</size>
  <input_file_ref idref="fl-4"/>
</object_component>
<object_component id="oc-21">
  <name>.data</name>
  <load_address>0x80000000</load_address>
  <run_address>0x80000000</run_address>
  <size>0x0</size>
  <input_file_ref idref="fl-4"/>
</object_component>
<object_component id="oc-22">
  <name>.bss</name>
  <load_address>0x80000000</load_address>
  <run_address>0x80000000</run_address>
  <size>0x0</size>
  <input_file_ref idref="fl-4"/>
</object_component>
```

A.2.4 Logical Group List

The **<logical_group_list>** section of the XML link information file is similar to the output section listing in a linker-generated map file. However, the XML link information file contains a specification of GROUP and UNION output sections, which are not represented in a map file. There are three kinds of list items that can occur in a **<logical_group_list>**:

- The **<logical_group>** is the specification of a section or GROUP that contains a list of object components or logical group members. Each **<logical_group>** element is given an id so that it may be referenced from other elements. Each **<logical_group>** is a container element enclosing the following elements:
 - The **<name>** element names the logical group (string).
 - The **<load_address>** element specifies the load-time address of the logical group (constant).
 - The **<run_address>** element specifies the run-time address of the logical group (constant).
 - The **<size>** element specifies the size of the logical group (constant).
 - The **<contents>** element lists elements contained in this logical group (container). These elements refer to each of the member objects contained in this logical group:
 - The **<object_component_ref>** is an object component that is contained in this logical group (reference).
 - The **<logical_group_ref>** is a logical group that is contained in this logical group (reference).
- The **<overlay>** is a special kind of logical group that represents a UNION, or a set of objects that share the same memory space (container). Each **<overlay>** element is given an id so that it may be referenced from other elements (like from an **<allocated_space>** element in the placement map). Each **<overlay>** contains the following elements:
 - The **<name>** element names the overlay (string).
 - The **<run_address>** element specifies the run-time address of overlay (constant).
 - The **<size>** element specifies the size of logical group (constant).
 - The **<contents>** container element lists elements contained in this overlay. These elements refer to each of the member objects contained in this logical group:
 - The **<object_component_ref>** is an object component that is contained in this logical group (reference).
 - The **<logical_group_ref>** is a logical group that is contained in this logical group (reference).
- The **<split_section>** is another special kind of logical group that represents a collection of logical groups that is split among multiple memory areas. Each **<split_section>** element is given an id so that it may be referenced from other elements. The id consists of the following elements.
 - The **<name>** element names the split section (string).
 - The **<contents>** container element lists elements contained in this split section. The **<logical_group_ref>** elements refer to each of the member objects contained in this split section, and each element referenced is a logical group that is contained in this split section (reference).

Example A-4. Logical Group List for the fl-4 Input File

```

<logical_group_list>
  ...
  <logical_group id="lg-7">
    <name>.text</name>
    <load_address>0x20</load_address>
    <run_address>0x20</run_address>
    <size>0xb240</size>
    <contents>
      <object_component_ref idref="oc-34"/>
      <object_component_ref idref="oc-108"/>
      <object_component_ref idref="oc-e2"/>
      ...
    </contents>
  </logical_group>
  ...
  <overlay id="lg-b">
    <name>UNION_1</name>
    <run_address>0xb600</run_address>
    <size>0xc0</size>
    <contents>
      <object_component_ref idref="oc-45"/>
      <logical_group_ref idref="lg-8"/>
    </contents>
  </overlay>
  ...
  <split_section id="lg-12">
    <name>.task_scn</name>
    <size>0x120</size>
    <contents>
      <logical_group_ref idref="lg-10"/>
      <logical_group_ref idref="lg-11"/>
    </contents>
    ...
  </split_section>
</logical_group_list>

```

A.2.5 Placement Map

The **<placement_map>** element describes the memory placement details of all named memory areas in the application, including unused spaces between logical groups that have been placed in a particular memory area.

The **<memory_area>** is a description of the placement details within a named memory area (container). The description consists of these items:

- The **<name>** names the memory area (string).
- The **<page_id>** gives the id of the memory page in which this memory area is defined (constant).
- The **<origin>** specifies the beginning address of the memory area (constant).
- The **<length>** specifies the length of the memory area (constant).
- The **<used_space>** specifies the amount of allocated space in this area (constant).
- The **<unused_space>** specifies the amount of available space in this area (constant).
- The **<attributes>** lists the RWXI attributes that are associated with this area, if any (string).
- The **<fill_value>** specifies the fill value that is to be placed in unused space, if the fill directive is specified with the memory area (constant).
- The **<usage_details>** lists details of each allocated or available fragment in this memory area. If the fragment is allocated to a logical group, then a **<logical_group_ref>** element is provided to facilitate access to the details of that logical group. All fragment specifications include **<start_address>** and **<size>** elements.
 - The **<allocated_space>** element provides details of an allocated fragment within this memory area (container):
 - The **<start_address>** specifies the address of the fragment (constant).
 - The **<size>** specifies the size of the fragment (constant).
 - The **<logical_group_ref>** provides a reference to the logical group that is allocated to this fragment (reference).
 - The **<available_space>** element provides details of an available fragment within this memory area (container):
 - The **<start_address>** specifies the address of the fragment (constant).
 - The **<size>** specifies the size of the fragment (constant).

Example A-5. Placement Map for the fl-4 Input File

```
<placement_map>
  <memory_area>
    <name>PMEM</name>
    <page_id>0x0</page_id>
    <origin>0x20</origin>
    <length>0x100000</length>
    <used_space>0xb240</used_space>
    <unused_space>0xf4dc0</unused_space>
    <attributes>RWXI</attributes>
    <usage_details>
      <allocated_space>
        <start_address>0x20</start_address>
        <size>0xb240</size>
        <logical_group_ref idref="lg-7"/>
      </allocated_space>
      <available_space>
        <start_address>0xb260</start_address>
        <size>0xf4dc0</size>
      </available_space>
    </usage_details>
  </memory_area>
  ...
</placement_map>
```

A.2.6 Far Call Trampoline List

The **<far_call_trampoline_list>** is a list of **<far_call_trampoline>** elements. The linker supports the generation of far call trampolines to help a call site reach a destination that is out of range. A far call trampoline function is guaranteed to reach the called function (callee) as it may utilize an indirect call to the called function.

The **<far_call_trampoline_list>** enumerates all of the far call trampolines that are generated by the linker for a particular link. The **<far_call_trampoline_list>** can contain any number of **<far_call_trampoline>** elements. Each **<far_call_trampoline>** is a container enclosing the following elements:

- The **<callee_name>** element names the destination function (string).
- The **<callee_address>** is the address of the called function (constant).
- The **<trampoline_object_component_ref>** is a reference to an object component that contains the definition of the trampoline function (reference).
- The **<trampoline_address>** is the address of the trampoline function (constant).
- The **<caller_list>** enumerates all call sites that utilize this trampoline to reach the called function (container).
- The **<trampoline_call_site>** provides the details of a trampoline call site (container) and consists of these items:
 - The **<caller_address>** specifies the call site address (constant).
 - The **<caller_object_component_ref>** is the object component where the call site resides (reference).

Example A-6. Fall Call Trampoline List for the fl-4 Input File

```
<far_call_trampoline_list>
...
  <far_call_trampoline>
    <callee_name>_foo</callee_name>
    <callee_address>0x08000030</callee_address>
    <trampoline_object_component_ref idref="oc-123"/>
    <trampoline_address>0x2020</trampoline_address>
    <caller_list>
      <call_site>
        <caller_address>0x1800</caller_address>
        <caller_object_component_ref idref="oc-23"/>
      </call_site>
      <call_site>
        <caller_address>0x1810</caller_address>
        <caller_object_component_ref idref="oc-23"/>
      </call_site>
    </caller_list>
  </far_call_trampoline>
...
</far_call_trampoline_list>
```

A.2.7 Symbol Table

The **<symbol_table>** contains a list of all of the global symbols that are included in the link. The list provides information about a symbol's name and value. In the future, the symbol_table list may provide type information, the object component in which the symbol is defined, storage class, etc.

The **<symbol>** is a container element that specifies the name and value of a symbol with these elements:

- The **<name>** element specifies the symbol name (string).
- The **<value>** element specifies the symbol value (constant).

Example A-7. Symbol Table for the fl-4 Input File

```
<symbol_table>
  <symbol>
    <name>_c_int00</name>
    <value>0xaf80</value>
  </symbol>
  <symbol>
    <name>_main</name>
    <value>0xb1e0</value>
  </symbol>
  <symbol>
    <name>_printf</name>
    <value>0xac00</value>
  </symbol>
  ...
</symbol_table>
```


Unsupported Tools and Features

B.1 List of Unsupported Tools and Features

The following tools and features will not be supported by the C7000 compiler toolset:

- Compiler Consultant
- Profile Directed Compilation
- CCS Optimizer Assistant
- Cache Layout Tool
- Hex Utility (We recommend that you instead use third-party tools, such as GNU “objcopy” or ARM Ltd. Tools.)
- Cross Reference Tool
- Absolute Lister
- C6x Linear Assembly
- C7x Linear Assembly
- C6x (Legacy) Assembly Compatibility
- MISRA-C:2012 checking (We recommend that you use third-party tooling, such as LDRA.)

Glossary

C.1 Terminology

Application Binary Interface (ABI)— A standard that specifies the interface between two object modules. An ABI specifies how functions are called and how information is passed from one program component to another.

assignment statement— A statement that initializes a variable with a value.

autoinitialization— The process of initializing global C variables (contained in the .cinit section) before program execution begins.

autoinitialization at run time— An autoinitialization method used by the linker when linking C code. The linker uses this method when you invoke it with the `--rom_model` link option. The linker loads the .cinit section of data tables into memory, and variables are initialized at run time.

alias disambiguation— A technique that determines when two pointer expressions cannot point to the same location, allowing the compiler to freely optimize such expressions.

aliasing— The ability for a single object to be accessed in more than one way, such as when two pointers point to a single object. It can disrupt optimization, because any indirect reference could refer to any other object.

allocation— A process in which the linker calculates the final memory addresses of output sections.

ANSI— American National Standards Institute; an organization that establishes standards voluntarily followed by industries.

archive library— A collection of individual files grouped into a single file by the archiver.

archiver— A software program that collects several individual files into a single file called an archive library. With the archiver, you can add, delete, extract, or replace members of the archive library.

assembler— A software program that creates a machine-language program from a source file that contains assembly language instructions, directives, and macro definitions. The assembler substitutes absolute operation codes for symbolic operation codes and absolute or relocatable addresses for symbolic addresses.

assignment statement— A statement that initializes a variable with a value.

autoinitialization— The process of initializing global C variables (contained in the .cinit section) before program execution begins.

autoinitialization at run time— An autoinitialization method used by the linker when linking C code. The linker uses this method when you invoke it with the `--rom_model` link option. The linker loads the .cinit section of data tables into memory, and variables are initialized at run time.

big endian— An addressing protocol in which bytes are numbered from left to right within a word. More significant bytes in a word have lower numbered addresses. Endian ordering is hardware-specific and is determined at reset. See also *little endian*

block— A set of statements that are grouped together within braces and treated as an entity.

.bss section— One of the default object file sections. You use the assembler `.bss` directive to reserve a specified amount of space in the memory map that you can use later for storing data. The `.bss` section is uninitialized.

- byte**— Per ANSI/ISO C, the smallest addressable unit that can hold a character.
- C/C++ compiler**— A software program that translates C source statements into assembly language source statements.
- code generator**— A compiler tool that takes the file produced by the parser or the optimizer and produces an assembly language source file.
- command file**— A file that contains options, filenames, directives, or commands for the linker or hex conversion utility.
- comment**— A source statement (or portion of a source statement) that documents or improves readability of a source file. Comments are not compiled, assembled, or linked; they have no effect on the object file.
- compiler program**— A utility that lets you compile, assemble, and optionally link in one step. The compiler runs one or more source modules through the compiler (including the parser, optimizer, and code generator), the assembler, and the linker.
- configured memory**— Memory that the linker has specified for allocation.
- constant**— A type whose value cannot change.
- cross-reference listing**— An output file created by the assembler that lists the symbols that were defined, what line they were defined on, which lines referenced them, and their final values.
- .data section**— One of the default object file sections. The .data section is an initialized section that contains initialized data. You can use the .data directive to assemble code into the .data section.
- direct call**— A function call where one function calls another using the function's name.
- directives**— Special-purpose commands that control the actions and functions of a software tool (as opposed to assembly language instructions, which control the actions of a device).
- disambiguation**— See *alias disambiguation*
- dynamic memory allocation**— A technique used by several functions (such as malloc, calloc, and realloc) to dynamically allocate memory for variables at run time. This is accomplished by defining a large memory pool (heap) and using the functions to allocate memory from the heap.
- ELF**— Executable and Linkable Format; a system of object files configured according to the System V Application Binary Interface specification.
- emulator**— A hardware development system that duplicates the device's operation.
- entry point**— A point in target memory where execution starts.
- environment variable**— A system symbol that you define and assign to a string. Environmental variables are often included in Windows batch files or UNIX shell scripts such as .cshrc or .profile.
- epilog**— The portion of code in a function that restores the stack and returns.
- executable object file**— A linked, executable object file that is downloaded and executed on a target system.
- expression**— A constant, a symbol, or a series of constants and symbols separated by arithmetic operators.
- external symbol**— A symbol that is used in the current program module but defined or declared in a different program module.
- file-level optimization**— A level of optimization where the compiler uses the information that it has about the entire file to optimize your code (as opposed to program-level optimization, where the compiler uses information that it has about the entire program to optimize your code).

- function inlining**— The process of inserting code for a function at the point of call. This saves the overhead of a function call and allows the optimizer to optimize the function in the context of the surrounding code.
- global symbol**— A symbol that is either defined in the current module and accessed in another, or accessed in the current module but defined in another.
- high-level language debugging**— The ability of a compiler to retain symbolic and high-level language information (such as type and function definitions) so that a debugging tool can use this information.
- indirect call**— A function call where one function calls another function by giving the address of the called function.
- initialization at load time**— An autoinitialization method used by the linker when linking C/C++ code. The linker uses this method when you invoke it with the `--ram_model` link option. This method initializes variables at load time instead of run time.
- initialized section**— A section from an object file that will be linked into an executable object file.
- input section**— A section from an object file that will be linked into an executable object file.
- integrated preprocessor**— A C/C++ preprocessor that is merged with the parser, allowing for faster compilation. Stand-alone preprocessing or preprocessed listing is also available.
- interlist feature**— A feature that inserts as comments your original C/C++ source statements into the assembly language output from the assembler. The C/C++ statements are inserted next to the equivalent assembly instructions.
- intrinsics**— Operators that are used like functions and produce assembly language code that would otherwise be inexpressible in C, or would take greater time and effort to code.
- ISO**— International Organization for Standardization; a worldwide federation of national standards bodies, which establishes international standards voluntarily followed by industries.
- kernel**— The body of a software-pipelined loop between the pipelined-loop prolog and the pipelined-loop epilog.
- K&R C**— Kernighan and Ritchie C, the de facto standard as defined in the first edition of *The C Programming Language* (K&R). Most K&R C programs written for earlier, non-ISO C compilers should correctly compile and run without modification.
- label**— A symbol that begins in column 1 of an assembler source statement and corresponds to the address of that statement. A label is the only assembler statement that can begin in column 1.
- linker**— A software program that combines object files to form an executable object file that can be allocated into system memory and executed by the device.
- listing file**— An output file, created by the assembler, which lists source statements, their line numbers, and their effects on the section program counter (SPC).
- little endian**— An addressing protocol in which bytes are numbered from right to left within a word. More significant bytes in a word have higher numbered addresses. Endian ordering is hardware-specific and is determined at reset. See also *big endian*.
- loader**— A device that places an executable object file into system memory.
- loop unrolling**— An optimization that expands small loops so that each iteration of the loop appears in your code. Although loop unrolling increases code size, it can improve the performance of your code.
- macro**— A user-defined routine that can be used as an instruction.
- macro call**— The process of invoking a macro.

- macro definition**— A block of source statements that define the name and the code that make up a macro.
- macro expansion**— The process of inserting source statements into your code in place of a macro call.
- map file**— An output file, created by the linker, which shows the memory configuration, section composition, section allocation, symbol definitions and the addresses at which the symbols were defined for your program.
- memory map**— A map of target system memory space that is partitioned into functional blocks.
- name mangling**— A compiler-specific feature that encodes a function name with information regarding the function's arguments return types.
- object file**— An assembled or linked file that contains machine-language object code.
- object library**— An archive library made up of individual object files.
- operand**— An argument of an assembly language instruction, assembler directive, or macro directive that supplies information to the operation performed by the instruction or directive.
- optimizer**— A software tool that improves the execution speed and reduces the size of C programs.
- options**— Command-line parameters that allow you to request additional or specific functions when you invoke a software tool.
- output section**— A final, allocated section in a linked, executable module.
- parser**— A software tool that reads the source file, performs preprocessing functions, checks the syntax, and produces an intermediate file used as input for the optimizer or code generator.
- partitioning**— The process of assigning a data path to each instruction.
- pipelining**— A technique where a second instruction begins executing before the first instruction has been completed. You can have several instructions in the pipeline, each at a different processing stage.
- pop**— An operation that retrieves a data object from a stack.
- pragma**— A preprocessor directive that provides directions to the compiler about how to treat a particular statement.
- preprocessor**— A software tool that interprets macro definitions, expands macros, interprets header files, interprets conditional compilation, and acts upon preprocessor directives.
- program-level optimization**— An aggressive level of optimization where all of the source files are compiled into one intermediate file. Because the compiler can see the entire program, several optimizations are performed with program-level optimization that are rarely applied during file-level optimization.
- prolog**— The portion of code in a function that sets up the stack.
- push**— An operation that places a data object on a stack for temporary storage.
- quiet run**— An option that suppresses the normal banner and the progress information.
- raw data**— Executable code or initialized data in an output section.
- relocation**— A process in which the linker adjusts all the references to a symbol when the symbol's address changes.
- run-time environment**— The run time parameters in which your program must function. These parameters are defined by the memory and register conventions, stack organization, function call conventions, and system initialization.

- run-time-support functions**— Standard ISO functions that perform tasks that are not part of the C language (such as memory allocation, string conversion, and string searches).
- run-time-support library**— A library file, `rts.src`, which contains the source for the run time-support functions.
- section**— A relocatable block of code or data that ultimately will be contiguous with other sections in the memory map.
- sign extend**— A process that fills the unused MSBs of a value with the value's sign bit.
- software pipelining**— A technique used by the C/C++ optimizer to schedule instructions from a loop so that multiple iterations of the loop execute in parallel.
- source file**— A file that contains C/C++ code or assembly language code that is compiled or assembled to form an object file.
- stand-alone preprocessor**— A software tool that expands macros, `#include` files, and conditional compilation as an independent program. It also performs integrated preprocessing, which includes parsing of instructions.
- static variable**— A variable whose scope is confined to a function or a program. The values of static variables are not discarded when the function or program is exited; their previous value is resumed when the function or program is reentered.
- storage class**— An entry in the symbol table that indicates how to access a symbol.
- string table**— A table that stores symbol names that are longer than eight characters (symbol names of eight characters or longer cannot be stored in the symbol table; instead they are stored in the string table). The name portion of the symbol's entry points to the location of the string in the string table.
- structure**— A collection of one or more variables grouped together under a single name.
- subsection**— A relocatable block of code or data that ultimately will occupy continuous space in the memory map. Subsections are smaller sections within larger sections. Subsections give you tighter control of the memory map.
- symbol**— A string of alphanumeric characters that represents an address or a value.
- symbolic debugging**— The ability of a software tool to retain symbolic information that can be used by a debugging tool such as an emulator.
- target system**— The system on which the object code you have developed is executed.
- .text section**— One of the default object file sections. The `.text` section is initialized and contains executable code. You can use the `.text` directive to assemble code into the `.text` section.
- trigraph sequence**— A 3-character sequence that has a meaning (as defined by the ISO 646-1983 Invariant Code Set). These characters cannot be represented in the C character set and are expanded to one character. For example, the trigraph `??'` is expanded to `^`.
- trip count**— The number of times that a loop executes before it terminates.
- unconfigured memory**— Memory that is not defined as part of the memory map and cannot be loaded with code or data.
- uninitialized section**— A object file section that reserves space in the memory map but that has no actual contents.
- unsigned value**— A value that is treated as a nonnegative number, regardless of its actual sign.
- variable**— A symbol representing a quantity that can assume any of a set of values.
- word**— A 32-bit addressable location in target memory

Revision History

D.1 Revisions

[Table D-1](#) lists significant changes made to this document. The left column identifies the first version of this document in which that particular change appeared.

Table D-1. Revision History

Version Added	Chapter	Location	Additions / Modifications / Deletions
SPRUIG8A	Introduction, Language	Section 1.3 , Section 5.1 , and Section 5.2	Support for C11 and C++14 has been added.
SPRUIG8A	Optimization	Section 4.14	Information about the vector length and element size for the Steaming Engine and Stream Address Generator has been added.

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