TMS320C6000 Assembly Language Tools v7.6

User's Guide

TEXAS INSTRUMENTS

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SPRU186X–March 2014

Read This First

About This Manual

The *TMS320C6000 Assembly Language Tools User's Guide* explains how to use these object file tools:

- Assembler
- Archiver
- Linker
- Library information archiver
- Absolute lister
- Cross-reference lister
- Disassembler
- Object file display utility
- Name utility
- Strip utility
- Hex conversion utility

How to Use This Manual

This book helps you learn how to use the Texas Instruments object file and assembly language tools designed specifically for the TMS320C6000 ™ 32-bit devices. This book consists of four parts:

- **Introductory information**, consisting of Chapter 1 through Chapter 3, gives you an overview of the object file and assembly language development tools. It also discusses object modules, which helps you to use the TMS320C6000 tools more effectively and program loading, initialization, and startup. In particular, read Chapter 2 before using the assembler and linker.
- **Assembler description**, consisting of Chapter 4 through Chapter 6, contains detailed information about using the assembler. This portion explains how to invoke the assembler and discusses source statement format, valid constants and expressions, assembler output, and assembler directives. It also describes the macro language.
- **Linker and other object file tools description**, consisting of Chapter 7 through Chapter 12, describes in detail each of the tools provided with the assembler to help you create executable object files. For example, Chapter 8 explains how to invoke the linker, how the linker operates, and how to use linker directives; Chapter 12 explains how to use the hex conversion utility.
- **Reference material**, consisting of Appendix A through Appendix C, provides supplementary information including symbolic debugging directives that the TMS320C6000 C/C++ compiler uses. It also provides a description of the XML link information file and a glossary.

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, cruel world\n");
  }
  ```

- In syntax descriptions, the instruction, command, or directive is 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:

cl6x [*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:

cl6x --run_linker {**--rom_model | --ram_model**} *filenames* [**--output_file=** *name.out*]
--library= *libraryname*

- In assembler syntax statements, column 1 is reserved for the first character of a label or symbol. If the label or symbol is optional, it is usually not shown. If it is a required parameter, it is shown starting against the left margin of the box, as in the example below. No instruction, command, directive, or parameter, other than a symbol or label, can begin in column 1.

symbol **.usect** "*section name*", *size in bytes*[, *alignment*]

- Some directives can have a varying number of parameters. For example, the .byte directive can have multiple parameters. This syntax is shown as [, ..., *parameter*].
- The TMS320C6200 core is referred to as C6200. The TMS320C6400 core is referred to as C6400. The TMS320C6700 core is referred to as C6700. TMS320C6000 and C6000 can refer to either C6200, C6400, C6400+, C6700, C6700+, C6740, or C6600.
- Following are other symbols and abbreviations used throughout this document:

Symbol	Definition
B,b	Suffix — binary integer
H, h	Suffix — hexadecimal integer
LSB	Least significant bit
MSB	Most significant bit
0x	Prefix — hexadecimal integer
Q, q	Suffix — octal integer

Related Documentation From Texas Instruments

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

SPRU187 —TMS320C6000 Optimizing C/C++ Compiler User's Guide. Describes the TMS320C6000 C/C++ compiler and the assembly optimizer. This C/C++ compiler accepts ANSI standard C/C++ source code and produces assembly language source code for the TMS320C6000 platform of devices (including the C64x+ and C67x+ generations). The assembly optimizer helps you optimize your assembly code.

SPRAB89— C6000 Embedded Application Binary Interface. Provides a specification for the ELF-based Embedded Application Binary Interface (EABI) for the C6000 family of processors from Texas Instruments. The EABI defines the low-level interface between programs, program components, and the execution environment, including the operating system if one is present.

SPRU190 —TMS320C6000 DSP Peripherals Overview Reference Guide. Provides an overview and briefly describes the peripherals available on the TMS320C6000 family of digital signal processors (DSPs).

SPRU198 —TMS320C6000 Programmer's Guide. Reference for programming the TMS320C6000 digital signal processors (DSPs). Before you use this manual, you should install your code generation and debugging tools. Includes a brief description of the C6000 DSP architecture and code development flow, includes C code examples and discusses optimization methods for the C code, describes the structure of assembly code and includes examples and discusses optimizations for the assembly code, and describes programming considerations for the C64x DSP.

SPRU731 —TMS320C62x DSP CPU and Instruction Set Reference Guide. Describes the CPU architecture, pipeline, instruction set, and interrupts for the TMS320C62x digital signal processors (DSPs) of the TMS320C6000 DSP family. The C62x DSP generation comprises fixed-point devices in the C6000 DSP platform.

SPRU732 —TMS320C64x/C64x+ DSP CPU and Instruction Set Reference Guide. Describes the CPU architecture, pipeline, instruction set, and interrupts for the TMS320C64x and TMS320C64x+ digital signal processors (DSPs) of the TMS320C6000 DSP family. The C64x/C64x+ DSP generation comprises fixed-point devices in the C6000 DSP platform. The C64x+ DSP is an enhancement of the C64x DSP with added functionality and an expanded instruction set.

SPRU733 —TMS320C67x/C67x+ DSP CPU and Instruction Set Reference Guide. Describes the CPU architecture, pipeline, instruction set, and interrupts for the TMS320C67x and TMS320C67x+ digital signal processors (DSPs) of the TMS320C6000 DSP platform. The C67x/C67x+ DSP generation comprises floating-point devices in the C6000 DSP platform. The C67x+ DSP is an enhancement of the C67x DSP with added functionality and an expanded instruction set.

SPRUGH7 —TMS320C66x CPU and Instruction Set Reference Guide Describes the CPU architecture, pipeline, instruction set, and interrupts for the TMS320C66x digital signal processors (DSPs) of the TMS320C6000 DSP platform. The C66x DSP generation comprises floating-point devices in the C6000 DSP platform.

SPRAAO8 — Common Object File Format Application Report. Provides supplementary information on the internal format of COFF object files. Much of this information pertains to the symbolic debugging information that is produced by the C compiler.

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Introduction to the Software Development Tools

The TMS320C6000™ is supported by a set of software development tools, which includes an optimizing C/C++ compiler, an assembly optimizer, an assembler, a linker, and assorted utilities. This chapter provides an overview of these tools.

The TMS320C6000 is supported by the following assembly language development tools:

- Assembler
- Archiver
- Linker
- Library information archiver
- Absolute lister
- Cross-reference lister
- Object file display utility
- Disassembler
- Name utility
- Strip utility
- Hex conversion utility

This chapter shows how these tools fit into the general software tools development flow and gives a brief description of each tool. For convenience, it also summarizes the C/C++ compiler and debugging tools. For detailed information on the compiler and debugger, and for complete descriptions of the TMS320C6000, refer to the books listed in *Related Documentation From Texas Instruments*.

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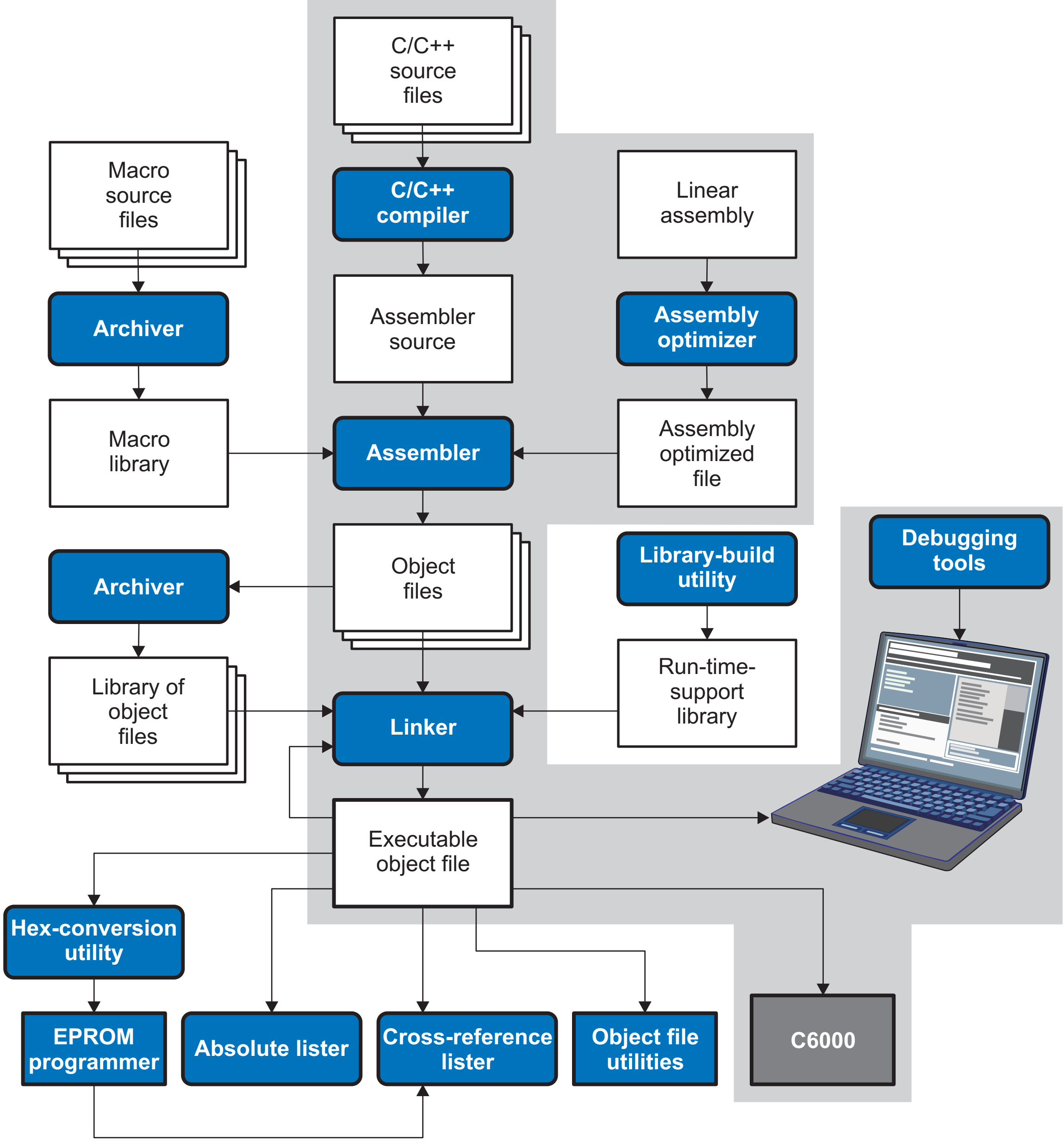
1.1 Software Development Tools Overview

Figure 1-1 shows the TMS320C6000 software development flow. The shaded portion highlights the most common development path; the other portions are optional. The other portions are peripheral functions that enhance the development process.

Figure 1-1. TMS320C6000 Software Development Flow



1.2 Tools Descriptions

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

- The **C/C++ compiler** accepts C/C++ source code and produces TMS320C6000 machine code object modules. A **shell program**, an **optimizer**, and an **interlist utility** are included in the installation:
  - The shell program enables you to compile, assemble, and link source modules in one step.
  - The optimizer modifies code to improve the efficiency of C/C++ programs.
  - The interlist utility interlists C/C++ source statements with assembly language output to correlate code produced by the compiler with your source code.

  See the *TMS320C6000 Optimizing Compiler User's Guide* for more information.
- The **assembly optimizer** allows you to write linear assembly code without being concerned with the pipeline structure or with assigning registers. It accepts assembly code that has not been register-allocated and is unscheduled. The assembly optimizer assigns registers and uses loop optimization to turn linear assembly into highly parallel assembly that takes advantage of software pipelining. See the *TMS320C6000 Optimizing Compiler User's Guide* for more information.
- The **assembler** translates assembly language source files into machine language object modules. Source files can contain instructions, assembler directives, and macro directives. You can use assembler directives to control various aspects of the assembly process, such as the source listing format, data alignment, and section content. See Chapter 4 through Chapter 6. See the *TMS320C62x DSP CPU and Instruction Set Reference Guide*, *TMS320C64x/C64x+ DSP CPU and Instruction Set Reference Guide*, *TMS320C67x/C67x+ DSP CPU and Instruction Set Reference Guide*, and *TMS320C66x CPU and Instruction Set Reference Guide* for detailed information on the assembly language instruction set.
- The **linker** combines object files into a single static executable or dynamic object module. It performs symbolic relocation and resolves external references. The linker accepts relocatable object modules (created by the assembler) as input. It also accepts archiver library members and output modules created by a previous linker run. Link directives allow you to combine object file sections, bind sections or symbols to addresses or within memory ranges, and define or redefine global symbols. See Chapter 8. For more information about creating a dynamic object module, see the C6000 Dynamic Linking wiki topic.
- The **archiver** allows you to collect a group of files into a single archive file, called a library. You can also use the archiver to collect a group of object files into an object library. You can collect several macros into a macro library. The assembler searches the library and uses the members that are called as macros by the source file. The linker extracts object library members to resolve external references during the link. The archiver allows you to modify a library by deleting, replacing, extracting, or adding members. See Section 7.1.
- The **library information archiver** allows you to create an index library of several object file library variants, which is useful when several variants of a library with different options are available. Rather than refer to a specific library, you can link against the index library, and the linker will choose the best match from the indexed libraries. See Section 7.5.
- You can use the **library-build utility** to build your own customized run-time-support library. See the *TMS320C6000 Optimizing Compiler User's Guide* for more information.
- The **hex conversion utility** converts object files to TI-Tagged, ASCII-Hex, Intel, Motorola-S, or Tektronix object format. The converted file can be downloaded to an EPROM programmer. See Chapter 12.
- The **absolute lister** uses linked object files to create .abs files. These files can be assembled to produce a listing of the absolute addresses of object code. See Chapter 9.
- The **cross-reference lister** uses object files to produce a cross-reference listing showing symbols, their definition, and their references in the linked source files. See Chapter 10.
- The main product of this development process is a executable object file that can be executed in a **TMS320C6000** device. You can use one of several debugging tools to refine and correct your code. Available products include:
  - An instruction-accurate and clock-accurate software simulator
  - An XDS emulator

In addition, the following utilities are provided:

- The **object file display utility** prints the contents of object files and object libraries in either human readable or XML formats. See Section 11.1.
- The **disassembler** decodes the machine code from object modules to show the assembly instructions that it represents. See Section 11.2.
- 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 11.3.
- The **strip utility** removes symbol table and debugging information from object files and object libraries. See Section 11.4.

Chapter 2

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Introduction to Object Modules

The assembler creates object modules from assembly code, and the linker creates executable object files from object modules. These executable object files can be executed by a TMS320C6000 device.

Object modules make modular programming easier because they encourage you to think in terms of *blocks* of code and data when you write an assembly language program. These blocks are known as sections. Both the assembler and the linker provide directives that allow you to create and manipulate sections.

This chapter focuses on the concept and use of sections in assembly language programs.

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2.1 Object File Format Specifications

The object files created by the assembler and linker conform to either the ELF (Executable and Linking Format) or COFF (Common Object File Format) binary formats, depending on the ABI selected when building your program. When using the EABI mode, the ELF format is used. For the older COFF ABI mode, the legacy COFF format is used.

Some features of the assembler may apply only to the ELF or COFF object file format. In these cases, the proper object file format is stated in the feature description.

See the *TMS320C6000 Optimizing Compiler User's Guide* and *The C6000 Embedded Application Binary Interface Application Report* for information on the different ABIs available.

See the *Common Object File Format Application Note* (SPRAAO8) for information about the COFF object file format.

The ELF object files generated by the assembler and linker conform to the December 17, 2003 snapshot of the System V generic ABI (or gABI).

2.2 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 3 for details about loading and running programs.

2.3 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 writeable 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.

COFF format executable object files contain *sections*.

Object files usually contain three default sections:

.text section	contains executable code [1]
.data section	usually contains initialized data
.bss section	usually reserves space for uninitialized variables

[1] Some targets allow content other than text, such as constants, in .text sections.

The assembler and linker allow 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; user-named sections created with the .sect assembler directive are also initialized.

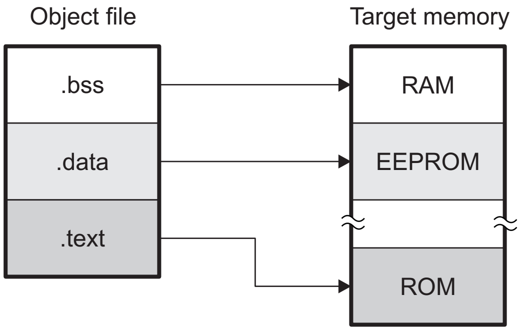
Uninitialized sections reserve space in the memory map for uninitialized data. The .bss section is uninitialized; user-named sections created with the .usect assembler directive are also uninitialized.

Several assembler directives allow you to associate various portions of code and data with the appropriate sections. The assembler builds these sections during the assembly process, creating an object file organized as shown in Figure 2-1.

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 the "Specifying Where to Allocate Sections in Memory" section of the *TMS320C6000 Optimizing Compiler User's Guide* .

Figure 2-1 shows the relationship between sections in an object file and a hypothetical target memory.

Figure 2-1. Partitioning Memory Into Logical Blocks



2.3.1 *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.
- .bss -- Used for uninitialized objects (global variables).
- .data -- Used for initialized non-const 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 the "Specifying Where to Allocate Sections in Memory" section of the *TMS320C6000 Optimizing Compiler User's Guide* .

2.4 How the Assembler Handles Sections

The assembler identifies the portions of an assembly language program that belong in a given section. The assembler has the following directives that support this function:

- .bss
- .data
- .sect
- .text
- .usect

The .bss and .usect directives create *uninitialized sections*; the .text, .data, and .sect directives create *initialized sections*.

You can create subsections of any section to give you tighter control of the memory map. Subsections are created using the .sect and .usect directives. Subsections are identified with the base section name and a subsection name separated by a colon; see Section 2.4.6.

Default Sections Directive

NOTE: If you do not use any of the sections directives, the assembler assembles everything into the .text section.

2.4.1 Uninitialized Sections

Uninitialized sections reserve space in TMS320C6000 memory; they are usually placed in RAM. These sections have no actual contents in the object file; they simply reserve memory. A program can use this space at run time for creating and storing variables.

Uninitialized data areas are built by using the following assembler directives.

- The .bss directive reserves space in the .bss section.
- The .usect directive reserves space in a specific uninitialized user-named section.

Each time you invoke the .bss or .usect directive, the assembler reserves additional space in the .bss or the user-named section. The syntaxes for these directives are:

	.bss *symbol*, *size in bytes*[, *alignment*[, *bank offset*]]
symbol	**.usect "***section name***"**, *size in bytes*[, *alignment*[, *bank offset*]]

symbol points to the first byte reserved by this invocation of the .bss or .usect directive. The *symbol* corresponds to the name of the variable that you are reserving space for. It can be referenced by any other section and can also be declared as a global symbol (with the .global directive).

size in bytes is an absolute expression (see Section 4.9). The .bss directive reserves *size in bytes* bytes in the .bss section. The .usect directive reserves *size in bytes* bytes in *section name*. For both directives, you must specify a size; there is no default value.

alignment is an optional parameter. It specifies the minimum alignment in bytes required by the space allocated. The default value is byte aligned; this option is represented by the value 1. The value must be a power of 2.

bank offset is an optional parameter. It ensures that the space allocated to the symbol occurs on a specific memory bank boundary. The *bank offset* measures the number of bytes to offset from the alignment specified before assigning the symbol to that location.

section name tells the assembler the user-named section in which to reserve space. See Section 2.4.3.

The initialized section directives (.text, .data, and .sect) change which section is considered the *current* section. (See Section 2.4.2). However, the .bss and .usect directives *do not* change which section is considered the current section; they simply escape from the current section temporarily. Immediately after a .bss or .usect directive, the assembler resumes assembling into whatever the current section was before the directive. The .bss and .usect directives can appear anywhere in an initialized section without affecting its contents. For an example, see Section 2.4.7.

The .usect directive can also be used to create uninitialized subsections. See Section 2.4.6, for more information on creating subsections.

The .nearcommon and .farcommon directives (ELF only) are similar to directives that create uninitialized data sections, except that common symbols are created, instead.

2.4.2 Initialized Sections

Initialized sections contain executable code or initialized data. The contents of these sections are stored in the object file and placed in TMS320C6000 memory when the program is loaded. Each initialized section is independently relocatable and may reference symbols that are defined in other sections. The linker automatically resolves these references.

The following directives tell the assembler to place code or data into a section. The syntaxes for these directives are:

.text

.data

.sect "*section name***"**

The .sect directive can also be used to create initialized subsections. See Section 2.4.6, for more information on creating subsections.

2.4.3 User-Named Sections

User-named sections are sections that *you* create. You can use them like the default .text, .data, and .bss sections, but each section with a distinct name is kept distinct during assembly.

For example, repeated use of the .text directive builds up a single .text section in the object file. This .text section is allocated in memory as a single unit. Suppose there is a portion of executable code (perhaps an initialization routine) that you want the linker to place in a different location than the rest of .text. If you assemble this segment of code into a user-named section, it is assembled separately from .text, and you can use the linker to allocate it into memory separately. You can also assemble initialized data that is separate from the .data section, and you can reserve space for uninitialized variables that is separate from the .bss section.

These directives let you create user-named sections:

- The **.usect** directive creates uninitialized sections that are used like the .bss section. These sections reserve space in RAM for variables.
- The **.sect** directive creates initialized sections, like the default .text and .data sections, that can contain code or data. The .sect directive creates user-named sections with relocatable addresses.

The syntaxes for these directives are:

symbol **.usect "***section name***",** *size in bytes*[**,** *alignment*[**,** *bank offset*]]

.sect "*section name***"**

For COFF, you can create up to 32 767 distinct named sections. For ELF, the max number of sections is 2^{32}-1 (4294967295).

The *section name* parameter is the name of the section. For the .usect and .sect directives, a section name can refer to a subsection; see Section 2.4.6 for details.

Each time you invoke one of these directives with a new name, you create a new user-named section. Each time you invoke one of these directives with a name that was already used, the assembler resumes assembling code or data (or reserves space) into the section with that name. *You cannot use the same names with different directives*. That is, you cannot create a section with the .usect directive and then try to use the same section with .sect.

2.4.4 Current Section

The assembler adds code or data to one section at a time. The section the assembler is currently filling is the *current section*. The .text, .data, and .sect directives change which section is considered the current section. When the assembler encounters one of these directives, it stops assembling into the current section (acting as an implied end of current section command). The assembler sets the designated section as the current section and assembles subsequent code into the designated section until it encounters another .text, .data, or .sect directive.

If one of these directives sets the current section to a section that already has code or data in it from earlier in the file, the assembler resumes adding to the end of that section. The assembler generates only one contiguous section for each given section name. This section is formed by concatenating all of the code or data which was placed in that section.

2.4.5 Section Program Counters

The assembler maintains a separate program counter for each section. These program counters are known as *section program counters*, or *SPCs*.

An SPC represents the current address within a section of code or data. Initially, the assembler sets each SPC to 0. As the assembler fills a section with code or data, it increments the appropriate SPC. If you resume assembling into a section, the assembler remembers the appropriate SPC's previous value and continues incrementing the SPC from that value.

The assembler treats each section as if it began at address 0; the linker relocates the symbols in each section according to the final address of the section in which that symbol is defined. See Section 2.7 for information on relocation.

2.4.6 Subsections

A subsection is created by creating a section with a colon in its name. Subsections are logical subdivisions of larger sections. Subsections are themselves sections and can be manipulated by the assembler and linker.

The assembler has no concept of subsections; to the assembler, the colon in the name is not special. The subsection .text:rts would be considered completely unrelated to its parent section .text, and the assembler will not combine subsections with their parent sections.

Subsections are used to keep parts of a section as distinct sections so that they can be separately manipulated. For instance, by placing each function and object in a uniquely-named subsection, the linker gets a finer-grained view of the section for memory placement and unused-function elimination.

By default, when the linker sees a SECTION directive in the linker command file like ".text", it will gather .text and all subsections of .text into one large output section named ".text". You can instead use the SECTION directive to control the subsection independently. See Section 8.5.4.1 for an example.

You can create subsections in the same way you create other user-named sections: by using the .sect or .usect directive.

The syntaxes for a subsection name are:

symbol	**.usect "***section_name***:***subsection_name***",***size in bytes*[**,***alignment*[**,***bank offset*]]
	.sect "*section_name***:***subsection_name***"**

A subsection is identified by the base section name followed by a colon and the name of the subsection. The subsection name may not contain any spaces.

A subsection can be allocated separately or grouped with other sections using the same base name. For example, you create a subsection called _func within the .text section:

```
.sect ".text:_func"
```

Using the linker's SECTIONS directive, you can allocate .text:_func separately, or with all the .text sections.

You can create two types of subsections:

- Initialized subsections are created using the .sect directive. See Section 2.4.2.
- Uninitialized subsections are created using the .usect directive. See Section 2.4.1.

Subsections are placed in the same manner as sections. See Section 8.5.4 for information on the SECTIONS directive.

2.4.7 Using Sections Directives

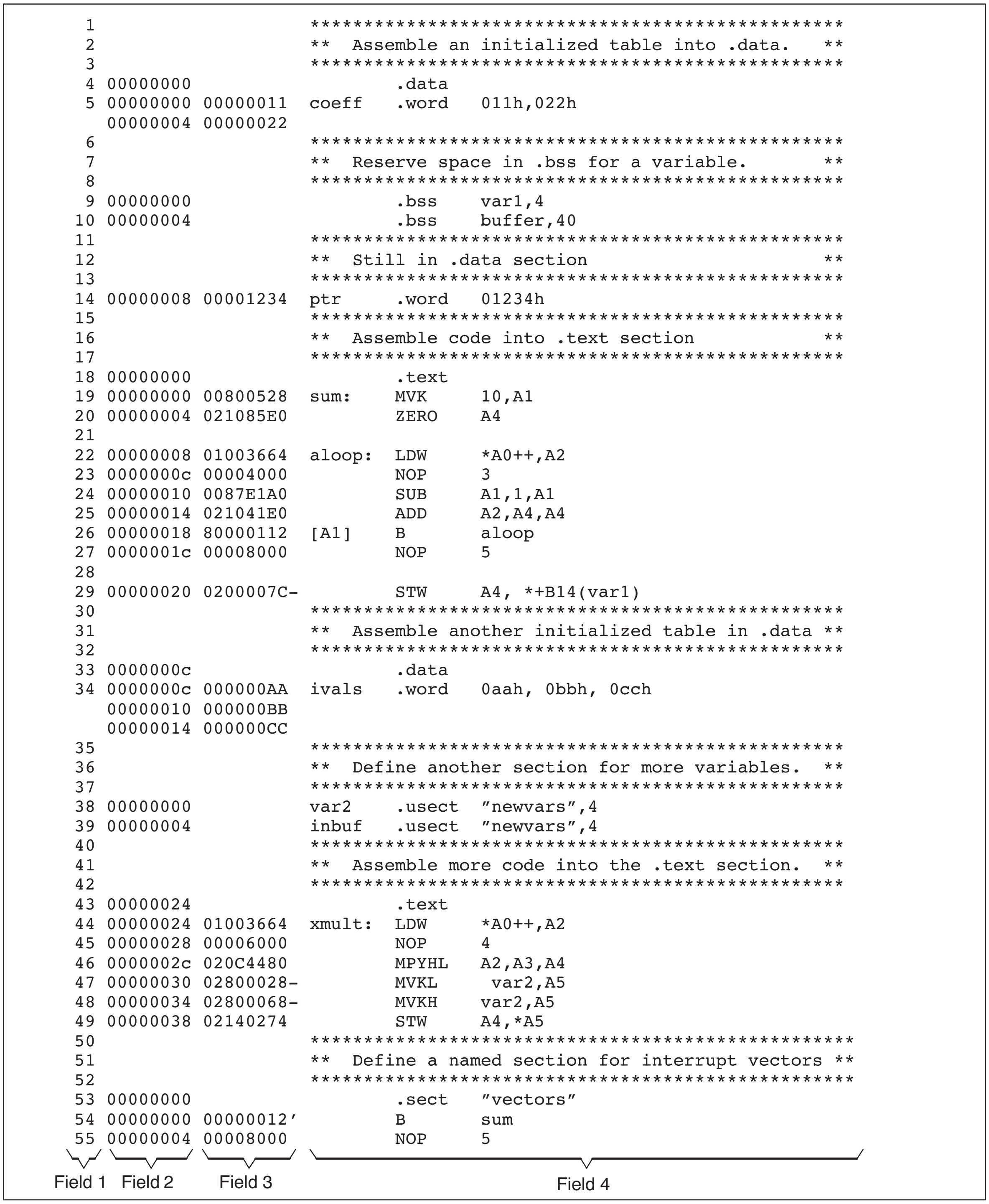
Figure 2-2 shows how you can build sections incrementally, using the sections directives to swap back and forth between the different sections. You can use sections directives to begin assembling into a section for the first time, or to continue assembling into a section that already contains code. In the latter case, the assembler simply appends the new code to the code that is already in the section.

The format in Figure 2-2 is a listing file. Figure 2-2 shows how the SPCs are modified during assembly. A line in a listing file has four fields:

Field 1	contains the source code line counter.
Field 2	contains the section program counter.
Field 3	contains the object code.
Field 4	contains the original source statement.

See Section 4.11 for more information on interpreting the fields in a source listing.

Figure 2-2. Using Sections Directives Example



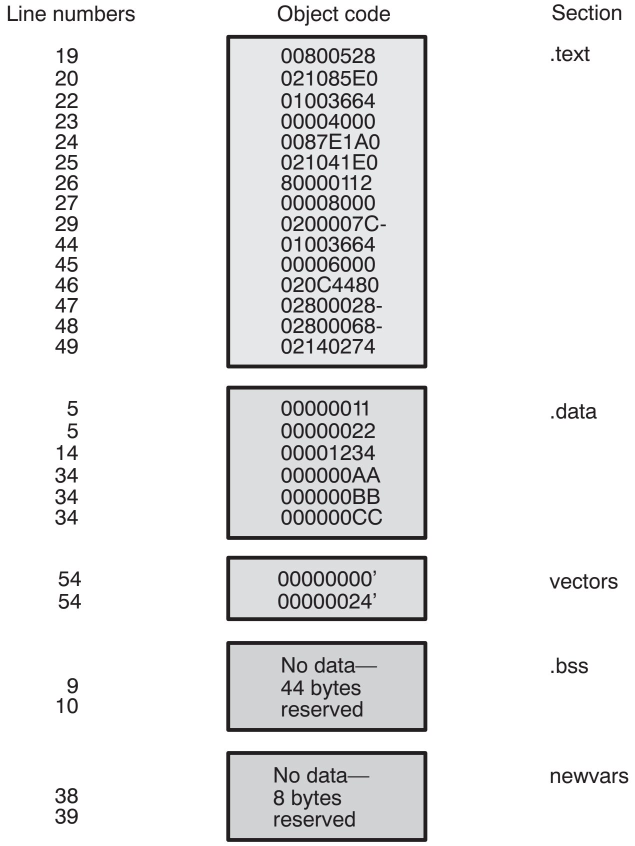
```
 1                    **************************************************
 2                    **  Assemble an initialized table into .data.   **
 3                    **************************************************
 4 00000000                   .data
 5 00000000 00000011  coeff   .word   011h,022h
   00000004 00000022
 6                    **************************************************
 7                    **  Reserve space in .bss for a variable.       **
 8                    **************************************************
 9 00000000                   .bss    var1,4
10 00000004                   .bss    buffer,40
11                    **************************************************
12                    **  Still in .data section                      **
13                    **************************************************
14 00000008 00001234  ptr     .word   01234h
15                    **************************************************
16                    **  Assemble code into .text section            **
17                    **************************************************
18 00000000                   .text
19 00000000 00800528  sum:    MVK     10,A1
20 00000004 021085E0          ZERO    A4
21
22 00000008 01003664  aloop:  LDW     *A0++,A2
23 0000000c 00004000          NOP     3
24 00000010 0087E1A0          SUB     A1,1,A1
25 00000014 021041E0          ADD     A2,A4,A4
26 00000018 80000112  [A1]    B       aloop
27 0000001c 00008000          NOP     5
28
29 00000020 0200007C-         STW     A4, *+B14(var1)
30                    **************************************************
31                    **  Assemble another initialized table in .data **
32                    **************************************************
33 0000000c                   .data
34 0000000c 000000AA  ivals   .word   0aah, 0bbh, 0cch
   00000010 000000BB
   00000014 000000CC
35                    **************************************************
36                    **  Define another section for more variables.  **
37                    **************************************************
38 00000000           var2    .usect  ”newvars”,4
39 00000004           inbuf   .usect  ”newvars”,4
40                    **************************************************
41                    **  Assemble more code into the .text section.  **
42                    **************************************************
43 00000024                   .text
44 00000024 01003664  xmult:  LDW     *A0++,A2
45 00000028 00006000          NOP     4
46 0000002c 020C4480          MPYHL   A2,A3,A4
47 00000030 02800028-         MVKL     var2,A5
48 00000034 02800068-         MVKH    var2,A5
49 00000038 02140274          STW     A4,*A5
50                    ***************************************************
51                    **  Define a named section for interrupt vectors **
52                    ***************************************************
53 00000000                   .sect   ”vectors”
54 00000000 00000012’         B       sum
55 00000004 00008000          NOP     5
```

As Figure 2-3 shows, the file in Figure 2-2 creates five sections:

.text	contains 15 32-bit words of object code.
.data	contains six words of initialized data.
vectors	is a user-named section created with the .sect directive; it contains two words of object code.
.bss	reserves 44 bytes in memory.
newvars	is a user-named section created with the .usect directive; it contains eight bytes in memory.

The second column shows the object code that is assembled into these sections; the first column shows the source statements that generated the object code.

Figure 2-3. Object Code Generated by the File in Figure 2-2



Line numbers	Object code	Section
19	00800528	.text
20	021085E0	
22	01003664	
23	00004000	
24	0087E1A0	
25	021041E0	
26	80000112	
27	00008000	
29	0200007C-	
44	01003664	
45	00006000	
46	020C4480	
47	02800028-	
48	02800068-	
49	02140274	
5	00000011	.data
5	00000022	
14	00001234	
34	000000AA	
34	000000BB	
34	000000CC	
54	00000000’	vectors
54	00000024’	
9 10	No data— 44 bytes reserved	.bss
38 39	No data— 8 bytes reserved	newvars

2.5 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 allow you to 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 explicitly, then the subsection is combined with the other sections with the same base section name. See Section 8.5.4.1.

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 8.7. 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:

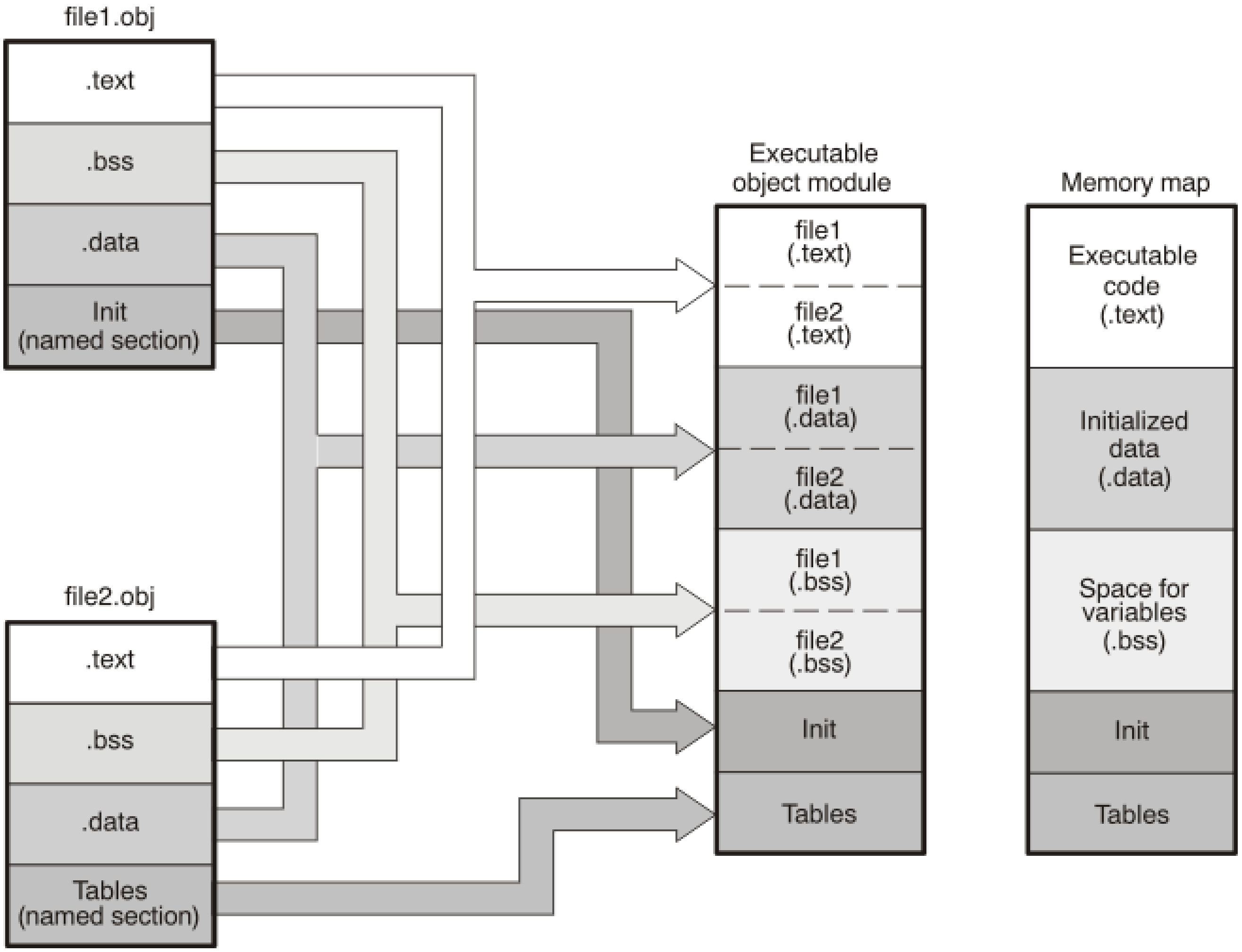
- Section 8.5, *Linker Command Files*
- Section 8.5.3, *The MEMORY Directive*
- Section 8.5.4, *The SECTIONS Directive*
- Section 8.7, *Default Placement Algorithm*

2.5.1 Combining Input Sections

Figure 2-4 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 8.7 for the actual default memory placement map for TMS320C6000.

Figure 2-4. Combining Input Sections to Form an Executable Object Module



In Figure 2-4, file1.obj and file2.obj have been assembled to be used as linker input. Each contains the .text, .data, and .bss 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 .bss sections, and finally places the user-named sections at the end. The memory map shows the combined sections to be placed into memory.

2.5.2 Placing Sections

Figure 2-4 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, EPROM, 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 8.5.3 and Section 8.5.4. See Section 8.7 for the actual default memory allocation map for TMS320C6000.

2.6 Symbols

An object file contains a symbol table that stores information about *external symbols* in the object file. The linker uses this table when it performs relocation. See Section 2.7.

An object file symbol is a named 32-bit integer value, usually representing an address. A symbol can represent such things as the starting address of a function, variable, or section.

An object file symbol can also represent an absolute integer, such as the size of the stack. To the linker, this integer is an unsigned value, 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 2^32-1 for unsigned treatment and -2^31 to 2^31-1 for signed treatment.

Symbols can be bound as *global symbols*, *local symbols*, or *weak symbols*. The linker handles symbols differently based on their binding. For example, the linker does not allow multiple global definitions of a symbol, but local symbols can be defined in multiple object files (but only once per object file). The linker does not resolve references to local symbols in different object files, but it does resolve references to global symbols in any other object file.

A global *symbol* is defined in the same manner as any other symbol; that is, it appears as a label or is defined by a directive, such as .set, .equ, .bss, or .usect. If a global symbol is defined more than once, the linker issues a multiple-definition error. (The assembler can provide a similar multiple-definition error for local symbols.)

A weak symbol is a symbol that is used in the current module but is defined in another module. The linker resolves this symbol's definition at link time. Weak symbols are similar to global symbols, except that if one object file contains a weak symbol, and another object file contains a global symbol with the same name, the global symbol is used to resolve references. A weak 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.

See Section 4.8 for information about assembler symbols.

2.6.1 External Symbols

External symbols are symbols that are visible to other object modules. Because they are visible across object modules, they may be defined in one file and referenced in another file. You can use the .def, .ref, or .global directive to identify a symbol as external:

.def The symbol is defined in the current file and may be used in another file.

.ref The symbol is referenced in the current file, but defined in another file.

.global The symbol can be either of the above. The assembler chooses either .def or .ref as appropriate for each symbol.

The following code fragment illustrates these definitions.

```
    .def    x
    .ref    y
    .global z
    .global q

q:  B       B3
    NOP     4
    MVK     1, B1
x:  MV      A0,A1
    MVKL    y,B3
    MVKH    y,B3
    B       z
    NOP     5
```

In this example, the .def definition of x says that it is an external symbol defined in this file and that other files can reference x. The .ref definition of y says that it is an undefined symbol that is defined in another file. The .global definition of z says that it is defined in some file and available in this file. The .global definition of q says that it is defined in this file and that other files can reference q.

The assembler places x, y, z, and q in the object file's symbol table. When the file is linked with other object files, the entries for x and q resolve references to x and q in other files. The entries for y and z cause the linker to look through the symbol tables of other files for y's and z's definitions.

The linker attempts to match all references with corresponding definitions. If the linker cannot find a symbol's definition, it prints an error message about the unresolved reference. This type of error prevents the linker from creating an executable object module.

An error also occurs if the same symbol is defined more than once.

2.6.2 The Symbol Table

The assembler generates an entry in the symbol table for each .ref, .def, or .global directive in Section 2.6.1). These are external symbols, which are visible to other object modules.

The assembler also creates special symbols that point to the beginning of each section.

The assembler does not usually create symbol table entries for any symbols other than those described above, because the linker does not use them. For example, labels (Section 4.8.2) are not included in the symbol table unless they are declared with the .global directive. For informational purposes, it is sometimes useful to have entries in the symbol table for each symbol in a program. To accomplish this, invoke the assembler with the --output_all_syms option (see Section 4.3).

2.7 Symbolic Relocations

The assembler treats each section as if it began at address 0. Of course, all sections cannot actually begin at address 0 in memory, so the linker must relocate sections. For COFF, all relocations are relative to address 0 in their sections. For the ELF EABI, relocations are symbol-relative rather than section-relative.

The linker can *relocate* sections by:

- Allocating them into the memory map so that they begin at the appropriate address as defined with the linker's MEMORY directive
- Adjusting symbol values to correspond to the new section addresses
- Adjusting references to relocated symbols to reflect the adjusted symbol values

The linker uses *relocation entries* to adjust references to symbol values. The assembler creates a relocation entry each time a relocatable symbol is referenced. The linker then uses these entries to patch the references after the symbols are relocated. Example 2-1 contains a code fragment for a TMS320C6000 device for which the assembler generates relocation entries.

Example 2-1. Code That Generates Relocation Entries

```
                          .global X
00000000 00000012! Z:     B       X      ; Uses an external relocation
00000004 0180082A'        MVKL    Y,B3   ; Uses an internal relocation
00000008 0180006A'        MVKH    Y,B3   ; Uses an internal relocation
0000000C 00004000         NOP     3

00000010 0001E000  Y:     IDLE
00000014 00000212         B       Y
00000018 00008000         NOP     5
```

In Example 2-1, both symbols X and Y are relocatable. Y is defined in the .text section of this module; X is defined in another module. When the code is assembled, X has a value of 0 (the assembler assumes all undefined external symbols have values of 0), and Y has a value of 16 (relative to address 0 in the .text section for COFF). The assembler generates two relocation entries: one for X and one for Y. The reference to X is an external reference (indicated by the **!** character in the listing). The reference to Y is to an internally defined relocatable symbol (indicated by the **'** character in the listing).

After the code is linked, suppose that X is relocated to address 0x7100. Suppose also that the .text section is relocated to begin at address 0x7200; Y now has a relocated value of 0x7210. The linker uses the two relocation entries to patch the two references in the object code:

```
00000012   B      X         becomes        0fffe012
0180082A   MVKL   Y         becomes        01B9082A
0180006A   MVKH   Y         becomes        1860006A
```

Under the ELF EABI, the relocations are symbol-relative rather than section-relative. This means that in COFF, the relocation in Example 2-1 generated for 'Y' will actually have a reference to the '.text' section symbol and will have an offset of 16. Under ELF, the relocation in the same example generated for 'Y' would actually refer to the symbol 'Y' and resolve the value for 'Y' in the opcode based on where the definition of 'Y' ends up.

2.7.1 Expressions With Multiple Relocatable Symbols (COFF Only)

Sometimes an expression contains more than one relocatable symbol, or cannot be evaluated at assembly time. In this case, the assembler encodes the entire expression in the object file. After determining the addresses of the symbols, the linker computes the value of the expression as shown in Example 2-2.

Example 2-2. Simple Assembler Listing

```
1                        .global  sym1, sym2
2
3 00000000 00800028%      MVKL     sym2 - sym1, A1
```

The symbols sym1 and sym2 are both externally defined. Therefore, the assembler cannot evaluate the expression sym2 - sym1, so it encodes the expression in the object file. The '%' listing character indicates a relocation expression. Suppose the linker relocates sym2 to 300h and sym1 to 200h. Then the linker computes the value of the expression to be 300h - 200h = 100h. Thus the MVKL instruction is patched to:

```
00808028             MVKL    100h,A1
```

Expression Cannot Be Larger Than Space Reserved

NOTE: If the value of an expression is larger, in bits, than the space reserved for it, you will receive a "relocation overflow" error message from the linker.

Each section in an object module has a table of relocation entries. The table contains one relocation entry for each relocatable reference in the section. The linker usually removes relocation entries after it uses them. This prevents the output file from being relocated again (if it is relinked or when it is loaded). A file that contains no relocation entries is an *absolute* file (all its addresses are absolute addresses). If you want the linker to retain relocation entries, invoke the linker with the --relocatable option (see Section 8.4.3.2).

2.7.2 Dynamic Relocation Entries (ELF Only)

Under dynamic linking models, the processing of relocation entries is handled slightly differently. If a relocation refers to a symbol that is imported from another dynamic module, then the static linker generates a dynamic relocation, which must be processed by the dynamic linker at dynamic load time (when the definition of the imported symbol is available). Only dynamic shared objects have dynamic relocations.

See Section 8.12 for information about dynamic linking. For information about creating a dynamic object module, see the C6000 Dynamic Linking wiki topic.

2.8 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, the hex conversion utility, or a standalone simulator. For details, see Section 3.1.

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. *Bootstrapping* is the process of a program performing some of its own initialization. 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*. See the C6000 Dynamic Linking wiki topic for information about dynamic loaders.

This chapter currently provides examples for the C6000 device family. Refer to your device documentation for various device-specific aspects of bootstrapping.

Topic **Page**

3.1 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. Additionally, with the COFF RAM model, the loader is responsible for parsing the .cinit section and performing the initializations encoded therein at load time.

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.
- **A standalone simulator.** The load6x command-line standalone simulator can be passed the name of the executable object module. The standalone simulator reads the executable file, copies the program into the simulated target memory and executes it, displaying any C I/O.
- **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.
- **"Burning" the load image onto an EPROM module.** The hex converter (hex6x) can assist with this by converting the executable object file into a format suitable for input to an EPROM programmer. The EPROM is placed onto the device itself and becomes a part of the device's memory. See Chapter 12 for details.
- **Bootstrap loading from a dedicated peripheral, such as an I^{2}C peripheral.** The device may require a small program called a bootloader to perform the loading from the peripheral. The hex converter can assist in creating a bootloader.

3.1.1 Load and Run Addresses

Consider an embedded device for which the program's load image is burned onto EPROM/ROM. Variable data in the program must be writable, and so must be located in writable memory, typically RAM. However, RAM is *volatile*, meaning it will lose its contents when the power goes out. If this data must have an initial value, that initial value must be stored somewhere else in the load image, or it would be lost when power is cycled. The initial value must be copied from the non-volatile ROM to its run-time location in RAM before it is used. See Section 8.8 for ways this is done.

The *load address* is the location of an object in the load image.

The *run address* is the location of the object as it exists during program execution.

An *object* is a chunk of memory. It represents a section, segment, function, or data.

The load and run addresses for an object may be the same. This is commonly the case for program code and read-only data, such as the .const section. In this case, the program can read the data directly from the load address. Sections that have no initial value, such as the .bss section, do not have load data and are considered to have load and run addresses that are the same. If you specify different load and run addresses for an uninitialized section, the linker provides a warning and ignores the load address.

The load and run addresses for an object may be different. This is commonly the case for writable data, such as the .data section. The .data section's starting contents are placed in ROM and copied to RAM. This often occurs during program startup, but depending on the needs of the object, it may be deferred to sometime later in the program as described in Section 3.5.

Symbols in assembly code and object files almost always refer to the run address. When you look at an address in the program, you are almost always looking at the run address. The load address is rarely used for anything but initialization.

The load and run addresses for a section are controlled by the linker command file and are recorded in the object file metadata.

The load address determines where a loader places the raw data for the section. Any references to the section (such as references to labels in it) refer to its run address. The application must copy the section from its load address to its run address before the first reference of the symbol is encountered at run time; this does *not* happen automatically simply because you specify a separate run address. For examples that specify load and run addresses, see Section 8.5.5.1.

For an example that illustrates how to move a block of code at run time, see Example 8-10. To create a symbol that lets you refer to the load-time address, rather than the run-time address, see the .label directive. To use copy tables to copy objects from load-space to run-space at boot time, see Section 8.8.

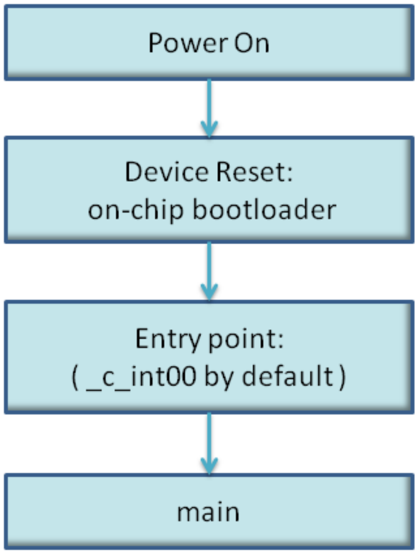
ELF format executable object files contain *segments*. COFF format executable object files contain *sections*.

3.1.2 Bootstrap Loading

The details of bootstrap loading (bootloading) vary a great deal between devices. Not every device supports every bootloading mode, and using the bootloader is optional. This section discusses various bootloading schemes to help you understand how they work. Refer to your device's data sheet to see which bootloading schemes are available and how to use them.

A typical embedded system uses bootloading to initialize the device. The program code and data may be stored in ROM or FLASH memory. At power-on, an on-chip bootloader (the *primary bootloader*) built into the device hardware starts automatically.

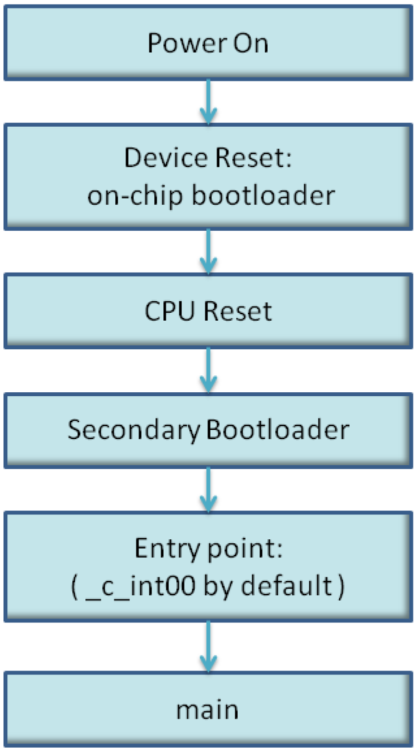
Figure 3-1. Bootloading Sequence (Simplified)



The primary bootloader is typically very small and copies a limited amount of memory from a dedicated location in ROM to a dedicated location in RAM. (Some bootloaders support copying the program from an I/O peripheral.) After the copy is completed, it transfers control to the program.

For many programs, the primary bootloader is not capable of loading the entire program, so these programs supply a more capable secondary bootloader. The primary bootloader loads the secondary bootloader and transfers control to it. Then, the secondary bootloader loads the rest of the program and transfers control to it. There can be any number of layers of bootloaders, each loading a more capable bootloader to which it transfers control.

Figure 3-2. Bootloading Sequence with Secondary Bootloader



3.1.2.1 Boot, Load, and Run Addresses

The *boot address* of a bootloaded object is where its raw data exists in ROM before power-on.

The boot, load, and run addresses for an object may all be the same; this is commonly the case for .const data. If they are different, the object's contents must be copied to the correct location before the object may be used.

The boot address may be different than the load address. The bootloader is responsible for copying the raw data to the load address.

The boot address is not controlled by the linker command file or recorded in the object file; it is strictly a convention shared by the bootloader and the program.

3.1.2.2 Primary Bootloader

The detailed operation of the primary bootloader is device-specific. Some devices have complex capabilities such as booting from an I/O peripheral or configuring memory controller parameters. This section describes only one example: the simple primary bootloader supported by the C621x/C671x/C64x. See your device documentation for variations on this pattern.

When ROM boot is selected as the boot configuration, at power-on, 1 KB of code will automatically be copied from external ROM CE1 to address 0 by the EDMA (using default ROM timings) following the release of /RESET while the CPU is stalled. Upon completion of the transfer, the CPU is released from the stalled state and starts executing from address 0. Place the secondary bootloader (or the program itself, if it is small enough) at the beginning of CE1.

3.1.2.3 Secondary Bootloader

The hex converter assumes the secondary bootloader is of a particular format. The hex converter's model bootloader uses a *boot table*. You can use whatever format you want, but if you follow this model, the hex converter can create the boot table automatically.

3.1.2.4 Boot Table

The input for the model secondary bootloader is the *boot table*. The boot table contains records that instruct the secondary bootloader to copy blocks of data contained in the table to specified destination addresses. The hex conversion utility automatically builds the boot table for the secondary bootloader. Using the utility, you specify the sections you want to initialize, the boot table location, and the name of the section containing the secondary bootloader routine and where it should be located. The hex conversion utility builds a complete image of the table and adds it to the program.

The boot table is target-specific. For C6000, the format of the boot table is simple. A header record contains a 4-byte field that indicates where the boot loader should branch after it has completed copying data. After the header, each section that is to be included in the boot table has the following contents:

- 4-byte field containing the size of the section
- 4-byte field containing the destination address for the copy
- the raw data
- 0 to 3 bytes of trailing padding to make the next field aligned to 4 bytes

More than one section can be entered; a termination block containing an all-zero 4-byte field follows the last section.

See Section 12.10.2 for details about the boot table format.

3.1.2.5 Bootloader Routine

The bootloader routine is a normal function, except that it executes before the C environment is set up. For this reason, it can't use the C stack, and it can't call any functions that have yet to be loaded!

The following sample code is for C6000 and is from *Creating a Second-Level Bootloader for FLASH Bootloading on TMS320C6000 Platform With Code Composer Studio* (SPRA999).

Example 3-1. Sample Secondary Bootloader Routine

```
;  ======== boot_c671x.s62 ========

; global EMIF symbols defined for the c671x family
            .include        boot_c671x.h62
            .sect ".boot_load"
            .global _boot
_boot:
;************************************************************************
;* DEBUG LOOP - COMMENT OUT B FOR NORMAL OPERATION
;************************************************************************
zero B1
_myloop: ;  [!B1] B _myloop
            nop  5
_myloopend: nop
;************************************************************************
;* CONFIGURE EMIF
;************************************************************************
        ;****************************************************************
        ; *EMIF_GCTL = EMIF_GCTL_V;
        ;****************************************************************
            mvkl  EMIF_GCTL,A4
      ||    mvkl  EMIF_GCTL_V,B4
            mvkh  EMIF_GCTL,A4
      ||    mvkh  EMIF_GCTL_V,B4
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_CE0 = EMIF_CE0_V
        ;****************************************************************
            mvkl  EMIF_CE0,A4
      ||    mvkl  EMIF_CE0_V,B4
            mvkh  EMIF_CE0,A4
      ||    mvkh  EMIF_CE0_V,B4
```

Example 3-1. Sample Secondary Bootloader Routine (continued)

```
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_CE1 = EMIF_CE1_V (setup for 8-bit async)
        ;****************************************************************
            mvkl  EMIF_CE1,A4
      ||    mvkl  EMIF_CE1_V,B4
            mvkh  EMIF_CE1,A4
      ||    mvkh  EMIF_CE1_V,B4
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_CE2 = EMIF_CE2_V (setup for 32-bit async)
        ;****************************************************************
            mvkl  EMIF_CE2,A4
      ||    mvkl  EMIF_CE2_V,B4
            mvkh  EMIF_CE2,A4
      ||    mvkh  EMIF_CE2_V,B4
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_CE3 = EMIF_CE3_V (setup for 32-bit async)
        ;****************************************************************
      ||    mvkl  EMIF_CE3,A4
      ||    mvkl  EMIF_CE3_V,B4      ;
            mvkh  EMIF_CE3,A4
      ||    mvkh  EMIF_CE3_V,B4
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_SDRAMCTL = EMIF_SDRAMCTL_V
        ;****************************************************************
      ||    mvkl  EMIF_SDRAMCTL,A4
      ||    mvkl  EMIF_SDRAMCTL_V,B4      ;
            mvkh  EMIF_SDRAMCTL,A4
      ||    mvkh  EMIF_SDRAMCTL_V,B4
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_SDRAMTIM = EMIF_SDRAMTIM_V
        ;****************************************************************
      ||    mvkl  EMIF_SDRAMTIM,A4
      ||    mvkl  EMIF_SDRAMTIM_V,B4      ;
            mvkh  EMIF_SDRAMTIM,A4
      ||    mvkh  EMIF_SDRAMTIM_V,B4
            stw   B4,*A4
        ;****************************************************************
        ; *EMIF_SDRAMEXT = EMIF_SDRAMEXT_V
        ;****************************************************************
      ||    mvkl  EMIF_SDRAMEXT,A4
      ||    mvkl  EMIF_SDRAMEXT_V,B4      ;
            mvkh  EMIF_SDRAMEXT,A4
      ||    mvkh  EMIF_SDRAMEXT_V,B4
            stw   B4,*A4
;****************************************************************************
; copy sections
;****************************************************************************
            mvkl  COPY_TABLE, a3 ; load table pointer
            mvkh  COPY_TABLE, a3
            ldw   *a3++, b1      ; Load entry point
copy_section_top:
            ldw   *a3++, b0      ; byte count
            ldw   *a3++, a4      ; ram start address
            nop   3
[!b0]       b copy_done          ; have we copied all sections?
            nop   5
copy_loop:
            ldb   *a3++,b5
            sub   b0,1,b0        ; decrement counter
```

Example 3-1. Sample Secondary Bootloader Routine (continued)

```
[ b0]       b     copy_loop       ; setup branch if not done
[!b0]       b     copy_section_top
            zero  a1
[!b0]       and   3,a3,a1
            stb   b5,*a4++
[!b0]       and   −4,a3,a5        ; round address up to next multiple of 4
[ a1]       add   4,a5,a3         ; round address up to next multiple of 4
;****************************************************************************
; jump to entry point
;****************************************************************************
copy_done:
            b    .S2 b1
            nop  5
```

3.2 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 3.3.1). 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 8.4.12. 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 an interrupt vector, the entry point is installed as the RESET interrupt handler. When RESET is applied, the startup routine will be invoked.
- 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.

3.3 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. An assembly-only program may not need to perform all of these steps.

3.3.1 _c_int00

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

3.3.2 RAM Model vs. ROM Model

In the COFF RAM model, the loader is additionally responsible for processing the .cinit section. The .cinit section is a NOLOAD section, which means it does not get allocated to target memory. Instead, the loader is responsible for parsing the .cinit section and performing the initializations encoded therein at load time.

In the EABI RAM model, no .cinit records are generated.

In both the COFF ROM and EABI ROM models, the .cinit section is loaded into memory along with other initialized sections. The linker defines a "cinit" symbol that points to the beginning of the initialization tables in memory. When the program begins running, the C boot routine copies data from these tables into the .bss section.

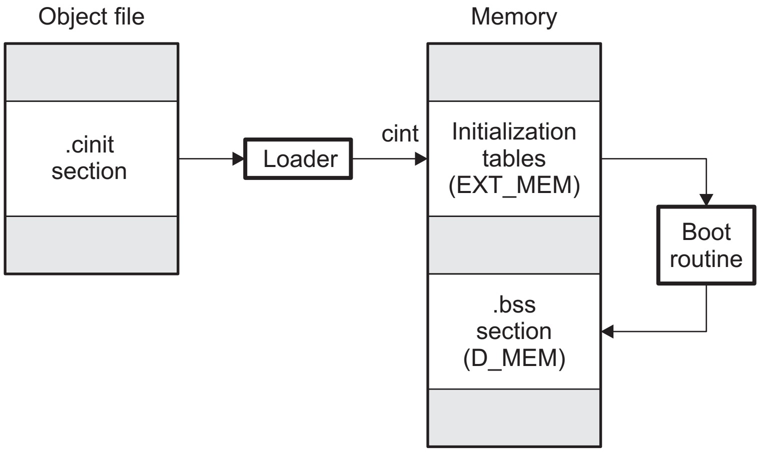
3.3.2.1 Autoinitializing Variables at Run Time (--rom_model)

Autoinitializing variables at run time is the default method of autoinitialization. To use this method, invoke the linker with the --rom_model option.

Using this method, the .cinit section is loaded into memory along with all the other initialized sections. The linker defines a special symbol called cinit 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 specified variables in the .bss section. This allows initialization data to be stored in slow non-volatile memory and copied to fast memory each time the program is reset.

Figure 3-3 illustrates autoinitialization at run time. Use this method in any system where your application runs from code burned into slow memory or needs to survive a reset.

Figure 3-3. Autoinitialization at Run Time



3.3.2.2 Initializing Variables at Load Time (--ram_model)

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.

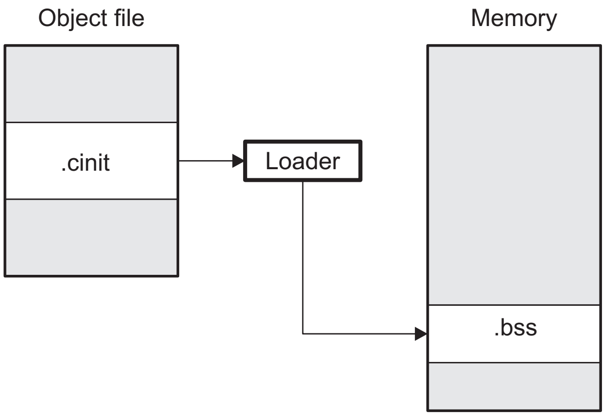
When you use the --ram_model linker option, the linker sets the STYP_COPY bit in the .cinit section's header. This tells the loader not to load the .cinit section into memory. (The .cinit section occupies no space in the memory map.) The linker also sets the cinit symbol to -1 (normally, cinit points to the beginning of the initialization tables). This indicates to the boot routine that the initialization tables are not present in memory; accordingly, no run-time initialization is performed at boot time.

A loader must be able to perform the following tasks to use initialization at load time:

- Detect the presence of the .cinit section in the object file.
- Determine that STYP_COPY is set in the .cinit section header, so that it knows not to copy the .cinit section into memory.
- Understand the format of the initialization tables.

Figure 3-4 illustrates the initialization of variables at load time.

Figure 3-4. Initialization at Load Time



3.3.2.3 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.obj; referencing _c_int00 ensures that boot.obj is automatically linked in from the appropriate run-time-support library.
- The .cinit output section is padded with a termination record to tell the boot routine (autoinitialize at run time) or the loader (initialize at load time) when to stop reading initialization tables.
- When you initialize at load time (--ram_model option):
  - The linker sets cinit to -1. This indicates that the initialization tables are not in memory, so no initialization is performed at run time.
  - The STYP_COPY flag (0010h) is set in the .cinit section header. STYP_COPY is the special attribute that tells the loader to perform initialization directly and not to load the .cinit section into memory. The linker does not allocate space in memory for the .cinit section.
- When you autoinitialize at run time (--rom_model option), the linker defines cinit as the starting address of the .cinit section. The C boot routine uses this symbol as the starting point for autoinitialization.

3.3.3 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 8.8.

You can create and control code overlays with copy tables. See Section 8.8.4 for details and examples.

Using copy tables is similar to performing run-time relocations as described in Section 3.5, however copy tables require a specific table format.

3.3.3.1 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 8.8.4.2 for more about the BINIT copy table name.

The BINIT copy table is copied immediately before .cinit processing.

3.3.3.2 CINIT

EABI .cinit tables are special kinds of copy tables. Refer to Section 8.10.4 for more about using the .cinit section with the ROM model and Section 8.10.5 for more using it with the RAM model.

COFF .cinit tables can be used to provide copy table functionality.

3.4 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 8.4.4 for information about allocating memory for argument passing.

3.5 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. See Section 3.1.1 for more about load and run addresses. 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 of the same size.

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 8.5.5.

3.6 Additional Information

See the following sections and documents for additional information:

Section 8.4.4, "Allocate Memory for Use by the Loader to Pass Arguments (--arg_size Option)"

Section 8.4.12, "Define an Entry Point (--entry_point Option)"

Section 8.5.5.1 ,"Specifying Load and Run Addresses"

Section 8.8, "Linker-Generated Copy Tables"

Section 8.10.1, "Run-Time Initialization"

Section 8.10.4, "Autoinitializing Variables at Run Time (--rom_model)"

Section 8.10.5, "Autoinitializing Variables at Load Time (--ram_model)"

Section 8.10.6, "The --rom_model and --ram_model Linker Options"

.label directive

Chapter 12, "Hex Conversion Utility Description"

"Run-Time Initialization," "Initialization by the Interrupt Vector," and "System Initialization" sections in the *TMS320C6000 Optimizing C/C++ Compiler User's Guide*

Creating a Second-Level Bootloader for FLASH Bootloading on TMS320C6000 Platform With Code Composer Studio (SPRA999).

Assembler Description

The TMS320C6000 assembler translates assembly language source files into machine language object files. These files are object modules, which are discussed in Chapter 2. Source files can contain the following assembly language elements:

Assembler directives	described in Chapter 5
Macro directives	described in Chapter 6
Assembly language instructions	described in the *TMS320C62x DSP CPU and Instruction Set Reference Guide*, *TMS320C64x/C64x+ DSP CPU and Instruction Set Reference Guide*, *TMS320C67x/C67x+ DSP CPU and Instruction Set Reference Guide*, and *TMS320C66x CPU and Instruction Set Reference Guide*.

Topic **Page**

4.1 Assembler Overview

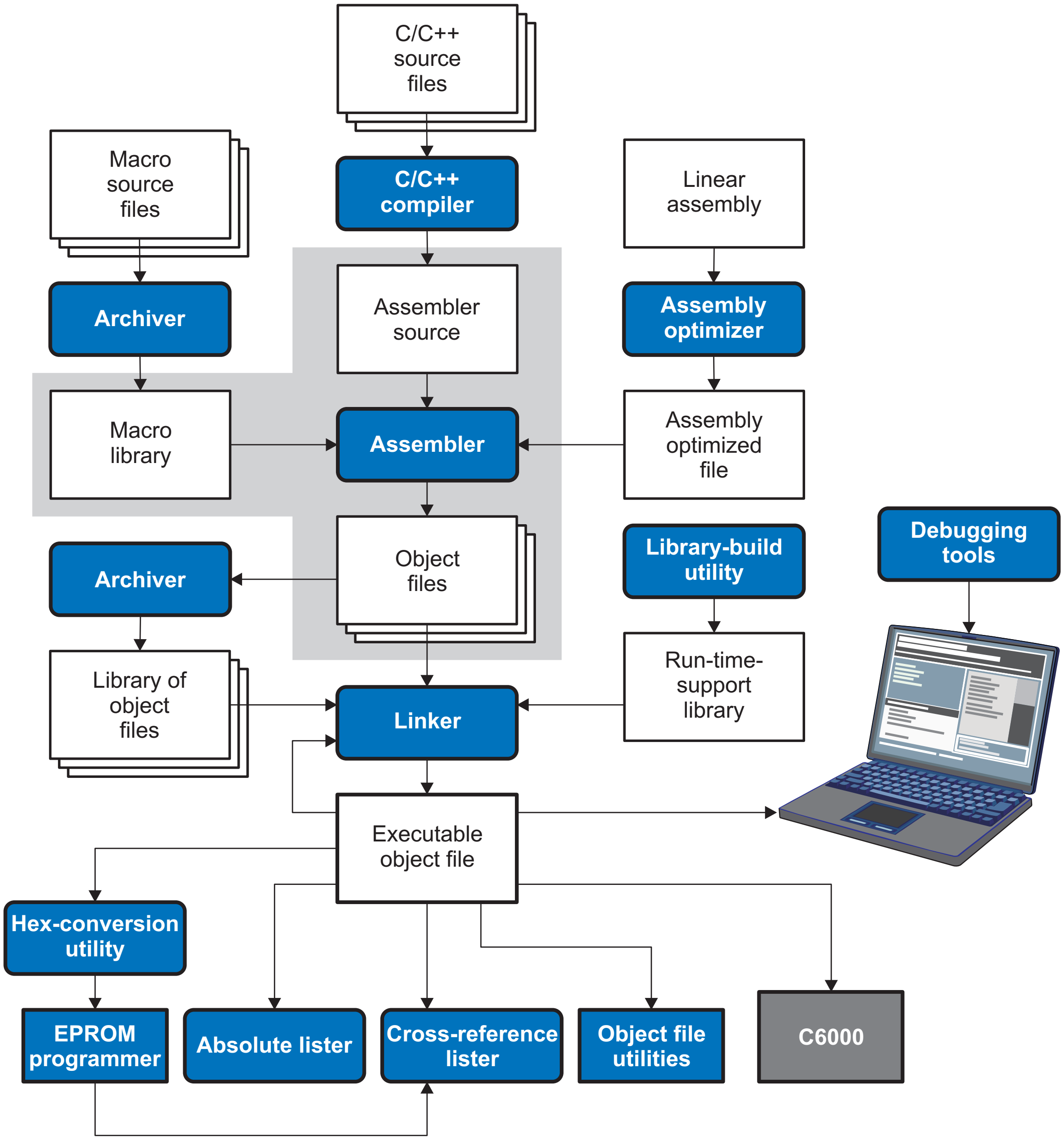
The assembler does the following:

- Processes the source statements in a text file to produce a relocatable object file
- Produces a source listing (if requested) and provides you with control over this listing
- Allows you to divide your code into sections and maintain a section program counter (SPC) for each section of object code
- Defines and references global symbols and appends a cross-reference listing to the source listing (if requested)
- Allows conditional assembly
- Supports macros, allowing you to define macros inline or in a library

4.2 The Assembler's Role in the Software Development Flow

Figure 4-1 illustrates the assembler's role in the software development flow. The shaded portion highlights the most common assembler development path. The assembler accepts assembly language source files as input, both those you create and those created by the TMS320C6000 C/C++ compiler.

Figure 4-1. The Assembler in the TMS320C6000 Software Development Flow



4.3 Invoking the Assembler

To invoke the assembler, enter the following:

```
cl6x input file [options]
```

cl6x is the command that invokes the assembler through the compiler. The compiler considers any file with an .asm extension to be an assembly file and invokes the assembler.

input file names the assembly language source file.

options identify the assembler options that you want to use. Options are case sensitive and can appear anywhere on the command line following the command. Precede each option with one or two hyphens as shown.

The valid assembler options are listed in Table 4-1.

Some runtime model options such as --abi=coffabi or --abi=eabi, --big_endian or little_endian, and --silicon version influence the behavior of the assembler. These options are passed to the compiler, assembler, and linker from the shell utility, which is detailed in the *TMS320C6000 Optimizing Compiler User's Guide.*

Table 4-1. TMS320C6000 Assembler Options

Option	Alias	Description
--absolute_listing	**-aa**	Creates an absolute listing. When you use --absolute_listing, the assembler does not produce an object file. The --absolute_listing option is used in conjunction with the absolute lister.
-ar=*num*		Suppresses the assembler remark identified by *num*. A remark is an informational assembler message that is less severe than a warning. If you do not specify a value for #, all remarks are suppressed.
--asm_define=*name*[=*def*]	**-ad**	Sets the *name* symbol. This is equivalent to defining *name* with a .set directive in the case of a numeric value or with an .asg directive otherwise. If *value* is omitted, the symbol is set to 1. See Section 4.8.5.
--asm_dependency	**-apd**	Performs preprocessing for assembly files, but instead of writing preprocessed output, writes a list of dependency lines suitable for input to a standard make utility. The list is written to a file with the same name as the source file but with a .ppa extension.
--asm_includes	**-api**	Performs preprocessing for assembly files, but instead of writing preprocessed output, writes a list of files included with the .include directive. The list is written to a file with the same name as the source file but with a .ppa extension.
--asm_listing	**-al**	Produces a listing file with the same name as the input file with a .lst extension.
--asm_undefine=*name*	**-au**	Undefines the predefined constant *name*, which overrides any --asm_define options for the specified constant.
--cmd_file=*filename*	**-@**	Appends the contents of a file to the command line. You can use this option to avoid limitations on command line length imposed by the host operating system. Use an asterisk or a semicolon (* or ;) at the beginning of a line in the command file to include comments. Comments that begin in any other column must begin with a semicolon. Within the command file, filenames or option parameters containing embedded spaces or hyphens must be surrounded with quotation marks. For example: "this-file.asm"
--copy_file=*filename*	**-ahc**	Copies the specified file for the assembly module. The file is inserted before source file statements. The copied file appears in the assembly listing files.
--cross_reference	**-ax**	Produces a cross-reference table and appends it to the end of the listing file; it also adds cross-reference information to the object file for use by the cross-reference utility. If you do not request a listing file but use the --cross_reference option, the assembler creates a listing file automatically, naming it with the same name as the input file with a .lst extension.
--include_file=*filename*	**-ahi**	Includes the specified file for the assembly module. The file is included before source file statements. The included file does not appear in the assembly listing files.
--include_path=*pathname*	**-I**	Specifies a directory where the assembler can find files named by the .copy, .include, or .mlib directives. There is no limit to the number of directories you can specify in this manner; each pathname must be preceded by the --include_path option. See Section 4.5.1.
--output_all_syms	**-as**	Puts all defined symbols in the object file's symbol table. The assembler usually puts only global symbols into the symbol table. When you use --output_all_syms, symbols defined as labels or as assembly-time constants are also placed in the table.
--quiet	**-q**	Suppresses the banner and progress information (assembler runs in quiet mode).

Table 4-1. TMS320C6000 Assembler Options (continued)

Option	Alias	Description
--symdebug:dwarf or **--symdebug:none**	**-g**	(On by default) Enables assembler source debugging in the C source debugger. Line information is output to the object module for every line of source in the assembly language source file. You cannot use this option on assembly code that contains .line directives. See Section 4.12.
--syms_ignore_case	**-ac**	Makes case insignificant in the assembly language files. For example, --syms_ignore_case makes the symbols ABC and abc equivalent. *If you do not use this option, case is significant* (default). Case significance is enforced primarily with symbol names, not with mnemonics and register names.

4.4 Selecting 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. The ABI exists to allow ABI-compliant object code to link together, regardless of its source, and allows the resulting executable to run on any system that supports that ABI

Object modules conforming to different ABIs cannot be linked together. The linker detects this situation and generates an error.

The C6000 compiler supports two ABIs. The ABI is chosen through the --abi option as follows:

- **COFF ABI** (--abi=coffabi)

  The COFF ABI is the original, legacy ABI format. It is not possible to convert COFF object files to ELF object files; you will need to recompile C code or reassemble assembly code in order to move from COFF to ELF.

- **C6000 EABI** (--abi=eabi)

  Use this option to select the C6000 Embedded Application Binary Interface (EABI).

  All code in an EABI application must be built for EABI. Make sure all your libraries are available in EABI mode before migrating your existing COFF ABI systems to C6000 EABI. For full details, see http://tiexpressdsp.com/index.php/EABI_Support_in_C6000_Compiler and *The C6000 Embedded Application Binary Interface Application Report* (SPRAB89).

Note that converting an assembly file from the COFF API to EABI requires some changes to the assembly code. See the C6000 EABI Migration topic on the TI Embedded Processors Wiki for details.

4.5 Naming Alternate Directories for Assembler Input

The .copy, .include, and .mlib directives tell the assembler to use code from external files. The .copy and .include directives tell the assembler to read source statements from another file, and the .mlib directive names a library that contains macro functions. Chapter 5 contains examples of the .copy, .include, and .mlib directives. The syntax for these directives is:

```
.copy ["]filename["]
.include ["]filename["]
.mlib ["]filename["]
```

The *filename* names a copy/include file that the assembler reads statements from or a macro library that contains macro definitions. If *filename* begins with a number the double quotes are required. Quotes are recommended so that there is no issue in dealing with path information that is included in the filename specification or path names that include white space. The filename may be a complete pathname, a partial pathname, or a filename with no path information.

The assembler searches for the file in the following locations in the order given:

1. The directory that contains the current source file. The current source file is the file being assembled when the .copy, .include, or .mlib directive is encountered.
2. Any directories named with the --include_path option
3. Any directories named with the C6X_A_DIR environment variable

4. Any directories named with the C6X_C_DIR environment variable

Because of this search hierarchy, you can augment the assembler's directory search algorithm by using the --include_path option (described in Section 4.5.1) or the C6X_A_DIR environment variable (described in Section 4.5.2). The C6X_C_DIR environment variable is discussed in the *TMS320C6000 Optimizing Compiler User's Guide*.

4.5.1 Using the --include_path Assembler Option

The --include_path assembler option names an alternate directory that contains copy/include files or macro libraries. The format of the --include_path option is as follows:

cl6x --include_path= *pathname source filename* [*other options*]

There is no limit to the number of --include_path options per invocation; each --include_path option names one pathname. In assembly source, you can use the .copy, .include, or .mlib directive without specifying path information. If the assembler does not find the file in the directory that contains the current source file, it searches the paths designated by the --include_path options.

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

```
.copy "copy.asm"
```

Assume the following paths for the copy.asm file:

UNIX:	/tools/files/copy.asm
Windows:	c:\tools\files\copy.asm

You could set up the search path with the commands shown below:

Operating System	Enter
UNIX (Bourne shell)	`cl6x --include_path=/tools/files source.asm`
Windows	`cl6x --include_path=c:\tools\files source.asm`

The assembler first searches for copy.asm in the current directory because source.asm is in the current directory. Then the assembler searches in the directory named with the --include_path option.

4.5.2 Using the C6X_A_DIR Environment Variable

An environment variable is a system symbol that you define and assign a string to. The assembler uses the C6X_A_DIR environment variable to name alternate directories that contain copy/include files or macro libraries.

The assembler looks for the C6X_A_DIR environment variable and then reads and processes it. If the assembler does not find the C6X_A_DIR variable, it then searches for C6X_C_DIR. The processor-specific variables are useful when you are using Texas Instruments tools for different processors at the same time.

See the *TMS320C6000 Optimizing Compiler User's Guide* for details on C6X_C_DIR.

The command syntax for assigning the environment variable is as follows:

Operating System	Enter
UNIX (Bourne Shell)	**C6X_A_DIR="** *pathname*$_1$ **;** *pathname*$_2$ **; . . . "; export C6X_A_DIR**
Windows	**set C6X_A_DIR=** *pathname*$_1$ **;** *pathname*$_2$ **; . . .**

The *pathnames* are directories that contain copy/include files or macro libraries. 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 C6X_A_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 C6X_A_DIR=c:\first path\to\tools;d:\second path\to\tools
  ```

In assembly source, you can use the .copy, .include, or .mlib directive without specifying path information. If the assembler does not find the file in the directory that contains the current source file or in directories named by the --include_path option, it searches the paths named by the environment variable.

For example, assume that a file called source.asm contains these statements:

```
    .copy "copy1.asm"
    .copy "copy2.asm"
```

Assume the following paths for the files:

UNIX:	/tools/files/copy1.asm and /dsys/copy2.asm
Windows:	c:\tools\files\copy1.asm and c:\dsys\copy2.asm

You could set up the search path with the commands shown below:

Operating System	Enter

UNIX (Bourne shell)	`C6X_A_DIR="/dsys"; export C6X_A_DIR`
	`cl6x  --include_path=/tools/files source.asm`

Windows	`set C6X_A_DIR=c:\dsys`
	`cl6x --include_path=c:\tools\files source.asm`

The assembler first searches for copy1.asm and copy2.asm in the current directory because source.asm is in the current directory. Then the assembler searches in the directory named with the --include_path option and finds copy1.asm. Finally, the assembler searches the directory named with C6X_A_DIR and finds copy2.asm.

The environment variable remains set until you reboot the system or reset the variable by entering one of these commands:

Operating System	Enter
UNIX (Bourne shell)	`unset C6X_A_DIR`
Windows	`set C6X_A_DIR=`

4.6 Source Statement Format

Each line in a TMS320C6000 assembly input file can be empty, a comment, an assembler directive, a macro invocation, or an assembly instruction.

Assembly language source statements can contain five ordered fields (label, mnemonic, unit specifier, operand list, and comment). The general syntax for source statements is as follows:

[*label*[:]] [||] **[[** *register* **]]** *mnemonic* [*unit specifier*] [*operand list*][;*comment*]

A label can only be associated with the first instruction in an execute packet (a group of instructions that is to be executed in parallel).

Following are examples of source statements:

```
two     .set   2      ; Symbol Two = 2
Label:  MVK    two,A2 ; Move 2 into register A2
        .word 016h    ; Initialize a word with 016h
```

There is no limit on characters per source statement. Each statement is one logical line of the input file. Use a backslash (\) to indicate continuation of the same instruction/directive across multiple lines.

Follow these guidelines:

- All statements must begin with a label, a blank, an asterisk, or a semicolon.
- Labels are optional for most statements; if used, they must begin in column 1.
- One or more space or tab characters must separate each field.
- Comments are optional. Comments that begin in column 1 can begin with an asterisk or a semicolon (* or ;), but comments that begin in any other column *must* begin with a semicolon.
- In a conditional instruction, the condition register must be surrounded by square brackets.
- The functional unit specifier is optional. If you do not specify the functional unit, the assembler assigns a legal functional unit based on the mnemonic field and the other instructions in the execute packet.

NOTE: A mnemonic cannot begin in column 1 or it will be interpreted as a label. Mnemonic opcodes and assembler directive names without the . prefix are valid label names. Remember to always use whitespace before the mnemonic, or the assembler will think the identifier is a new label definition.

The following sections describe each of the fields.

4.6.1 Label Field

A label must be a legal identifier (see Section 4.8.1) placed in column 1. Every instruction may optionally have a label. Many directives allow a label, and some require a label.

A label can be followed by a colon (:). The colon is not treated as part of the label name. If you do not use a label, the first character position must contain a blank, a semicolon, or an asterisk. You cannot use a label on an instruction that is in parallel with a previous instruction.

When you use a label on an assembly instruction or data directive, an *assembler symbol* (Section 4.8) with the same name is created. Its value is the current value of the *section program counter* (SPC, see Section 2.4.5). This symbol represents the address of that instruction. In the following example, the .word directive is used to create an array of 3 words. Because a label was used, the assembly symbol Start refers to the first word, and the symbol will have the value 40h.

```
.    .    .    .
.    .    .    .
       9                  * Assume some code was assembled
      10 00000040 0000000A  Start:  .word 0Ah,3,7
         00000044 00000003
         00000048 00000007
```

When a label appears on a line by itself, it points to the instruction on the next line (the SPC is not incremented):

```
1 00000000           Here:
2 00000000 00000003           .word 3
```

A label on a line by itself is equivalent to writing:

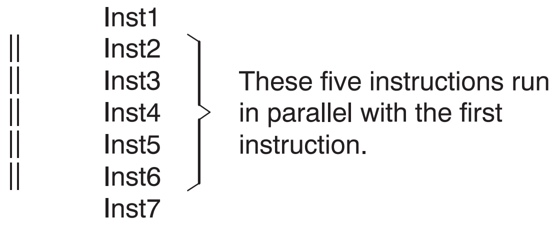
```
Here: .equ $  ; $ provides the current value of the SPC
```

If you do not use a label, the character in column 1 must be a blank, an asterisk, or a semicolon.

4.6.2 Mnemonic Field

The mnemonic field follows the label field. The mnemonic field cannot start in column 1; if it does, it is interpreted as a label. There is one exception: the parallel bars (||) of the mnemonic field can start in column 1. The mnemonic field contains one of the following items:

- Parallel bars (||) indicate instructions that are in parallel with a previous instruction. You can have up to eight instructions that will be executed in parallel. The following example demonstrates six instructions to be executed in parallel:



```
      Inst1
||    Inst2
||    Inst3     These five instructions run
||    Inst4     in parallel with the first
||    Inst5     instruction.
||    Inst6
      Inst7
```

- Square brackets ([ ]) indicate conditional instructions. The machine-instruction mnemonic is executed based on the value of the register within the brackets; valid register names are A0 for C64xx only, A1, A2, B0, B1, and B2. These registers are often called predicate registers.

  The instruction is executed if the value of the register is nonzero. If the register name is preceded by an exclamation point (!), then the instruction is executed if the value of the register is 0. For example:

  ```
  [A1] ZERO A2  ; If A1 is not equal to zero, A2 = 0
  ```

  The preceding exclamation point, if specified, is called a "logical NOT operator" or a "unary NOT operator".

Next, the mnemonic field contains one of the following items:

- Machine-instruction mnemonic (such as ADDK, MVKH, B)
- Assembler directive (such as .data, .list, .equ, .macro, .var, .mexit)

  The || and "[*predicate register*]" constructs are not legal in combination with an assembler directive.
- Macro invocation

4.6.3 Unit Specifier Field

The unit specifier field is an optional field that follows the mnemonic field for machine-instruction mnemonics. The unit specifier field begins with a period (.) followed by a functional unit specifier. In general, one instruction can be assigned to each functional unit in a single instruction cycle. There are eight functional units, two of each functional type:

.D1 and **.D2**	Data/addition/subtraction
.L1 and **.L2**	ALU/compares/long data arithmetic
.M1 and **.M2**	Multiply
.S1 and **.S2**	Shift/ALU/branch/bit field

ALU refers to an arithmetic logic unit.

There are several ways to use the unit specifier field:

- You can specify the particular functional unit (for example, .D1).
- You can specify only the functional type (for example, .M), and the assembler assigns the specific unit (for example, .M2).
- If you do not specify the functional unit, the assembler assigns the functional unit based on the mnemonic field, operand fields, and other instructions in the same execute packet.

For more information on functional units, including which assembly instructions require which functional type, see the *TMS320C62x DSP CPU and Instruction Set Reference Guide*, *TMS320C64x/C64x+ DSP CPU and Instruction Set Reference Guide*, or *TMS320C67x/C67x+ DSP CPU and Instruction Set Reference Guide*.

4.6.4 Operand Field

The operand field follows the mnemonic field and contains zero or more comma-separated operands. An operand can be one of the following:

- an immediate operand (usually a constant or symbol) (see Section 4.7 and Section 4.8)
- a register operand
- a memory reference operand
- an expression that evaluates to one of the above (see Section 4.9)

An *immediate operand* is encoded directly in the instruction. The value of an immediate operand must be a *constant expression*. Most instructions with an immediate operand require an *absolute constant expression*, such as 1234. Some instructions (such as a call instruction) allow a *relocatable constant expression*, such as a symbol defined in another file. (See Section 4.9 for details about types of expressions.)

A *register operand* is a special pre-defined symbol that represents a CPU register.

A *memory reference operand* uses one of several memory addressing modes to refer to a location in memory. Memory reference operands use a special target-specific syntax defined in the appropriate *CPU and Instruction Set Reference Guide*.

You must separate operands with commas. Not all operand types are supported for all operands. See the description of the specific instruction in the *CPU and Instruction Set Reference Guide* for your device family.

4.6.5 Comment Field

A comment can begin in any column and extends to the end of the source line. A comment can contain any ASCII character, including blanks. Comments are printed in the assembly source listing, but they do not affect the assembly.

A source statement that contains only a comment is valid. If it begins in column 1, it can start with a semicolon (**;**) or an asterisk (*****). Comments that begin anywhere else on the line must begin with a semicolon. The asterisk identifies a comment only if it appears in column 1.

4.7 Literal Constants

A *literal constant* (also known as a *literal* or in some other documents as an *immediate value*) is a value that represents itself, such as 12, 3.14, or "hello".

The assembler supports several types of literals:

- Binary integer literals
- Octal integer literals
- Decimal integer literals
- Hexadecimal integer literals
- Character literals
- Character string literals
- Floating-point literals

Error checking for invalid or incomplete literals is performed.

4.7.1 Integer Literals

The assembler maintains each integer literal internally as a 32-bit signless quantity. Literals are considered unsigned values, and are not sign extended. For example, the literal 00FFh is equal to 00FF (base 16) or 255 (base 10); it *does not* equal -1. which is 0FFFFFFFFh (base 16). Note that if you store 0FFh in a .byte location, the bits will be exactly the same as if you had stored -1. It is up to the reader of that location to interpret the signedness of the bits.

4.7.1.1 Binary Integer Literals

A binary integer literal is a string of up to 32 binary digits (0s and 1s) followed by the suffix B (or b). Binary literals of the form "0[bB][10]+" are also supported. If fewer than 32 digits are specified, the assembler right justifies the value and fills the unspecified bits with zeros. These are examples of valid binary literals:

00000000B	Literal equal to 0_{10} or 0_{16}
0100000b	Literal equal to 32_{10} or 20_{16}
01b	Literal equal to 1_{10} or 1_{16}
11111000B	Literal equal to 248_{10} or $0F8_{16}$
0b00101010	Literal equal to 42_{10} or $2A_{16}$
0B101010	Literal equal to 42_{10} or $2A_{16}$

4.7.1.2 Octal Integer Literals

An octal integer literal is a string of up to 11 octal digits (0 through 7) followed by the suffix Q (or q). Octal literals may also begin with a 0, contain no 8 or 9 digits, and end with no suffix. These are examples of valid octal literals:

10Q	Literal equal to 8_{10} or 8_{16}
054321	Literal equal to 22737_{10} or $58D1_{16}$
100000Q	Literal equal to 32768_{10} or 8000_{16}
226q	Literal equal to 150_{10} or 96_{16}

4.7.1.3 Decimal Integer Literals

A decimal integer literal is a string of decimal digits ranging from -2147 483 648 to 4 294 967 295. These are examples of valid decimal integer literals:

1000	Literal equal to 1000_{10} or $3E8_{16}$
-32768	Literal equal to $-32\ 768_{10}$ or -8000_{16}
25	Literal equal to 25_{10} or 19_{16}
4815162342	Literal equal to 4815162342_{10} or $11F018BE6_{16}$

4.7.1.4 Hexadecimal Integer Literals

A hexadecimal integer literal is a string of up to eight hexadecimal digits followed by the suffix H (or h) or preceded by 0x. *A hexadecimal literal must begin with a decimal value (0-9) if it is indicated by the H or h suffix.*

Hexadecimal digits include the decimal values 0-9 and the letters A-F or a-f. If fewer than eight hexadecimal digits are specified, the assembler right-justifies the bits.

These are examples of valid hexadecimal literals:

78h	Literal equal to 120_{10} or 0078_{16}
0x78	Literal equal to 120_{10} or 0078_{16}
0Fh	Literal equal to 15_{10} or $000F_{16}$
37ACh	Literal equal to 14252_{10} or $37AC_{16}$

4.7.1.5 Character Literals

A character literal is a single character enclosed in *single* quotes. The characters are represented internally as 8-bit ASCII characters. Two consecutive single quotes are required to represent each single quote that is part of a character literal. A character literal consisting only of two single quotes is valid and is assigned the value 0. These are examples of valid character literals:

'a'	Defines the character literal *a* and is represented internally as 61_{16}
'C'	Defines the character literal *C* and is represented internally as 43_{16}
''''	Defines the character literal *'* and is represented internally as 27_{16}
''	Defines a null character and is represented internally as 00_{16}

Notice the difference between character *literals* and character *string literals* (Section 4.7.2 discusses character strings). A character literal represents a single integer value; a string is a sequence of characters.

4.7.2 Character String Literals

A character string is a sequence of characters enclosed in *double* quotes. Double quotes that are part of character strings are represented by two consecutive double quotes. The maximum length of a string varies and is defined for each directive that requires a character string. Characters are represented internally as 8-bit ASCII characters.

These are examples of valid character strings:

"sample program"	defines the 14-character string *sample program.*
"PLAN ""C"""	defines the 8-character string *PLAN "C".*

Character strings are used for the following:

- Filenames, as in .copy "filename"
- Section names, as in .sect "section name"
- Data initialization directives, as in .byte "charstring"
- Operands of .string directives

4.7.3 *Floating-Point Literals*

A floating-point literal is a string of decimal digits followed by a required decimal point, an optional fractional portion, and an optional exponent portion. The syntax for a floating-point number is:

[+|-] *nnn* . [*nnn*] [**E|e** [+|-] *nnn*]

Replace *nnn* with a string of decimal digits. You can precede *nnn* with a + or a -. You must specify a decimal point. For example, 3.e5 is valid, but 3e5 is not valid. The exponent indicates a power of 10. These are examples of valid floating-point literals:

```
3.0
3.14
3.
-0.314e13
+314.59e-2
```

The assembler syntax does not support all C89-style float literals nor C99-style hexadecimal constants, but the $strtod built-in mathematical function supports both. If you want to specify a floating-point literal using one of those formats, use $strtod. For example:

```
$strtod(".3")
$strtod("0x1.234p-5")
```

You cannot directly use NaN, Inf, or -Inf as floating-point literals. Instead, use $strtod to express these values. The "NaN" and "Inf" strings are handled case-insensitively. See Section 4.10.1 for built-in functions.

```
$strtod("NaN")
$strtod("Inf")
```

4.8 Assembler Symbols

An assembler symbol is a named 32-bit signless integer value, usually representing an address or absolute integer. A symbol can represent such things as the starting address of a function, variable, or section. The name of a symbol must be a legal identifier. The identifier becomes a symbolic representation of the symbol's value, and may be used in subsequent instructions to refer to the symbol's location or value.

Some assembler symbols become external symbols, and are placed in the object file's symbol table. A symbol is valid only within the module in which it is defined, unless you use the .global directive or the .def directive to declare it as an *external symbol* (see .global directive).

See Section 2.6 for more about symbols and the symbol tables in object files.

4.8.1 *Identifiers*

Identifiers are names used as labels, registers, symbols, and substitution symbols. An identifier is a string of alphanumeric characters, the dollar sign, and underscores (A-Z, a-z, 0-9, $, and _). The first character in an identifier cannot be a number, and identifiers cannot contain embedded blanks. The identifiers you define are case sensitive; for example, the assembler recognizes ABC, Abc, and abc as three distinct identifiers. You can override case sensitivity with the --syms_ignore_case assembler option (see Section 4.3).

4.8.2 Labels

An identifier used as a label becomes an assembler symbol, which represent an address in the program. Labels within a file must be unique.

NOTE: A mnemonic cannot begin in column 1 or it will be interpreted as a label. Mnemonic opcodes and assembler directive names without the . prefix are valid label names. Remember to always use whitespace before the mnemonic, or the assembler will think the identifier is a new label definition.

Symbols derived from labels can also be used as the operands of .global, .ref, .def, or .bss directives; for example:

```
        .global label1

label2: MVKL    label2, B3
        MVKH    label2, B3
        B       label1
        NOP     5
```

4.8.3 Local Labels

Local labels are special labels whose scope and effect are temporary. A local label can be defined in two ways:

- $n, where n is a decimal digit in the range 0-9. For example, $4 and $1 are valid local labels. See Example 4-1.
- *name*?, where *name* is any legal identifier as described above. The assembler replaces the question mark with a period followed by a unique number. When the source code is expanded, *you will not see the unique number in the listing file*. Your label appears with the question mark as it did in the source definition. See Example 4-2.

You cannot declare these types of labels as global.

Normal labels must be unique (they can be declared only once), and they can be used as constants in the operand field. Local labels, however, can be undefined and defined again. Local labels cannot be defined by directives.

A local label can be undefined or reset in one of these ways:

- By using the .newblock directive
- By changing sections (using a .sect, .text, or .data directive)
- By entering an include file (specified by the .include or .copy directive)
- By leaving an include file (specified by the .include or .copy directive)

Example 4-1. Local Labels of the Form $n

This is an example of code that declares and uses a local label legally:

```
$1:
     SUB   A1,1,A1
[A1] B     $1
     SUBC  A3,A0,A3
     NOP    4

     .newblock      ; undefine $1 to use it again

$1   SUB   A2,1,A2
[A2] B     $1
     MPY   A3,A3,A3
     NOP   4
```

The following code uses a local label illegally:

```
$1:
     SUB   A1,1,A1
[A1] B     $1
     SUBC  A3,A0,A3
     NOP   4
$1   SUB   A2,1,A2    ; WRONG - $1 is multiply defined
[A2] B     $1
     MPY   A3,A3,A3
     NOP   4
```

The $1 label is not undefined before being reused by the second branch instruction. Therefore, $1 is redefined, which is illegal.

Local labels are especially useful in macros. If a macro contains a normal label and is called more than once, the assembler issues a multiple-definition error. If you use a local label and .newblock within a macro, however, the local label is used and reset each time the macro is expanded.

Up to ten local labels of the $n form can be in effect at one time. Local labels of the form name? are not limited. After you undefine a local label, you can define it and use it again. Local labels do not appear in the object code symbol table.

Example 4-2. Local Labels of the Form name?

```
****************************************************************
** First definition of local label mylab                      **
****************************************************************
        nop
mylab?  nop
        B mylab?
        nop 5
****************************************************************
** Include file has second definition of mylab                **
****************************************************************
        .copy  "a.inc"
****************************************************************
** Third definition of mylab, reset upon exit from .include   **
****************************************************************
mylab?  nop
        B mylab?
        nop 5
****************************************************************
** Fourth definition of mylab in macro, macros use different  **
** namespace to avoid conflicts                               **
****************************************************************
mymac  .macro
mylab?  nop
        B mylab?
        nop 5
        .endm
****************************************************************
** Macro invocation                                           **
****************************************************************
        mymac
****************************************************************
** Reference to third definition of mylab. Definition is not  **
** reset by macro invocation.                                 **
****************************************************************
        B mylab?
        nop 5
****************************************************************
** Changing section, allowing fifth definition of mylab       **
****************************************************************
        .sect  "Sect_One"
        nop
mylab?  .word 0
        nop
        nop
        B mylab?
        nop 5
****************************************************************
** The .newblock directive allows sixth definition of mylab   **
****************************************************************
        .newblock
mylab?  .word 0
        nop
        nop
        B mylab?
        nop 5
```

For more information about using labels in macros see Section 6.6.

4.8.4 Symbolic Constants

A symbolic constant is a symbol with a value that is an absolute constant expression (see Section 4.9). By using symbolic constants, you can assign meaningful names to constant expressions. The .set and .struct/.tag/.endstruct directives enable you to set symbolic constants (see Define Assembly-Time Constant). Once defined, symbolic constants *cannot* be redefined.

If you use the .set directive to assign a value to a symbol , the symbol becomes a symbolic constant and may be used where a constant expression is expected. For example:

```
sym   .set 3
      MVK  sym,B1
```

You can also use the .set directive to assign symbolic constants for other symbols, such as register names. In this case, the symbolic constant becomes a synonym for the register:

```
sym   .set B1
      MVK  10,sym
```

The following example shows how the .set directive can be used with the .struct, .tag. and .endstruct directives. It creates the symbolic constants K, maxbuf, item, value, delta, and i_len.

```
K      .set  1024           ; constant definitions
maxbuf .set  2*K

item   .struct              ; item structure definition
value  .int                 ; value offset = 0
delta  .int                 ; delta offset = 4
i_len  .endstruct           ; item size    = 8

array  .tag  item
       .bss  array, i_len*K ; declare an array of K "items"
       .text
       LDW   *+B14(array.delta + 2*i_len),A1
                            ; access array [2].delta
```

The assembler also has many predefined symbolic constants; these are discussed in Section 4.8.6.

4.8.5 Defining Symbolic Constants (--asm_define Option)

The --asm_define option equates a constant value or a string with a symbol. The symbol can then be used in place of a value in assembly source. The format of the --asm_define option is as follows:

cl6x --asm_define=*name*[**=***value*]

The *name* is the name of the symbol you want to define. The *value* is the constant or string value you want to assign to the symbol. If the *value* is omitted, the symbol is set to 1. If you want to define a quoted string and keep the quotation marks, do one of the following:

- For Windows, use **--asm_define=** *name* **="\"** *value* **\""**. For example, --asm_define=car="\"sedan\""
- For UNIX, use **--asm_define=** *name* **='"** *value* **"'**. For example, --asm_define=car='"sedan"'
- For Code Composer, enter the definition in a file and include that file with the --cmd_file (or -@) option.

Once you have defined the name with the --asm_define option, the symbol can be used with assembly directives and instructions as if it had been defined with the .set directive. For example, on the command line you enter:

```
cl6x --asm_define=SYM1=1 --asm_define=SYM2=2 --asm_define=SYM3=3 --asm_define=SYM4=4 value.asm
```

Since you have assigned values to SYM1, SYM2, SYM3, and SYM4, you can use them in source code. Example 4-3 shows how the value.asm file uses these symbols without defining them explicitly.

Within assembler source, you can test the symbol defined with the --asm_define option with these directives:

Type of Test	Directive Usage
Existence	**.if $isdefed("** *name* **")**
Nonexistence	**.if $isdefed("** *name* **") = 0**
Equal to value	**.if** *name* **=** *value*
Not equal to value	**.if** *name* **!=** *value*

The argument to the $isdefed built-in function must be enclosed in quotes. The quotes cause the argument to be interpreted literally rather than as a substitution symbol.

Example 4-3. Using Symbolic Constants Defined on Command Line

```
IF_4:  .if       SYM4 = SYM2 * SYM2
       .byte     SYM4          ; Equal values
       .else
       .byte     SYM2 * SYM2   ; Unequal values
       .endif

IF_5:  .if       SYM1 <= 10
       .byte     10            ; Less than / equal
       .else
       .byte     SYM1          ; Greater than
       .endif

IF_6:  .if       SYM3 * SYM2 != SYM4 + SYM2
       .byte     SYM3 * SYM2   ; Unequal value
       .else
       .byte     SYM4 + SYM4   ; Equal values
       .endif

IF_7:  .if       SYM1 = SYM2
       .byte     SYM1
       .elseif   SYM2 + SYM3 = 5
       .byte     SYM2 + SYM3
       .endif
```

4.8.6 Predefined Symbolic Constants

The assembler has several types of predefined symbols.

$, the dollar-sign character, represents the current value of the section program counter (SPC). $ is a relocatable symbol if you are using COFF.

In addition, the following predefined processor symbolic constants are available:

Table 4-2. C6000 Processor Symbolic Constants

Symbol name	Description
_ _TI_EABI_ _	Set to 1 if EABI is enabled (see Section 4.4); otherwise, it is set to 0
.TMS320C6X	Always set to 1
.TMS320C6200	Set to 1 if target is C6200, otherwise 0
.TMS320C6400	Set to 1 if target is C6400, C6400+, C6740, or C6600; otherwise 0
.TMS320C6400_PLUS	Set to 1 if target is C6400+, C6740, or C6600; otherwise 0
.TMS320C6600	Set to 1 if target is C6600, otherwise 0
.TMS320C6700	Set to 1 if target is C6700, C6700+, C6740, or C6600; otherwise 0
.TMS320C6700_PLUS	Set to 1 if target is C6700+, C6740, or C6600; otherwise 0
.TMS320C6740	Set to 1 if target is C6740 or C6600, otherwise 0
.LITTLE_ENDIAN	Set to 1 if little-endian mode is selected (the -me assembler option is not used); otherwise 0
.ASSEMBLER_VERSION	Set to major * 1000000 + minor * 1000 + patch version.
.BIG_ENDIAN	Set to 1 if big-endian mode is selected (the -me assembler option is used); otherwise 0
.SMALL_MODEL	Set to 1 if --memory_model:code=near and --memory_model:data=near, otherwise 0.
.LARGE_MODEL	Set to 1 if .SMALL_MODEL is 0, otherwise 0.

4.8.7 Registers

The names of C6000 registers are predefined symbols, including A0-A15 and B0-B15; and A16-31 and B16-31 for C6400, C6400+, C6700+, C6740, and C6600.

In addition, control register names are predefined symbols.

Register symbols and aliases can be entered as all uppercase or all lowercase characters.

Control register symbols can be entered in all upper-case or all lower-case characters. For example, CSR can also be entered as csr.

Table 4-3. CPU Control Registers

Register	Description
AMR	Addressing mode register
CSR	Control status register
DESR	(C6700+ only) dMAX event status register
DETR	(C6700+ only) dMAX event trigger register
DNUM	(C6400+, C6740, C6600 only) DSP core number register
ECR	(C6400+, C6740, C6600 only) Exception clear register
EFR	(C6400+, C6740, C6600 only) Exception flag register
FADCR	(C6700, C6700+, C6740, C6600 only) Floating-point adder configuration register
FAUCR	(C6700, C6700+, C6740, C6600 only) Floating-point auxiliary configuration register
FMCR	(C6700, C6700+, C6740, C6600 only) Floating-point multiplier configuration register
GFPGFR	(C6400 only) Galois field polynomial generator function register

Table 4-3. CPU Control Registers (continued)

Register	Description
GPLYA	(C6400+, C6740, C6600 only) GMPY A-side polynomial register
GPLYB	(C6400+, C6740, C6600 only) GMPY B-side polynomial register
ICR	Interrupt clear register
IER	Interrupt enable register
IERR	(C6400+, C6740, C6600 only) Interrupt exception report register
IFR	Interrupt flag register
ILC	(C6400+, C6740, C6600 only) Inner loop count register
NRP	Nonmaskable interrupt return pointer
IRP	Interrupt return pointer
ISR	Interrupt set register
ITSR	(C6400+, C6740, C6600 only) Interrupt task state register
ISTP	Interrupt service table pointer
NTSR	(C6400+, C6740, C6600 only) NMI/Exception task state register
PCE1	Program counter
REP	(C6400+, C6740, C6600 only) Restricted entry point address register
RILC	(C6400+, C6740, C6600 only) Reload inner loop count register
SSR	(C6400+, C6740, C6600 only) Saturation status register
TSCH	(C6400+, C6740, C6600 only) Time-stamp counter (high 32) register
TSCL	(C6400+, C6740, C6600 only) Time-stamp counter (low 32) register
TSR	(C6400+, C6740, C6600 only) Task status register

4.8.8 Register Pairs

Many instructions in the C6000 instruction set across the various available target processors (C6200, C6400, C6400+, etc.) support a 64-bit register operand which can be specified as a register pair.

A register pair should be specified on the A side or the B side, depending on which functional unit an instruction is to be executed on, and whether a cross functional unit data path is utilized by the instruction. You cannot mix A-side and B-side registers in the same register pair operand.

The syntax for a register pair is as follows where (n%2 == 0):

*Rn+1***:***Rn*

The legal register pairs are:

A1:A0	B1:B0
A3:A2	B3:B2
A5:A4	B5:B4
A7:A6	B7:B6
A9:A8	B9:B8
A11:A10	B11:B10
A13:A12	B13:B12
A15:A14	B15:B14

In addition, these register pairs are available on C6400, C6400+, C6600 (not C62xx or C67xx):

A17:A16	B17:B16
A19:A18	B19:B18
A21:A20	B21:B20
A23:A22	B23:B22
A25:A24	B25:B24
A27:A26	B27:B26
A29:A30	B29:B30
A31:A32	B31:B32

Here is an example of an ADD instruction that uses a register pair operand:

```
        ADD.L1 A5:A4,A1,A3:A2
```

For details on using register pairs in linear assembly, see the *TMS320C6000 Optimizing Compiler User's Guide*.

For more information on functional units, including which assembly instructions require which functional type, see the *TMS320C62x DSP CPU and Instruction Set Reference Guide*, *TMS320C64x/C64x+ DSP CPU and Instruction Set Reference Guide*, *TMS320C67x/C67x+ DSP CPU and Instruction Set Reference Guide*, or *TMS320C66x CPU and Instruction Set Reference Guide*.

4.8.9 Register Quads (C6600 Only)

Several instructions in the C6600 instruction set support a 128-bit register operand which can be specified as a register quad.

A register quad should be specified on the A side or the B side, depending on which functional unit an instruction is to be executed on, and whether a cross functional unit data path is utilized by the instruction. You cannot mix A-side and B-side registers in the same register quad operand.

The general syntax for a register quad is as follows, where (n%4 == 0):

*Rn+3***:***Rn+2***:***Rn+1***:***Rn* or *Rn+3***::***Rn*

The legal register quads are:

A Register Quads	Short Form	B Register Quads	Short Form
A3:A2:A1:A0	A3::A0	B3:B2:B1:B0	B3::B0
A7:A6:A5:A4	A7::A4	B7:B6:B5:B4	B7::B4
A11:A10:A9:A8	A11::A8	B11:B10:B9:B8	B11::B8
A15:A14:A13:A12	A15::A12	B15:B14:B13:B12	B15::B12
A19:A18:A17:A16	A19::A16	B19:B18:B17:B16	B19::B16
A23:A22:A21:A20	A23::A20	B23:B22:B21:B20	B23::B20
A27:A26:A25:A24	A27::A24	B27:B26:B25:B24	B27::B24
A31:A30:A29:A28	A31::A28	B31:B30:B29:B28	B31::B28

Here is an example of an ADD instruction that uses register quad operands:

```
    QMPYSP  .M1     A27:A26:A25:A24, A11:A10:A9:A8, A19:A18:A17:A16
```

For details on using register quads in C6600 linear assembly, see the *TMS320C6000 Optimizing Compiler User's Guide*.

For more information on functional units, including which assembly instructions require which functional type, see the *TMS320C66x CPU and Instruction Set Reference Guide*.

4.8.10 Substitution Symbols

Symbols can be assigned a string value. This enables you to create aliases for character strings by equating them to symbolic names. Symbols that represent character strings are called substitution symbols. When the assembler encounters a substitution symbol, its string value is substituted for the symbol name. Unlike symbolic constants, substitution symbols can be redefined.

A string can be assigned to a substitution symbol anywhere within a program; for example:

```
    .global _table
    .asg    "B14", PAGEPTR
    .asg    "*+B15(4)", LOCAL1
    .asg    "*+B15(8)", LOCAL2
    LDW     *+PAGEPTR(_table),A0
    NOP     4
    STW     A0,LOCAL1
```

When you are using macros, substitution symbols are important because macro parameters are actually substitution symbols that are assigned a macro argument. The following code shows how substitution symbols are used in macros:

```
MAC .macro  src1, src2, dst  ; Multiply/Accumulate macro
    MPY     src1, src2, src2
    NOP
    ADD     src2, dst, dst
    .endm
* MAC macro invocation
    MAC    A0,A1,A2
```

See Chapter 6 for more information about macros.

4.9 Expressions

Nearly all values and operands in assembly language are *expressions*, which may be any of the following:

- a literal constant
- a register
- a register pair
- a memory reference
- a symbol
- a built-in function invocation
- a mathematical or logical operation on one or more expressions

This section defines several types of expressions that are referred to throughout this document. Some instruction operands accept limited types of expressions. For example, the .if directive requires its operand be an absolute constant expression with an integer value. Absolute in the context of assembly code means that the value of the expression must be known at assembly time.

A *constant expression* is any expression that does not in any way refer to a register or memory reference. An *immediate operand* will usually not accept a register or memory reference. It must be given a constant expression. Constant expressions may be any of the following:

- a literal constant
- an address constant expression
- a symbol whose value is a constant expression
- a built-in function invocation on a constant expression
- a mathematical or logical operation on one or more constant expressions

An *address constant expression* is a special case of a constant expression. Some immediate operands that require an address value can accept a symbol plus an addend; for example, some branch instructions. The symbol must have a value that is an address, and it may be an external symbol. The addend must be an absolute constant expression with an integer value. For example, a valid address constant expression is "array+4".

A constant expression may be absolute or relocatable. *Absolute* means known at assembly time. *Relocatable* means constant, but not known until link time. External symbols are relocatable, even if they refer to a symbol defined in the same module.

An *absolute constant expression* may not refer to any external symbols anywhere in the expression. In other words, an absolute constant expression may be any of the following:

- a literal constant
- an absolute address constant expression
- a symbol whose value is an absolute constant expression
- a built-in function invocation whose arguments are all absolute constant expressions
- a mathematical or logical operation on one or more absolute constant expressions

A *relocatable constant expression* refers to at least one external symbol. For ELF, such expressions may contain at most one external symbol. A relocatable constant expression may be any of the following:

- an external symbol
- a relocatable address constant expression
- a symbol whose value is a relocatable constant expression
- a built-in function invocation with any arguments that are relocatable constant expressions
- a mathematical or logical operation on one or more expressions, at least one of which is a relocatable constant expression

In some cases, the value of a relocatable address expression may be known at assembly time. For example, a relative displacement branch may branch to a label defined in the same section.

4.9.1 Mathematical and Logical Operators

The operands of a mathematical or logical operator must be well-defined expressions. That is, you must use the correct number of operands and the operation must make sense. For example, you cannot take the XOR of a floating-point value. In addition, well-defined expressions contain only symbols or assembly-time constants that have been defined before they occur in the directive's expression.

Three main factors influence the order of expression evaluation:

Parentheses Expressions enclosed in parentheses are always evaluated first.

8 / (4 / 2) = 4, but 8 / 4 / 2 = 1

You *cannot* substitute braces ({ }) or brackets ([ ]) for parentheses.

Precedence groups Operators, listed in Table 4-4, are divided into nine precedence groups. When parentheses do not determine the order of expression evaluation, the highest precedence operation is evaluated first.

8 + 4 / 2 = 10 (4 / 2 is evaluated first)

Left-to-right evaluation When parentheses and precedence groups do not determine the order of expression evaluation, the expressions are evaluated from left to right, except for Group 1, which is evaluated from right to left.

8 / 4*2 = 4, but 8 / (4*2) = 1

Table 4-4 lists the operators that can be used in expressions, according to precedence group.

Table 4-4. Operators Used in Expressions (Precedence)

Group[1]	Operator	Description[2]
1	+ - ~ !	Unary plus Unary minus 1s complement Logical NOT
2	* / %	Multiplication Division Modulo
3	+ -	Addition Subtraction
4	<< >>	Shift left Shift right
5	< <= > >=	Less than Less than or equal to Greater than Greater than or equal to
6	=[=] !=	Equal to Not equal to
7	&	Bitwise AND
8	^	Bitwise exclusive OR (XOR)
9	|	Bitwise OR

[1] Group 1 operators are evaluated right to left. All other operators are evaluated left to right.

[2] Unary + and - have higher precedence than the binary forms.

The assembler checks for overflow and underflow conditions when arithmetic operations are performed during assembly. It issues a warning (the "value truncated" message) whenever an overflow or underflow occurs. The assembler *does not* check for overflow or underflow in multiplication.

4.9.2 Relational Operators and Conditional Expressions

The assembler supports relational operators that can be used in any expression; they are especially useful for conditional assembly. Relational operators include the following:

=	Equal to	**! =**	Not equal to
<	Less than	**<=**	Less than or equal to
>	Greater than	**> =**	Greater than or equal to

Conditional expressions evaluate to 1 if true and 0 if false and can be used only on operands of equivalent types; for example, absolute value compared to absolute value, but not absolute value compared to relocatable value.

4.9.3 Well-Defined Expressions

Some assembler directives, such as .if, require well-defined absolute constant expressions as operands. Well-defined expressions contain only symbols or assembly-time constants that have been defined before they occur in the directive's expression. In addition, they must use the correct number of operands and the operation must make sense. The evaluation of a well-defined expression must be unambiguous.

This is an example of a well-defined expression:

```
1000h+X
```

where X was previously defined as an absolute symbol.

4.9.4 Legal Expressions

With the exception of the following expression contexts, there is no restriction on combinations of operations, constants, internally defined symbols, and externally defined symbols.

When using COFF, if an expression contains more than one relocatable symbol or cannot be evaluated during assembly, the assembler encodes a relocation expression in the object file that is later evaluated by the linker. If the final value of the expression is larger in bits than the space reserved for it, you receive a "relocation overflow" error message from the linker. See Section 2.7 for more information on relocation expressions.

- When using the register relative addressing mode, the expression in brackets or parenthesis must be a well-defined expression, as described in Section 4.9.3. For example:

  ```
  *+A4[15]
  ```

- Expressions used to describe the offset in register relative addressing mode for the registers B14 and B15, or expressions used as the operand to the branch instruction, are subject to the same limitations. For these two cases, all legal expressions can be reduced to one of two forms:

  ```
  *+XA4[7]
  ```

relocatable symbol ± *absolute symbol*	`B (`**`extern_1-10`**`)`
or	
a well-defined expression	`*+B14/B15[`**`14`**`]`

4.9.5 Expression Examples

Following are examples of expressions that use relocatable and absolute symbols. These examples use four symbols that are defined in the same section:

```
          .global extern_1 ; Defined in an external module
intern_1: .word '"D'       ; Relocatable, defined in
                           ;   current module
intern_2                   ; Relocatable, defined in
                           ;   current module
intern_3                   ; Relocatable, defined in
                           ;   current module
```

- **Example 1**

  In these contexts, there are no limitations on how expressions can be formed when using COFF.If you are using ELF, the internal values must instead by absolute constant expressions.

  ```
  .word   extern_1 * intern_2 - 13  ; Legal for COFF, illegal for ELF

  MVKL    (intern_1 - extern_1),A1  ; Legal for COFF, illegal for ELF
  ```

- **Example 2**

  The first statement in the following example is valid; the statements that follow it are invalid.

  ```
  B (extern_1 - 10)            ; Legal
  B (10-extern_1)              ; Can't negate reloc. symbol
  LDW *+B14 (-(intern_1)), A1  ; Can't negate reloc. symbol
  LDW *+B14 (extern_1/10), A1  ; / not an additive operator
  B (intern_1 + extern_1)      ; Multiple relocatables
  ```

- **Example 3**

  The first statement below is legal; although intern_1 and intern_2 are relocatable, their difference is absolute because they are in the same section. Subtracting one relocatable symbol from another reduces the expression to *relocatable symbol* + *absolute value*. The second statement is illegal because the sum of two relocatable symbols is not an absolute value.

  ```
  B (intern_1 - intern_2 + extern_3)    ; Legal

  B (intern_1 + intern_2 + extern_3)    ; Illegal
  ```

- **Example 4**

  A relocatable symbol's placement in the expression is important to expression evaluation. Although the statement below is similar to the first statement in the previous example, it is illegal because of left-to-right operator precedence; the assembler attempts to add intern_1 to extern_3.

  ```
  B (intern_1 + extern_3 - intern_2)    ; Illegal
  ```

4.10 Built-in Functions and Operators

The assembler supports built-in mathematical functions and built-in addressing operators.

The built-in substitution symbol functions are discussed in Section 6.3.2.

4.10.1 Built-In Math and Trigonometric Functions

The assembler supports built-in functions for conversions and various math computations. Table 4-5 describes the built-in functions. The *expr* must be an absolute constant expression.

Table 4-5. Built-In Mathematical Functions

Function	Description
$acos(*expr*)	Returns the arccosine of *expr* as a floating-point value
$asin(*expr*)	Returns the arcsine of *expr* as a floating-point value
$atan(*expr*)	Returns the arctangent of *expr* as a floating-point value
$atan2(*expr*, *y*)	Returns the arctangent of *expr* as a floating-point value in range [-π, π]
$ceil(*expr*)	Returns the smallest integer not less than *expr*
$cos(*expr*)	Returns the cosine of *expr* as a floating-point value
$cosh(*expr*)	Returns the hyperbolic cosine of *expr* as a floating-point value
$cvf(*expr*)	Converts *expr* to a floating-point value
$cvi(*expr*)	converts *expr* to integer value
$exp(*expr*)	Returns the exponential function e^{expr}
$fabs(*expr*)	Returns the absolute value of *expr* as a floating-point value
$floor(*expr*)	Returns the largest integer not greater than *expr*
$fmod(*expr*, *y*)	Returns the remainder of *expr1* ÷ *expr2*
$int(*expr*)	Returns 1 if *expr* has an integer value; else returns 0. Returns an integer.
$ldexp(*expr*, *expr2*)	Multiplies *expr* by an integer power of 2. That is, $expr1 \times 2^{expr2}$
$log(*expr*)	Returns the natural logarithm of *expr*, where *expr*>0
$log10(*expr*)	Returns the base 10 logarithm of *expr*, where *expr*>0
$max(*expr1*, *expr2*)	Returns the maximum of two values
$min(*expr1*, *expr2*)	Returns the minimum of two values
$pow(*expr1*, *expr2*)	Returns *expr1*raised to the power of *expr2*
$round(*expr*)	Returns *expr* rounded to the nearest integer
$sgn(*expr*)	Returns the sign of *expr*.
$sin(*expr*)	Returns the sine of *expr*
$sinh(*expr*)	Returns the hyperbolic sine of *expr* as a floating-point value
$sqrt(*expr*)	Returns the square root of expr, expr≥0, as a floating-point value
$strtod(*str*)	Converts a character string to a double precision floating-point value. The string contains a properly-formatted C99-style floating-point literal.
$tan(*expr*)	Returns the tangent of *expr* as a floating-point value
$tanh(*expr*)	Returns the hyperbolic tangent of *expr* as a floating-point value
$trunc(*expr*)	Returns *expr* rounded toward 0

4.10.2 C6x Built-In ELF Relocation Generating Operators

The assembler supports several C6000-specific ELF relocation generating built-in operators. The operators are used in compiler-generated code to support symbolic addressing of objects.

The operators are used to support various forms of DP-relative and PC-relative addressing instruction sequences. For more detailed information about DP-relative and PC-relative addressing instruction sequences, please see *The C6000 Embedded Application Binary Interface Application Report* (SPRAB89).

4.10.2.1 $DPR_BYTE(sym) / $DPR_HWORD(sym) / $DPR_WORD(sym)

The $DPR_BYTE(sym), $DPR_HWORD(sym), or $DPR_WORD(sym) operator can be applied in the source operand of a MVKL or MVKH instruction to load the DP-relative offset of a symbol's address into a register. These operators are used by the compiler when accessing data objects that are not within the signed 15-bit offset range that is needed for using the DP-relative addressing mode.

For example, suppose the compiler needs to access a 32-bit aligned data object called 'xyz' that is defined in the .far section. The compiler must assume that the .far section is too far away from the base of the .bss section (whose address the runtime library's boot routine has loaded into the DP register), so using DP-relative addressing mode to access 'xyz' directly is not possible. Instead, the compiler will use a MVKL/MVKH/LDW sequence of instructions:

```
MVKL  $DPR_WORD(xyz),A0       ; load (xyz - $bss)/4 into A0
MVKH  $DPR_WORD(xyz),A0
LDW   *+DP[A0],A1             ; load *xyz into A1
```

This sequence of instructions is also referred to as far DP-relative addressing. The LDW instruction uses a scaled version of DP-relative indexed addressing. Similar to the $DPR_WORD(sym) operator, the $DPR_BYTE(sym) operator is provided to facilitate far DP-relative addressing of 8-bit data objects:

```
MVKL  $DPR_BYTE(xyz),A0       ; load (xyz - $bss) into A0
MVKH  $DPR_BYTE(xyz),A0
LDB   *+DP[A0],A1             ; load *xyz into A1
```

The $DPR_HWORD(sym) operator is provided to facilitate far DP-relative addressing of 16-bit data objects:

```
MVKL  $DPR_HWORD(xyz),A0      ; load (xyz - $bss)/2 into A0
MVKH  $DPR_HWORD(xyz),A0
LDH   *+DP[A0],A1             ; load *xyz into A1
```

For code on processors that are not compatible with C64x+, the compiler also uses these operators when it needs to take the address of an object that is within signed 16-bit range of the DP. For example, the compiler can compute the address of an 8-bit data object in the .bss section:

```
MVK   $DPR_BYTE(_char_X),A4   ; load (_char_X - $bss) into A4
ADD   DP,A4,A4                ; compute address of _char_X
```

Similarly, the compiler can compute the address of a 16-bit data object that is defined in the .bss section:

```
MVK   $DPR_HWORD(_short_X),A4 ; load (_short_X - $bss)/2 into A4
ADD   DP,A4,A4                ; compute address of _short_X
```

It can also compute a 32-bit data object that is defined in the .bss section:

```
MVK   $DPR_WORD(_int_X),A4    ; load (_int_X - $bss)/4 into A4
ADD   DP,A4,A4                ; compute address of _int_X
```

These operators were added to the assembler to assist in migrating existing COFF code, which used expressions like 'xyz - $bss' to indicate DP-relative access to the address of a data object, to ELF code which is able to resolve the DP-relative offset calculation with a single relocation.

In summary:

$DPR_BYTE(sym) is equivalent to 'sym - $bss'

$DPR_HWORD(sym) is equivalent to '(sym - $bss) / 2'

$DPR_WORD(sym) is equivalent to '(sym - $bss) / 4'

4.10.2.2 $GOT(sym) / $DPR_GOT(sym)

The $GOT(sym) operator can be applied in the source operand of an LDW instruction. The $DPR_GOT(sym) operator can be applied in the source operand of a MVKL or MVKH instruction. These operators are used in the context of compiler-generated code under a dynamic linking ABI (either the Bare-Metal or Linux Dynamic Linking Model; see the external wiki (http://processors.wiki.ti.com/index.php/C6000_Dynamic_Linking) for more details on the dynamic linking models supported in the C6000 Code Generation Tools (CGT)).

Symbols that are preemptable or are imported by a dynamic module will be accessed via the Global Offset Table (GOT). A GOT entry for a symbol will contain the address of the symbol as it is determined at dynamic load time. To facilitate this resolution, the static linker will emit a dynamic relocation entry that is to be processed by the dynamic linker/loader. For more information on the GOT, see the Dynamic Linking wiki site or *The C6000 Embedded Application Binary Interface Application Report* (SPRAB89).

If the GOT entry for a symbol, xyz, is accessible using DP-relative addressing mode, then the compiler will generate a sequence to load the symbol that uses the $GOT(sym) op0erator as the offset part of the DP-relative addressing mode operand:

```
    LDW    *+DP[$GOT(xyz)],A0      ; load address of xyz into A0
                                   ; via access to GOT entry
    LDW    *A0,A1                  ; load xyz into A2
```

The actual semantics of the $GOT(sym) operator is to return the DP- relative offset of the GOT entry for the referenced symbol (xyz above).

While $DPR_GOT(sym) is semantically similar to the $GOT(sym) operator, it is used when the GOT is not accessible using DP-relative addressing mode (offset is not within signed 15-bit range of the static base address that is loaded into the data pointer register (DP)). The DP-relative offset to the GOT entry is then loaded into an index register using a MVKL/MVKH instruction sequence, and the GOT entry is then accessed via DP-relative indexed addressing to load the address of the referenced symbol:

```
    MVKL   $DPR_GOT(xyz),A0        ; load DP-relative offset of
    MVKH   $DPR_GOT(xyz),A0        ; GOT entry for xyz into A0
    LDW    *+DP[A0],A1             ; get address of xyz via GOT entry
    LDW    *A1,A2                  ; load xyz into A2
```

4.10.2.3 $PCR_OFFSET(x,y)

The $PCR_OFFSET(x,y) operator can be applied in the source operand of a MVKL, MVKH, or ADDK instruction to compute a PC-relative offset to be loaded into (in the case of MVKL/MVKH) or added to (in the case of ADDK) a register.

This operator is used in the context of compiler-generated code under the Linux ABI (using --linux compiler option). It helps the compiler to generate position-independent code by accessing a symbol that is defined in the same RO segment using PC-relative addressing.

For example, if there is to be a call to a function defined in the same file, but you would like to avoid generating a dynamic relocation that accesses the symbol that represents the destination of the call, then you can use the $PCR_OFFSET operator as follows:

```
dest:
    <code>
    ...

make_pcr_call:
    MVC PCE1, B0                            ; set up PC reference point in B0
    MVKL $PCR_OFFSET(dest, make_pcr_call), B1 ; compute dest - make_pcr_call
    MVKH $PCR_OFFSET(dest, make_pcr_call), B1 ; and load it into B1
    ADD B0,B1,B0                            ; compute dest address into B0 register
    B B0                                    ; call dest indirectly through B0
    ...
```

The above code sequence is position independent. No matter what address 'dest' is placed at load time, the call to 'dest' will still work since it is independent of the actual address of 'dest'. However, the call does have to maintain its position relative to the definition of 'dest'.

Also in the above sequence, the compiler creates a coupling between the MVC instruction and the 'make_pcr_call' label. The 'make_pcr_call' label must be associated with the address of the MVC instruction so that when the $PCR_OFFSET(dest, make_pcr_call) operator is applied, the 'make_pcr_call' symbol becomes a representative for the PC reference point. This means that the result of 'dest - make_pcr_call' becomes the PC-relative offset which when added to the PC reference point in B0 gives the address of 'dest'.

The relocation that is generated for the $PCR_OFFSET() operator is handled during the static link step in which a dynamic module is built. This static relocation can then be discarded and no dynamic relocation will be needed to resolve the call to 'dest' in the above example.

4.10.2.4 $LABEL_DIFF(x,y) Operator

The $LABEL_DIFF(x,y) operator can be applied to an argument for a 32-bit data-defining directive (like .word, for example). The operator simply computes the difference between two labels that are defined in the same section. This operator is sometimes used by the compiler under the Linux ABI (--linux compiler option) when generating position independent code for a switch statement.

For example, in Example 4-4 a switch table is generated which contains the PC-relative offsets of the switch case labels:

Example 4-4. Generating a Switch Table With Offset Switch Case Labels

```
      .asg A15, FP
      .asg B14, DP
      .asg B15, SP

      .global $bss

      .sect ".text"
      .clink
      .global myfunc
;******************************************************************************
;* FUNCTION NAME: myfunc *
;******************************************************************************
myfunc:
;** ------------------------------------------------------------------------*
      B .S1          $C$L10
||    SUB .L2X    A4,10,B5
||    STW .D2T2   B3,*SP--(16)
      CMPGTU .L2  B5,7,B0
||    STW .D2T1   A4,*+SP(12)
||    MV .S2X     A4,B4
  [ B0] BNOP .S1  $C$L9,3
      ; BRANCH OCCURS {$C$L10} ; |6|
;** ------------------------------------------------------------------------*
$C$L1:
      <case 0 code>
      ...
;** ------------------------------------------------------------------------*
$C$L2:
      <case 1 code>
      ...
;** ------------------------------------------------------------------------*
$C$L3:
      <case 2 code>
      ...
;** ------------------------------------------------------------------------*
$C$L4:
      <case 3 code>
      ...
;** ------------------------------------------------------------------------*
$C$L5:
      <case 4 code>
```

Example 4-4. Generating a Switch Table With Offset Switch Case Labels (continued)

```
      ...
;** --------------------------------------------------------------------------*
$C$L6:
      <case 5 code>
      ...
;** --------------------------------------------------------------------------*
$C$L7:
      <case 6 code>
      ...
;** --------------------------------------------------------------------------*
$C$L8:
      <case 7 code>
      ...
;** --------------------------------------------------------------------------*
$C$L9:
      <default case code>
      ...
;** --------------------------------------------------------------------------*
$C$L10:
      NOP 2
      ; BRANCHCC OCCURS {$C$L9} {-9} ;
;** --------------------------------------------------------------------------*
      SUB .L2     B4,10,B5    ; Norm switch value -> switch table index
||    ADDKPC .S2  $C$SW1,B4,0 ; Load address of switch table to B4
      LDW .D2T2   *+B4[B5],B5 ; Load PC-relative offset from switch table
      NOP         4
      ADD .L2     B5,B4,B4    ; Combine to get case label into B5
      BNOP .S2    B4,5        ; Branch to case label
      ; BRANCH OCCURS {B4} ;

; Switch table definition
      .align 32
      .clink
$C$SW1: .nocmp
      .word $LABEL_DIFF($C$L1,$C$SW1) ; 10
      .word $LABEL_DIFF($C$L2,$C$SW1) ; 11
      .word $LABEL_DIFF($C$L3,$C$SW1) ; 12
      .word $LABEL_DIFF($C$L4,$C$SW1) ; 13
      .word $LABEL_DIFF($C$L5,$C$SW1) ; 14
      .word $LABEL_DIFF($C$L6,$C$SW1) ; 15
      .word $LABEL_DIFF($C$L7,$C$SW1) ; 16
      .word $LABEL_DIFF($C$L8,$C$SW1) ; 17
      .align 32
      .sect ".text"
      ...
```

Example 4-4 mixes data into the code section. For C64+ compatible processors, compression will be disabled for the code section that contains the $LABEL_DIFF() operator since the label difference must resolve to a constant value during assembly.

4.11 Source Listings

A source listing shows source statements and the object code they produce. To obtain a listing file, invoke the assembler with the --asm_listing option (see Section 4.3).

Two banner lines, a blank line, and a title line are at the top of each source listing page. Any title supplied by the .title directive is printed on the title line. A page number is printed to the right of the title. If you do not use the .title directive, the name of the source file is printed. The assembler inserts a blank line below the title line.

Each line in the source file produces at least one line in the listing file. This line shows a source statement number, an SPC value, the object code assembled, and the source statement. Figure 4-2 shows these in an actual listing file.

Field 1: Source Statement Number

Line number

The source statement number is a decimal number. The assembler numbers source lines as it encounters them in the source file; some statements increment the line counter but are not listed. (For example, .title statements and statements following a .nolist are not listed.) The difference between two consecutive source line numbers indicates the number of intervening statements in the source file that are not listed.

Include file letter

A letter preceding the line number indicates the line is assembled from the include file designated by the letter.

Nesting level number

A number preceding the line number indicates the nesting level of macro expansions or loop blocks.

Field 2: Section Program Counter

This field contains the SPC value, which is hexadecimal. All sections (.text, .data, .bss, and named sections) maintain separate SPCs. Some directives do not affect the SPC and leave this field blank.

Field 3: Object Code

This field contains the hexadecimal representation of the object code. All machine instructions and directives use this field to list object code. This field also indicates the relocation type associated with an operand for this line of source code. If more than one operand is relocatable, this column indicates the relocation type for the first operand. The characters that can appear in this column and their associated relocation types are listed below:

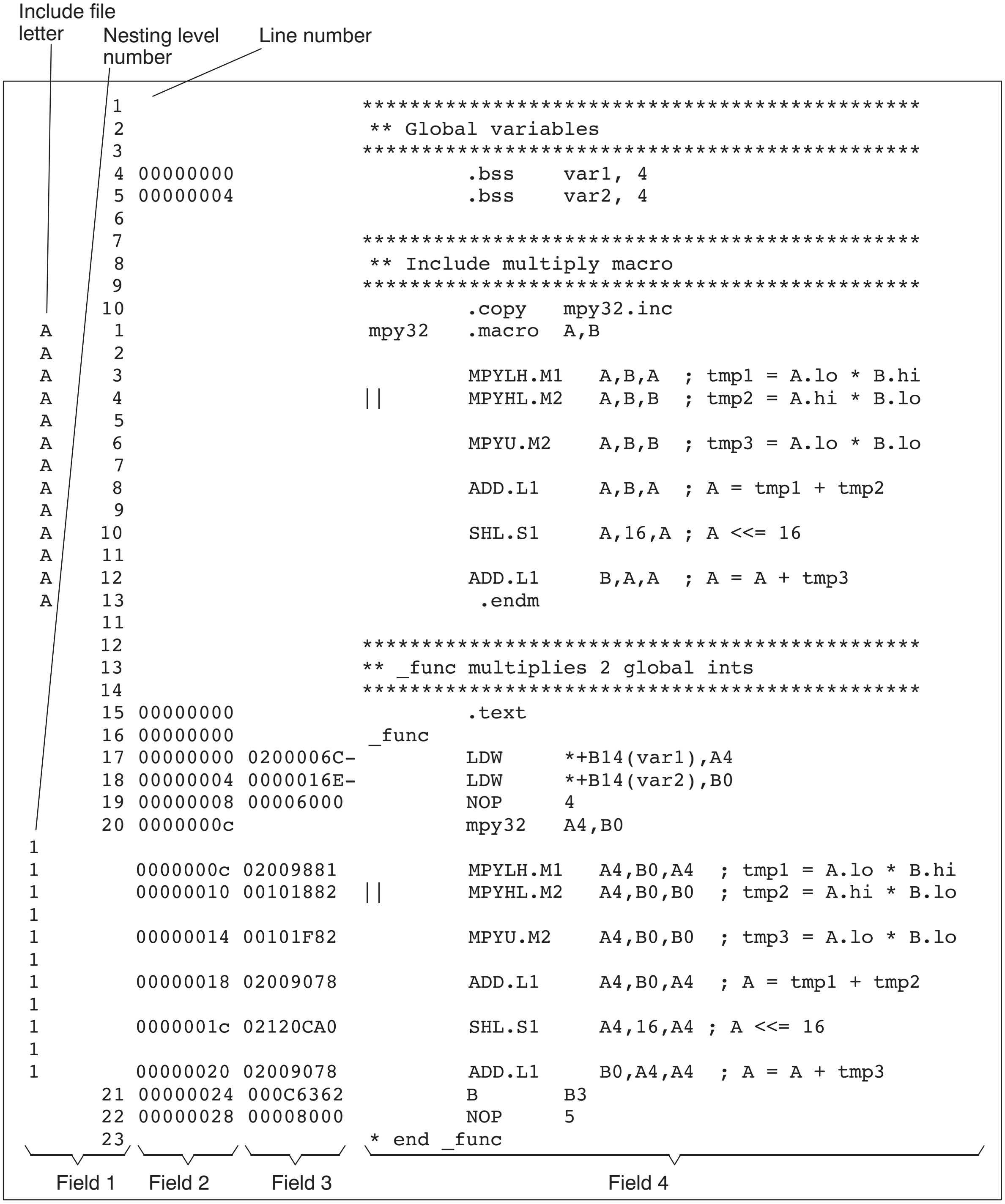
!	undefined external reference
'	.text relocatable
+	.sect relocatable
"	.data relocatable
-	.bss, .usect relocatable
%	relocation expression

Field 4: Source Statement Field

This field contains the characters of the source statement as they were scanned by the assembler. The assembler accepts a maximum line length of 200 characters. Spacing in this field is determined by the spacing in the source statement.

Figure 4-2 shows an assembler listing with each of the four fields identified.

Figure 4-2. Example Assembler Listing



```
       1                    ***********************************************
       2                    ** Global variables
       3                    ***********************************************
       4 00000000                    .bss    var1, 4
       5 00000004                    .bss    var2, 4
       6
       7                    ***********************************************
       8                    ** Include multiply macro
       9                    ***********************************************
      10                             .copy   mpy32.inc
 A     1                    mpy32    .macro  A,B
 A     2
 A     3                             MPYLH.M1   A,B,A  ; tmp1 = A.lo * B.hi
 A     4                    ||       MPYHL.M2   A,B,B  ; tmp2 = A.hi * B.lo
 A     5
 A     6                             MPYU.M2    A,B,B  ; tmp3 = A.lo * B.lo
 A     7
 A     8                             ADD.L1     A,B,A  ; A = tmp1 + tmp2
 A     9
 A    10                             SHL.S1     A,16,A ; A <<= 16
 A    11
 A    12                             ADD.L1     B,A,A  ; A = A + tmp3
 A    13                              .endm
      11
      12                    ***********************************************
      13                    ** _func multiplies 2 global ints
      14                    ***********************************************
      15 00000000                    .text
      16 00000000           _func
      17 00000000 0200006C-          LDW     *+B14(var1),A4
      18 00000004 0000016E-          LDW     *+B14(var2),B0
      19 00000008 00006000           NOP     4
      20 0000000c                    mpy32   A4,B0
1
1        0000000c 02009881           MPYLH.M1   A4,B0,A4   ; tmp1 = A.lo * B.hi
1        00000010 00101882  ||       MPYHL.M2   A4,B0,B0   ; tmp2 = A.hi * B.lo
1
1        00000014 00101F82           MPYU.M2    A4,B0,B0   ; tmp3 = A.lo * B.lo
1
1        00000018 02009078           ADD.L1     A4,B0,A4   ; A = tmp1 + tmp2
1
1        0000001c 02120CA0           SHL.S1     A4,16,A4 ; A <<= 16
1
1        00000020 02009078           ADD.L1     B0,A4,A4   ; A = A + tmp3
      21 00000024 000C6362           B       B3
      22 00000028 00008000           NOP     5
      23                    * end _func
```

4.12 Debugging Assembly Source

By default, when you compile an assembly file, the assembler provides symbolic debugging information that allows you to step through your assembly code in a debugger rather than using the Disassembly window in Code Composer Studio. This enables you to view source comments and other source-code annotations while debugging. The default has the same behavior as using the --symdebug:dwarf option. You can disable the generation of debugging information by using the --symdebug:none option.

The .asmfunc and .endasmfunc (see .asmfunc directive) directives enable you to use C characteristics in assembly code that makes the process of debugging an assembly file more closely resemble debugging a C/C++ source file.

The .asmfunc and .endasmfunc directives allow you to name certain areas of your code, and make these areas appear in the debugger as C functions. Contiguous sections of assembly code that are not enclosed by the .asmfunc and .endasmfunc directives are automatically placed in assembler-defined functions named with this syntax:

$ *filename* **:** *starting source line* **:** *ending source line* **$**

If you want to view your variables as a user-defined type in C code, the types must be declared and the variables must be defined in a C file. This C file can then be referenced in assembly code using the .ref directive (see .ref directive). Example 4-5 shows the cvar.c C program that defines a variable, svar, as the structure type X. The svar variable is then referenced in the addfive.asm assembly program in Example 4-6 and 5 is added to svar's second data member.

Compile both source files with the --symdebug:dwarf option (-g) and link them as follows:

```
cl6x --symdebug:dwarf cvars.c addfive.asm --run_linker --library=lnk.cmd --library=rts6200.lib
     --output_file=addfive.out
```

When you load this program into a symbolic debugger, addfive appears as a C function. You can monitor the values in svar while stepping through main just as you would any regular C variable.

Example 4-5. Viewing Assembly Variables as C Types C Program

```
typedef struct
{
   int m1;
   int m2;
} X;
X svar = { 1, 2 };
```

Example 4-6. Assembly Program for Example 4-5

```
;-------------------------------------------------------------------------------------
; Tell the assembler we're referencing variable "_svar", which is defined in
; another file (cvars.c).
;-------------------------------------------------------------------------------------
          .ref _svar
;-------------------------------------------------------------------------------------
; addfive() - Add five to the second data member of _svar
;-------------------------------------------------------------------------------------
          .text
          .global addfive
addfive:  .asmfunc
           LDW     .D2T2    *+B14(_svar+4),B4 ; load svar.m2 into B4
           RET     .S2      B3                ; return from function
           NOP              3                 ; delay slots 1-3
           ADD     .D2      5,B4,B4           ; add 5 to B4 (delay slot 4)
           STW     .D2T2    B4,*+B14(_svar+4) ; store B4 back into svar.m2 (delay slot 5)
          .endasmfunc
```

4.13 Cross-Reference Listings

A cross-reference listing shows symbols and their definitions. To obtain a cross-reference listing, invoke the assembler with the --cross_reference option (see Section 4.3) or use the .option directive with the X operand (see Select Listing Options). The assembler appends the cross-reference to the end of the source listing. Example 4-7 shows the four fields contained in the cross-reference listing.

Example 4-7. An Assembler Cross-Reference Listing

```
LABEL                         VALUE          DEFN    REF

.BIG_ENDIAN                   00000000        0
.LITTLE_ENDIAN                00000001        0
.TMS320C6200                  00000001        0
.TMS320C6700                  00000000        0
.TMS320C6X                    00000001        0
_func                         00000000'      18
var1                          00000000-       4       17
var2                          00000004-       5       18
```

Label column contains each symbol that was defined or referenced during the assembly.

Value column contains an 8-digit hexadecimal number (which is the value assigned to the symbol) *or* a name that describes the symbol's attributes. A value may also be preceded by a character that describes the symbol's attributes. Table 4-6 lists these characters and names.

Definition (DEFN) column contains the statement number that defines the symbol. This column is blank for undefined symbols.

Reference (REF) column lists the line numbers of statements that reference the symbol. A blank in this column indicates that the symbol was never used.

Table 4-6. Symbol Attributes

Character or Name	Meaning
REF	External reference (global symbol)
UNDF	Undefined
'	Symbol defined in a .text section
"	Symbol defined in a .data section
+	Symbol defined in a .sect section
-	Symbol defined in a .bss or .usect section

Chapter 5

SPRU186X – March 2014

Assembler Directives

Assembler directives supply data to the program and control the assembly process. Assembler directives enable you to do the following:

- Assemble code and data into specified sections
- Reserve space in memory for uninitialized variables
- Control the appearance of listings
- Initialize memory
- Assemble conditional blocks
- Define global variables
- Specify libraries from which the assembler can obtain macros
- Examine symbolic debugging information

This chapter is divided into two parts: the first part (Section 5.1 through Section 5.11) describes the directives according to function, and the second part (Section 5.12) is an alphabetical reference.

Topic **Page**

5.1 Directives Summary

Table 5-1 through Table 5-17 summarize the assembler directives.

Besides the assembler directives documented here, the TMS320C6000 software tools support the following directives:

- Macro directives are discussed in Chapter 6; they are not discussed in this chapter.
- The assembly optimizer uses several directives that supply data and control the optimization process. Assembly optimizer directives are discussed in the *TMS320C6000 Optimizing Compiler User's Guide*.
- The C compiler uses directives for symbolic debugging. Unlike other directives, symbolic debugging directives are not used in most assembly language programs. Appendix A discusses these directives; they are not discussed in this chapter.

Labels and Comments Are Not Shown in Syntaxes

NOTE: Most source statements that contain a directive can also contain a label and a comment. Labels begin in the first column (only labels and comments can appear in the first column), and comments must be preceded by a semicolon, or an asterisk if the comment is the only element in the line. To improve readability, labels and comments are not shown as part of the directive syntax here. See the detailed description of each directive for using labels with directives.

Table 5-1. Directives that Control Section Use

Mnemonic and Syntax	Description	See
.bss *symbol, size in bytes*[**,** *alignment* [**,** *bank offset*]]	Reserves *size* bytes in the .bss (uninitialized data) section	.bss topic
.data	Assembles into the .data (initialized data) section	.data topic
.sect "*section name***"**	Assembles into a named (initialized) section	.sect topic
.text	Assembles into the .text (executable code) section	.text topic
symbol **.usect "***section name***",** *size in bytes* [**,** *alignment*[**,** *bank offset*]]	Reserves *size* bytes in a named (uninitialized) section	.usect topic

Table 5-2. Directives that Gather Sections into Common Groups

Mnemonic and Syntax	Description	See
.endgroup	Ends the group declaration	.endgroup topic
.gmember *section name*	Designates *section name* as a member of the group	.gmember topic
.group *group section name group type* **:**	Begins a group declaration	.group topic

Table 5-3. Directives that Affect Unused Section Elimination

Mnemonic and Syntax	Description	See
.clink "*section name***"**	Enables conditional linking for the current or specified section	.clink topic
.retain "*section name***"**	EABI only. Instructs the linker to include the current or specified section in the linked output file, regardless of whether the section is referenced or not	.retain topic
.retainrefs "*section name***"**	EABI only. Instructs the linker to include any data object that references the current or specified section.	.retain topic

Table 5-4. Directives that Initialize Values (Data and Memory)

Mnemonic and Syntax	Description	See
.bits $value_1$[**,** ... **,** $value_n$]	Initializes one or more successive bits in the current section	.bits topic
.byte $value_1$[**,** ... **,** $value_n$]	Initializes one or more successive bytes in the current section	.byte topic
.char $value_1$[**,** ... **,** $value_n$]	Initializes one or more successive bytes in the current section	.char topic

Table 5-4. Directives that Initialize Values (Data and Memory) (continued)

Mnemonic and Syntax	Description	See
.cstring {*expr*$_1$|**"***string*$_1$**"**}[,... , {*expr*$_n$|**"***string*$_n$**"**}]	Initializes one or more text strings	.string topic
.double *value*$_1$[, ... , *value*$_n$]	Initializes one or more 64-bit, IEEE double-precision, floating-point constants	.double topic
.field *value*[, *size*]	Initializes a field of *size* bits (1-32) with *value*	.field topic
.float *value*$_1$[, ... , *value*$_n$]	Initializes one or more 32-bit, IEEE single-precision, floating-point constants	.float topic
.half *value*$_1$[, ... , *value*$_n$]	Initializes one or more 16-bit integers (halfword)	.half topic
.int *value*$_1$[, ... , *value*$_n$]	Initializes one or more 32-bit integers	.int topic
.long *value*$_1$[, ... , *value*$_n$]	Initializes one or more 32-bit integers	.long topic
.short *value*$_1$[, ... , *value*$_n$]	Initializes one or more 16-bit integers (halfword)	.short topic
.string {*expr*$_1$|**"***string*$_1$**"**}[,... , {*expr*$_n$|**"***string*$_n$**"**}]	Initializes one or more text strings	.string topic
.ubyte *value*$_1$[, ... , *value*$_n$]	Initializes one or more successive unsigned bytes in the current section	.ubyte topic
.uchar *value*$_1$[, ... , *value*$_n$]	Initializes one or more successive unsigned bytes in the current section	.uchar topic
.uhalf *value*$_1$[, ... , *value*$_n$]	Initializes one or more unsigned 16-bit integers (halfword)	.uhalf topic
.uint *value*$_1$[, ... , *value*$_n$]	Initializes one or more unsigned 32-bit integers	.uint topic
.ulong *value*$_1$[, ... , *value*$_n$]	Initializes one or more unsigned 32-bit integers	.long topic
.ushort *value*$_1$[, ... , *value*$_n$]	Initializes one or more unsigned 16-bit integers (halfword)	.short topic
.uword *value*$_1$[, ... , *value*$_n$]	Initializes one or more unsigned 32-bit integers	.uword topic
.word *value*$_1$[, ... , *value*$_n$]	Initializes one or more 32-bit integers	.word topic

Table 5-5. Directives that Perform Alignment and Reserve Space

Mnemonic and Syntax	Description	See
.align [*size in bytes*]	Aligns the SPC on a boundary specified by *size in bytes*, which must be a power of 2; defaults to byte boundary	.align topic
.bes *size*	Reserves *size* bytes in the current section; a label points to the end of the reserved space	.bes topic
.space *size*	Reserves *size* bytes in the current section; a label points to the beginning of the reserved space	.space topic

Table 5-6. Directives that Format the Output Listing

Mnemonic and Syntax	Description	See
.drlist	Enables listing of all directive lines (default)	.drlist topic
.drnolist	Suppresses listing of certain directive lines	.drnolist topic
.fclist	Allows false conditional code block listing (default)	.fclist topic
.fcnolist	Suppresses false conditional code block listing	.fcnolist topic
.length [*page length*]	Sets the page length of the source listing	.length topic
.list	Restarts the source listing	.list topic
.mlist	Allows macro listings and loop blocks (default)	.mlist topic
.mnolist	Suppresses macro listings and loop blocks	.mnolist topic
.nolist	Stops the source listing	.nolist topic
.option *option*$_1$ [, *option*$_2$, . . .]	Selects output listing options; available options are A, B, D, H, L, M, N, O, R, T, W, and X	.option topic
.page	Ejects a page in the source listing	.page topic
.sslist	Allows expanded substitution symbol listing	.sslist topic
.ssnolist	Suppresses expanded substitution symbol listing (default)	.ssnolist topic
.tab *size*	Sets tab to *size* characters	.tab topic

Table 5-6. Directives that Format the Output Listing (continued)

Mnemonic and Syntax	Description	See
.title "*string***"**	Prints a title in the listing page heading	.title topic
.width [*page width*]	Sets the page width of the source listing	.width topic

Table 5-7. Directives that Reference Other Files

Mnemonic and Syntax	Description	See
.copy ["]*filename*["]	Includes source statements from another file	.copy topic
.include ["]*filename*["]	Includes source statements from another file	.include topic
.mlib ["]*filename*["]	Specifies a macro library from which to retrieve macro definitions	.mlib topic

Table 5-8. Directives that Affect Symbol Linkage and Visibility

Mnemonic and Syntax	Description	See
.common *symbol, size in bytes* [, *alignment*]r **.common** *symbol, structure tag* [, *alignment*]	Defines a common symbol for a variable. (ELF only)	.common topic
.def *symbol*$_1$[**,** ... **,** *symbol*$_n$]	Identifies one or more symbols that are defined in the current module and that can be used in other modules	.def topic
.farcommon *symbol, size in bytes* [, *alignment*]r **.farcommon** *symbol, structure tag* [, *alignment*]	Defines a common symbol in far memory	.farcommon topic
.global *symbol*$_1$[**,** ... **,** *symbol*$_n$]	Identifies one or more global (external) symbols	.global topic
.nearcommon *symbol, size in bytes* [, *alignment*]r **.nearcommon** *symbol, structure tag* [, *alignment*]	Defines a common symbol in near memory	.farcommon topic
.ref *symbol*$_1$[**,** ... **,** *symbol*$_n$]	Identifies one or more symbols used in the current module that are defined in another module	.ref topic
.symdepend *dst symbol name*[**,** *src symbol name*]	Creates an artificial reference from a section to a symbol	.symdepend topic
.weak *symbol name*	Identifies a symbol used in the current module that is defined in another module	.weak topic

Table 5-9. Directives that Control Dynamic Symbol Visibility

Mnemonic and Syntax	Description	See
.export "*symbolname*"	Sets visibility of *symbolname* to STV_EXPORT	.export topic
.hidden"*symbolname*"	Sets visibility of *symbolname* to STV_HIDDEN	.hidden topic
.import "*symbolname*"	Sets visibility of *symbolname* to STV_IMPORT	.import topic
.protected "*symbolname*"	Sets visibility of *symbolname* to STV_PROTECTED	.protected topic

Table 5-10. Directives that Enable Conditional Assembly

Mnemonic and Syntax	Description	See
.if *condition*	Assembles code block if the *condition* is true	.if topic
.else	Assembles code block if the .if *condition* is false. When using the .if construct, the .else construct is optional.	.else topic
.elseif *condition*	Assembles code block if the .if *condition* is false and the .elseif condition is true. When using the .if construct, the .elseif construct is optional.	.elseif topic
.endif	Ends .if code block	.endif topic
.loop [*count*]	Begins repeatable assembly of a code block; the loop count is determined by the *count*.	.loop topic
.break [*end condition*]	Ends .loop assembly if *end condition* is true. When using the .loop construct, the .break construct is optional.	.break topic
.endloop	Ends .loop code block	.endloop topic

Table 5-11. Directives that Define Union or Structure Types

Mnemonic and Syntax	Description	See
.cstruct	Acts like .struct, but adds padding and alignment like that which is done to C structures	.cstruct topic
.cunion	Acts like .union, but adds padding and alignment like that which is done to C unions	.cunion topic
.emember	Sets up C-like enumerated types in assembly code	Section 5.9
.endenum	Sets up C-like enumerated types in assembly code	Section 5.9
.endstruct	Ends a structure definition	.cstruct topic, .struct topic
.endunion	Ends a union definition	.cunion topic, .union topic
.enum	Sets up C-like enumerated types in assembly code	Section 5.9
.union	Begins a union definition	.union topic
.struct	Begins structure definition	.struct topic
.tag	Assigns structure attributes to a label	.cstruct topic, .struct topic .union topic

Table 5-12. Directives that Define Symbols

Mnemonic and Syntax	Description	See
.asg [**"**]*character string*[**"**]**,** *substitution symbol*	Assigns a character string to *substitution symbol*. Substitution symbols created with .asg can be redefined.	.asg topic
.clearmap	Cancels all .map assignments. Used by compiler for linear assembly source.	.clearmap topic
.define [**"**]*character string*[**"**]**,** *substitution symbol*	Assigns a character string to *substitution symbol*. Substitution symbols created with .define cannot be redefined.	.asg topic
symbol **.equ** *value*	Equates *value* with *symbol*	.equ topic
.elfsym *name*, SYM_SIZE(*size*)	Provides ELF symbol information	.elfsym topic
.eval *expression* **,** *substitution symbol*	Performs arithmetic on a numeric *substitution symbol*	.eval topic
.label *symbol*	Defines a load-time relocatable label in a section	.label topic
.map *symbol*/*register*	Assigns *symbol* to *register*. Used by compiler for linear assembly source.	.map topic
.newblock	Undefines local labels	.newblock topic
symbol **.set** *value*	Equates *value* with *symbol*	.set topic
.unasg *symbol*	Turns off assignment of *symbol* as a substitution symbol	.unasg topic
.undefine *symbol*	Turns off assignment of *symbol* as a substitution symbol	.unasg topic

Table 5-13. Directives that Create or Affect Macros

Mnemonic and Syntax	Description	See
macname **.macro** [*parameter*$_1$][**,**... **,** *parameter*$_n$]	Begin definition of macro named *macname*	.macro topic
.endm	End macro definition	.endm topic
.mexit	Go to .endm	Section 6.2
.mlib *filename*	Identify library containing macro definitions	.mlib topic
.var	Adds a local substitution symbol to a macro's parameter list	.var topic

Table 5-14. Directives that Control Diagnostics

Mnemonic and Syntax	Description	See
.emsg *string*	Sends user-defined error messages to the output device; produces no .obj file	.emsg topic
.mmsg *string*	Sends user-defined messages to the output device	.mmsg topic
.noremark[*num*]	Identifies the beginning of a block of code in which the assembler suppresses the *num* remark	.noremark topic
.remark [*num*]	Resumes the default behavior of generating the remark(s) previously suppressed by .noremark	.remark topic
.wmsg *string*	Sends user-defined warning messages to the output device	.wmsg topic

Table 5-15. Directives that Perform Assembly Source Debug

Mnemonic and Syntax	Description	See
.asmfunc	Identifies the beginning of a block of code that contains a function	.asmfunc topic
.endasmfunc	Identifies the end of a block of code that contains a function	.endasmfunc topic

Table 5-16. Directives that Are Used by the Absolute Lister

Mnemonic and Syntax	Description	See
.setsect	Produced by absolute lister; sets a section	Chapter 9
.setsym	Produced by the absolute lister; sets a symbol	Chapter 9

Table 5-17. Directives that Perform Miscellaneous Functions

Mnemonic and Syntax	Description	See
.cdecls [*options* **,**]**"***filename***"**[**, "***filename2***"**[**,** ...]	Share C headers between C and assembly code	.cdecls topic
.end	Ends program	.end topic
.nocmp	Instructs tools to not utilize 16-bit instructions for section	.nocmp topic

In addition to the assembly directives that you can use in your code, the C/C++ compiler produces several directives when it creates assembly code. These directives are to be used only by the compiler; do not attempt to use these directives.

- DWARF directives listed in Section A.1
- COFF/STABS directives listed in Section A.2
- The **.battr** directive is used to encode build attributes for the object file. For more information about build attributes generated and used by the C6000 Code Generation Tools, please see *The C6000 Embedded Application Binary Interface* application report (SPRAB89).
- The **.bound** directive is used internally for EABI only.
- The **.comdat** directive is used internally for EABI only
- The **.compiler_opts** directive indicates that the assembly code was produced by the compiler, and which build model options were used for this file.
- The **.template** directive is used for early template instantiation. It encodes information about a template that has yet to be instantiated. This is a COFF C++ directive.
- The **.tls** directive is used internally.

5.2 Directives that Define Sections

These directives associate portions of an assembly language program with the appropriate sections:

- The **.bss** directive reserves space in the .bss section for uninitialized variables.
- The **.clink** directive can be used in the COFF ABI model to indicate that a section is eligible for removal at link-time via conditional linking. Thus if no other sections included in the link reference the current or specified section, then the section is not included in the link. The .clink directive can be applied to initialized or uninitialized sections.
- The **.data** directive identifies portions of code in the .data section. The .data section usually contains initialized data.
- The **.retain** directive can be used in the EABI model to indicate that the current or specified section must be included in the linked output. Thus even if no other sections included in the link reference the current or specified section, it is still included in the link.
- The **.retainrefs** directive can be used in the EABI model to force sections that refer to the specified section. This is useful in the case of interrupt vectors.
- The **.sect** directive defines an initialized named section and associates subsequent code or data with that section. A section defined with .sect can contain code or data.
- The **.text** directive identifies portions of code in the .text section. The .text section usually contains executable code.
- The **.usect** directive reserves space in an uninitialized named section. The .usect directive is similar to the .bss directive, but it allows you to reserve space separately from the .bss section.

Chapter 2 discusses these sections in detail.

Example 5-1 shows how you can use sections directives to associate code and data with the proper sections. This is an output listing; column 1 shows line numbers, and column 2 shows the SPC values. (Each section has its own program counter, or SPC.) When code is first placed in a section, its SPC equals 0. When you resume assembling into a section after other code is assembled, the section's SPC resumes counting as if there had been no intervening code.

The directives in Example 5-1 perform the following tasks:

.text	initializes words with the values 1, 2, 3, 4, 5, 6, 7, and 8.
.data	initializes words with the values 9, 10, 11, 12, 13, 14, 15, and 16.
var_defs	initializes words with the values 17 and 18.
.bss	reserves 19 bytes.
xy	reserves 20 bytes.

The .bss and .usect directives do not end the current section or begin new sections; they reserve the specified amount of space, and then the assembler resumes assembling code or data into the current section.

Example 5-1. Sections Directives

```
   00000004 00000002
 6 00000008 00000003           .word   3,4
   0000000c 00000004
 7
 8                    **************************************************
 9                    *     Start assembling into the .data section    *
10                    **************************************************
11 00000000                    .data
12 00000000 00000009           .word   9, 10
   00000004 0000000A
13 00000008 0000000B           .word   11, 12
   0000000c 0000000C
14
15                    **************************************************
16                    *       Start assembling into a named,           *
17                    *       initialized section, var_defs            *
18                    **************************************************
19 00000000                    .sect   "var_defs"
20 00000000 00000011           .word   17, 18
   00000004 00000012
21
22                    **************************************************
23                    *    Resume assembling into the .data section    *
24                    **************************************************
25 00000010                    .data
26 00000010 0000000D           .word   13, 14
   00000014 0000000E
27 00000000                    .bss    sym, 19   ; Reserve space in .bss
28 00000018 0000000F           .word   15, 16    ; Still in .data
   0000001c 00000010
29
30                    **************************************************
31                    *    Resume assembling into the .text section    *
32                    **************************************************
33 00000010                    .text
34 00000010 00000005           .word   5, 6
   00000014 00000006
35 00000000           usym    .usect  "xy", 20   ; Reserve space in xy
36 00000018 00000007           .word   7, 8      ; Still in .text
   0000001c 00000008
```

5.3 Directives that Initialize Values

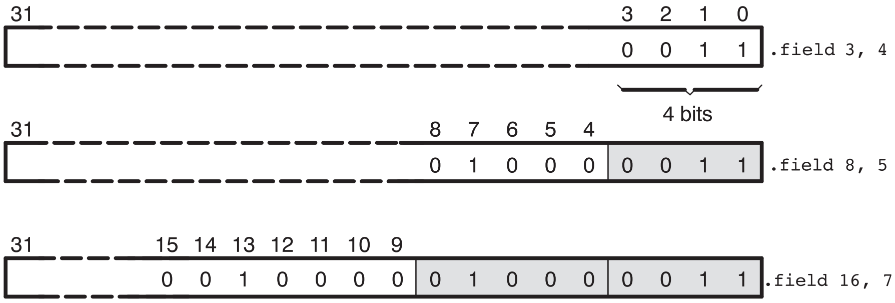
Several directives assemble values for the current section. For example:

- The **.byte** and **.char** directives place one or more 8-bit values into consecutive bytes of the current section. These directives are similar to .word, .int, and .long, except that the width of each value is restricted to 8 bits.
- The **.double** directive calculates the double-precision (64-bit) IEEE floating-point representation of one or more floating-point values and stores them in two consecutive words in the current section. The .double directive automatically aligns to the double-word boundary.
- The **.field** directive places a single value into a specified number of bits in the current word. With .field, you can pack multiple fields into a single word; the assembler does not increment the SPC until a word is filled.

Figure 5-1 shows how fields are packed into a word. Using the following assembled code, notice that the SPC does not change (the fields are packed into the same word):

```
1 00000000 00000003          .field  3,4
2 00000000 00000083          .field  8,5
3 00000000 00002083          .field  16,7
```

Figure 5-1. The .field Directive



- The **.float** directive calculates the single-precision (32-bit) IEEE floating-point representation of a single floating-point value and stores it in a word in the current section that is aligned to a word boundary.
- The **.half** and **.short** directives place one or more 16-bit values into consecutive 16-bit fields (halfwords) in the current section. These directives automatically align to a short (2-byte) boundary.
- The **.int**, **.long**, and **.word** directives place one or more 32-bit values into consecutive 32-bit fields (words) in the current section. These directives automatically align to a word boundary.
- The **.string** and **.cstring** directives place 8-bit characters from one or more character strings into the current section. The .string and .cstring directives are similar to .byte, placing an 8-bit character in each consecutive byte of the current section. The .cstring directive adds a NUL character needed by C; the .string directive does not add a NUL character.
- The **.ubyte**, **.uchar**, **.uhalf**, **.uint**, **.ulong**, **.ushort**, and **.uword** directives are provided as unsigned versions of their respective signed directives. These directives are used primarily by the C/C++ compiler to support unsigned types in C/C++.

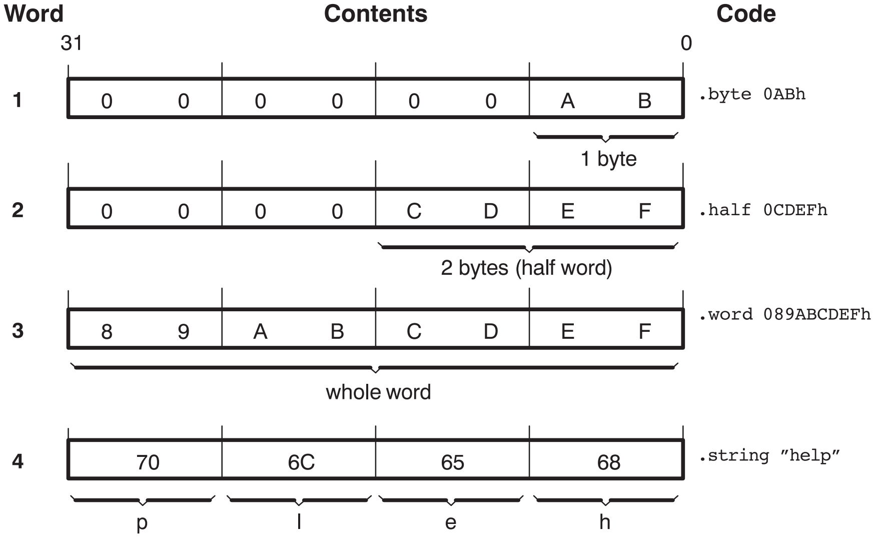
Directives that Initialize Constants When Used in a .struct/.endstruct Sequence

NOTE: The .bits, .byte, .char, .int, .long, .word, .double, .half, .short, .string, .ubyte, .uchar, .uhalf, .uint, .ulong, .ushort, .uword, .float, and .field directives do not initialize memory when they are part of a .struct/ .endstruct sequence; rather, they define a member's size. For more information, see the .struct/.endstruct directives.

Figure 5-2 compares the .byte, .half, .word, and .string directives using the following assembled code:

```
1 00000000 000000AB          .byte   0ABh
2                            .align 4
3 00000004 0000CDEF          .half   0CDEFh
4 00000008 89ABCDEF          .word   089ABCDEFh
5 0000000c 00000068          .string "help"
  0000000d 00000065
  0000000e 0000006C
  0000000f 00000070
```

Figure 5-2. Initialization Directives



5.4 Directives that Perform Alignment and Reserve Space

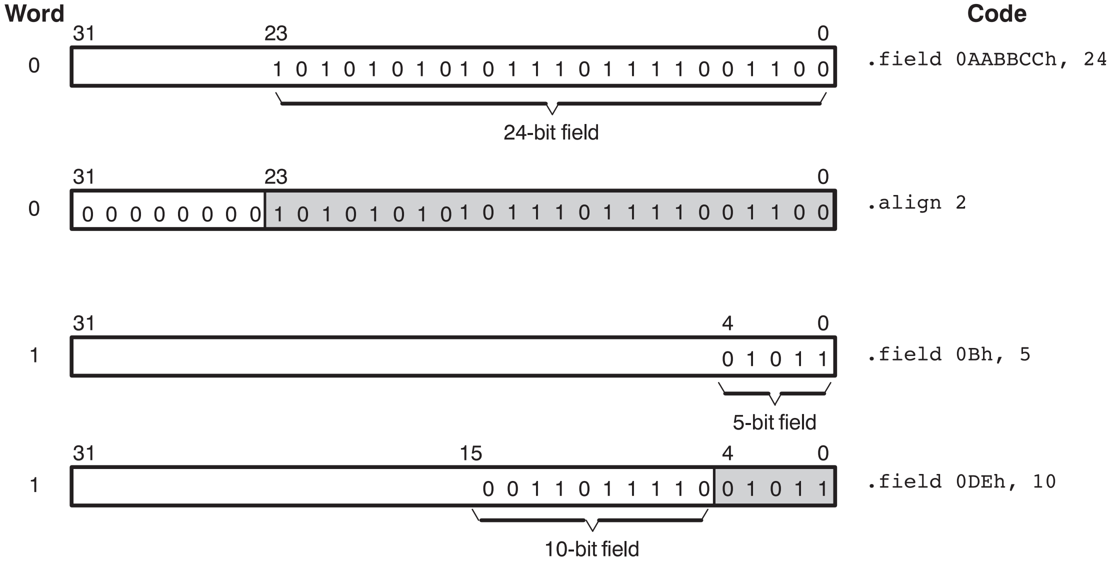
These directives align the section program counter (SPC) or reserve space in a section:

- The **.align** directive aligns the SPC at the next byte boundary. This directive is useful with the .field directive when you do not want to pack two adjacent fields in the same byte. The size specified by the .align directive must equal a power of 2; the value must be between 1 and 32,768, inclusive.

  Figure 5-3 demonstrates the .align directive. Using the following assembled code:

```
1
2 00000000 00AABBCC          .field  0AABBCCh,24
3                            .align  2
4 00000000 0BAABBCC          .field  0Bh,5
5 00000004 000000DE          .field  0DEh,10
```

Figure 5-3. The .align Directive



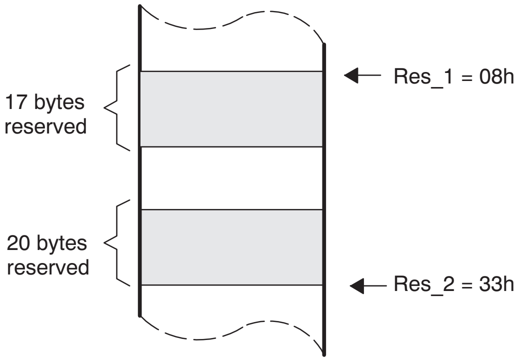
- The **.bes** and **.space** directives reserve a specified number of bytes in the current section. The assembler fills these reserved bytes with 0s.
  – When you use a label with .space, it points to the *first* byte that contains reserved bits.
  – When you use a label with .bes, it points to the *last* byte that contains reserved bits.

  Figure 5-4 shows how the .space and .bes directives work for the following assembled code:

```
1
2 00000000 00000100           .word     100h, 200h
  00000004 00000200
3 00000008          Res_1:    .space    17
4 0000001c 0000000F           .word     15
5 00000033          Res_2:    .bes      20
6 00000034 000000BA           .byte     0BAh
```

  Res_1 points to the first byte in the space reserved by .space. Res_2 points to the last byte in the space reserved by .bes.

Figure 5-4. The .space and .bes Directives



5.5 Directives that Format the Output Listings

These directives format the listing file:

- The **.drlist** directive causes printing of the directive lines to the listing; the **.drnolist** directive turns it off for certain directives. You can use the .drnolist directive to suppress the printing of the following directives. You can use the .drlist directive to turn the listing on again.

.asg
.break
.emsg
.eval
.fclist
.fcnolist
.length
.mlist
.mmsg
.mnolist
.sslist
.ssnolist
.var
.width
.wmsg

- The source code listing includes false conditional blocks that do not generate code. The **.fclist** and **.fcnolist** directives turn this listing on and off. You can use the .fclist directive to list false conditional blocks exactly as they appear in the source code. You can use the .fcnolist directive to list only the conditional blocks that are actually assembled.
- The **.length** directive controls the page length of the listing file. You can use this directive to adjust listings for various output devices.
- The **.list** and **.nolist** directives turn the output listing on and off. You can use the .nolist directive to prevent the assembler from printing selected source statements in the listing file. Use the .list directive to turn the listing on again.
- The source code listing includes macro expansions and loop blocks. The **.mlist** and **.mnolist** directives turn this listing on and off. You can use the .mlist directive to print all macro expansions and loop blocks to the listing, and the .mnolist directive to suppress this listing.

- The **.option** directive controls certain features in the listing file. This directive has the following operands:

  A turns on listing of all directives and data, and subsequent expansions, macros, and blocks.
  B limits the listing of .byte and .char directives to one line.
  D turns off the listing of certain directives (same effect as .drnolist).
  H limits the listing of .half and .short directives to one line.
  L limits the listing of .long directives to one line.
  M turns off macro expansions in the listing.
  N turns off listing (performs .nolist).
  O turns on listing (performs .list).
  R resets the B, H, L, M, T, and W directives (turns off the limits of B, H, L, M, T, and W).
  T limits the listing of .string directives to one line.
  W limits the listing of .word and .int directives to one line.
  X produces a cross-reference listing of symbols. You can also obtain a cross-reference listing by invoking the assembler with the --cross_reference option (see Section 4.3).

- The **.page** directive causes a page eject in the output listing.
- The source code listing includes substitution symbol expansions. The **.sslist** and **.ssnolist** directives turn this listing on and off. You can use the .sslist directive to print all substitution symbol expansions to the listing, and the .ssnolist directive to suppress this listing. These directives are useful for debugging the expansion of substitution symbols.
- The **.tab** directive defines tab size.
- The **.title** directive supplies a title that the assembler prints at the top of each page.
- The **.width** directive controls the page width of the listing file. You can use this directive to adjust listings for various output devices.

5.6 Directives that Reference Other Files

These directives supply information for or about other files that can be used in the assembly of the current file:

- The **.copy** and **.include** directives tell the assembler to begin reading source statements from another file. When the assembler finishes reading the source statements in the copy/include file, it resumes reading source statements from the current file. The statements read from a copied file are printed in the listing file; the statements read from an included file are *not* printed in the listing file.
- The **.def** directive identifies a symbol that is defined in the current module and that can be used in another module. The assembler includes the symbol in the symbol table.
- The **.global** directive declares a symbol external so that it is available to other modules at link time. (For more information about global symbols, see Section 2.6.1). The .global directive does double duty, acting as a .def for defined symbols and as a .ref for undefined symbols. The linker resolves an undefined global symbol reference only if the symbol is used in the program. The .global directive declares a 16-bit symbol.
- The **.mlib** directive supplies the assembler with the name of an archive library that contains macro definitions. When the assembler encounters a macro that is not defined in the current module, it searches for it in the macro library specified with .mlib.
- The **.ref** directive identifies a symbol that is used in the current module but is defined in another module. The assembler marks the symbol as an undefined external symbol and enters it in the object symbol table so the linker can resolve its definition. The .ref directive forces the linker to resolve a symbol reference.
- The **.symdepend** directive creates an artificial reference from the section defining the source symbol name to the destination symbol. The .symdepend directive prevents the linker from removing the section containing the destination symbol if the source symbol section is included in the output module.
- The **.weak** directive identifies a symbol that is used in the current module but is defined in another module. It is equivalent to the .ref directive, except that the reference has weak linkage.

5.7 Directives that Enable Conditional Assembly

Conditional assembly directives enable you to instruct the assembler to assemble certain sections of code according to a true or false evaluation of an expression. Two sets of directives allow you to assemble conditional blocks of code:

- The **.if/.elseif/.else/.endif** directives tell the assembler to conditionally assemble a block of code according to the evaluation of an expression.

  .if *condition* marks the beginning of a conditional block and assembles code if the .if *condition* is true.

  [**.elseif** *condition*] marks a block of code to be assembled if the .if *condition* is false and the .elseif condition is true.

  .else marks a block of code to be assembled if the .if *condition* is false and any .elseif conditions are false.

  .endif marks the end of a conditional block and terminates the block.

- The **.loop/.break/.endloop** directives tell the assembler to repeatedly assemble a block of code according to the evaluation of an expression.

  .loop [*count*] marks the beginning of a repeatable block of code. The optional expression evaluates to the loop count.

  .break [*end condition*] tells the assembler to assemble repeatedly when the .break *end condition* is false and to go to the code immediately after .endloop when the expression is true or omitted.

  .endloop marks the end of a repeatable block.

The assembler supports several relational operators that are useful for conditional expressions. For more information about relational operators, see Section 4.9.2.

5.8 Directives that Define Union or Structure Types

These directives set up specialized types for later use with the .tag directive, allowing you to use symbolic names to refer to portions of a complex object. The types created are analogous to the struct and union types of the C language.

The .struct, .union, .cstruct, and .cunion directives group related data into an aggregate structure which is more easily accessed. These directives do not allocate space for any object. Objects must be separately allocated, and the .tag directive must be used to assign the type to the object.

```
COORDT .struct                  ; structure tag definition
X      .byte                    ;
Y      .byte
T_LEN  .endstruct

COORD  .tag COORDT              ; declare COORD (coordinate)
       .bss COORD, T_LEN        ; actual memory allocation

       LDB  *+B14(COORD.Y), A2 ; move member Y of structure
                                ; COORD into register A2
```

The .cstruct and .cunion directives guarantee that the data structure will have the same alignment and padding as if the structure were defined in analogous C code. This allows structures to be shared between C and assembly code. See Chapter 13. For .struct and .union, element offset calculation is left up to the assembler, so the layout may be different than .cstruct and .cunion.

5.9 Directives that Define Enumerated Types

These directives set up specialized types for later use in expressions allowing you to use symbolic names to refer to compile-time constants. The types created are analogous to the enum type of the C language. This allows enumerated types to be shared between C and assembly code. See Chapter 13.

See Section 13.2.10 for an example of using .enum.

5.10 Directives that Define Symbols at Assembly Time

Assembly-time symbol directives equate meaningful symbol names to constant values or strings.

- The **.asg** directive assigns a character string to a substitution symbol. The value is stored in the substitution symbol table. When the assembler encounters a substitution symbol, it replaces the symbol with its character string value. Substitution symbols created with .asg can be redefined.

  ```
  .asg "10, 20, 30, 40", coefficients
          ; Assign string to substitution symbol.
  .byte coefficients
          ; Place the symbol values 10, 20, 30, and 40
          ; into consecutive bytes in current section.
  ```

- The **.define** directive assigns a character string to a substitution symbol. The value is stored in the substitution symbol table. When the assembler encounters a substitution symbol, it replaces the symbol with its character string value. Substitution symbols created with .define cannot be redefined.
- The **.eval** directive evaluates a well-defined expression, translates the results into a character string, and assigns the character string to a substitution symbol. This directive is most useful for manipulating counters:

  ```
  .asg      1 , x   ; x = 1
  .loop             ; Begin conditional loop.
  .byte     x*10h   ; Store value into current section.
  .break    x = 4   ; Break loop if x = 4.
  .eval     x+1, x  ; Increment x by 1.
  .endloop          ; End conditional loop.
  ```

- The **.label** directive defines a special symbol that refers to the load-time address within the current section. This is useful when a section loads at one address but runs at a different address. For example, you may want to load a block of performance-critical code into slower off-chip memory to save space and move the code to high-speed on-chip memory to run. See the .label topic for an example using a load-time address label.
- The **.set** and **.equ** directives set a constant value to a symbol. The symbol is stored in the symbol table and cannot be redefined; for example:

  ```
  bval .set 0100h   ; Set bval = 0100h
       .long bval, bval*2, bval+12
          ; Store the values 0100h, 0200h, and 010Ch
          ; into consecutive words in current section.
  ```

  The .set and .equ directives produce no object code. The two directives are identical and can be used interchangeably.
- The **.unasg** directive turns off substitution symbol assignment made with .asg.
- The **.undefine** directive turns off substitution symbol assignment made with .define.
- The **.var** directive allows you to use substitution symbols as local variables within a macro.

5.11 Miscellaneous Directives

These directives enable miscellaneous functions or features:

- The **.asmfunc** and **.endasmfunc** directives mark function boundaries. These directives are used with the compiler --symdebug:dwarf (-g) option to generate debug information for assembly functions.
- The **.cdecls** directive enables programmers in mixed assembly and C/C++ environments to share C headers containing declarations and prototypes between C and assembly code.
- The **.end** directive terminates assembly. If you use the .end directive, it should be the last source statement of a program. This directive has the same effect as an end-of-file character.
- The **.group**, **.gmember**, and **.endgroup** directives define an ELF group section to be shared by several sections.
- The **.import**, **.export**, **.hidden**, and **.protected** directives set the dynamic visibility of a global symbol for ELF only. See Section 8.12 for an explanation of symbol visibility.
- The **.newblock** directive resets local labels. Local labels are symbols of the form $n, where n is a decimal digit, or of the form NAME?, where you specify NAME. They are defined when they appear in the label field. Local labels are temporary labels that can be used as operands for jump instructions. The .newblock directive limits the scope of local labels by resetting them after they are used. See Section 4.8.3 for information on local labels.
- The **.nocmp** directive for C6400+, C6740, and C6600 instructs the tools to not utilize 16-bit instructions for the section .nocmp appears in.
- The **.noremark** directive begins a block of code in which the assembler suppresses the specified assembler remark. A remark is an informational assembler message that is less severe than a warning. The **.remark** directive re-enables the remark(s) previously suppressed by .noremark.

These three directives enable you to define your own error and warning messages:

- The **.emsg** directive sends error messages to the standard output device. The .emsg directive generates errors in the same manner as the assembler, incrementing the error count and preventing the assembler from producing an object file.
- The **.mmsg** directive sends assembly-time messages to the standard output device. The .mmsg directive functions in the same manner as the .emsg and .wmsg directives but does not set the error count or the warning count. It does not affect the creation of the object file.
- The **.wmsg** directive sends warning messages to the standard output device. The .wmsg directive functions in the same manner as the .emsg directive but increments the warning count rather than the error count. It does not affect the creation of the object file.

For more information about using the error and warning directives in macros, see Section 6.7.

5.12 Directives Reference

The remainder of this chapter is a reference. Generally, the directives are organized alphabetically, one directive per topic. Related directives (such as .if/.else/.endif), however, are presented together in one topic.

.align *Align SPC on the Next Boundary*

Syntax **.align** [*size in bytes*]

Description The **.align** directive aligns the section program counter (SPC) on the next boundary, depending on the *size in bytes* parameter. The *size* can be any power of 2, although only certain values are useful for alignment. An operand of 1 aligns the SPC on the next byte boundary, and this is the default if no *size in bytes* is given. The *size in bytes* must equal a power of 2; the value must be between 1 and 32,768, inclusive. The assembler assembles words containing null values (0) up to the next *size in bytes* boundary:

1	aligns SPC to byte boundary
2	aligns SPC to halfword boundary
4	aligns SPC to word boundary
8	aligns SPC to doubleword boundary

Using the .align directive has two effects:

- The assembler aligns the SPC on an x-byte boundary *within* the current section.
- The assembler sets a flag that forces the linker to align the section so that individual alignments remain intact when a section is loaded into memory.

Example This example shows several types of alignment, including .align 2, .align 8, and a default .align.

```
 1 00000000 00000004       .byte      4
 2                         .align     2
 3 00000002 00000045       .string    "Errorcnt"
   00000003 00000072
   00000004 00000072
   00000005 0000006F
   00000006 00000072
   00000007 00000063
   00000008 0000006E
   00000009 00000074
 4                         .align
 5 00000008 0003746E       .field     3,3
 6 00000008 002B746E       .field     5,4
 7                         .align     2
 8 0000000c 00000003       .field     3,3
 9                         .align     8
10 00000010 00000005       .field     5,4
11                         .align
12 00000011 00000004       .byte      4
```

.asg/.define/.eval Assign a Substitution Symbol

Syntax

.asg "*character string***",***substitution symbol*

.define "*character string***",***substitution symbol*

.eval *expression***,***substitution symbol*

Description

The **.asg** and **.define** directives assign character strings to substitution symbols. Substitution symbols are stored in the substitution symbol table. The .asg directive can be used in many of the same ways as the .set directive, but while .set assigns a constant value (which cannot be redefined) to a symbol, .asg assigns a character string (which can be redefined) to a substitution symbol.

- The assembler assigns the *character string* to the substitution symbol.
- The *substitution symbol* must be a valid symbol name. The substitution symbol is up to 128 characters long and must begin with a letter. Remaining characters of the symbol can be a combination of alphanumeric characters, the underscore (_), and the dollar sign ($).

The **.define** directive functions in the same manner as the .asg directive, except that .define disallows creation of a substitution symbol that has the same name as a register symbol or mnemonic. It does not create a new symbol name space in the assembler, rather it uses the existing substitution symbol name space. The .define directive is used to prevent corruption of the assembly environment when converting C/C++ headers. See Chapter 13 for more information about using C/C++ headers in assembly source.

The **.eval** directive performs arithmetic on substitution symbols, which are stored in the substitution symbol table. This directive evaluates the *expression* and assigns the string value of the result to the substitution symbol. The .eval directive is especially useful as a counter in .loop/.endloop blocks.

- The *expression* is a well-defined alphanumeric expression in which all symbols have been previously defined in the current source module, so that the result is an absolute expression.
- The *substitution symbol* must be a valid symbol name. The substitution symbol is up to 128 characters long and must begin with a letter. Remaining characters of the symbol can be a combination of alphanumeric characters, the underscore (_), and the dollar sign ($).

See the .unasg/.undefine topic for information on turning off a substitution symbol.

Example

This example shows how .asg and .eval can be used.

```
       1                            .sslist ; show expanded substitution symbols
       2
       3                            .asg    *+B14(100), GLOB100
       4                            .asg    *+B15(4),   ARG0
       5
       6 00000000 003B22E4          LDW     GLOB100,A0
#                                   LDW     *+B14(100),A0
       7 00000004 00BC22E4          LDW     ARG0,A1
#                                   LDW     *+B15(4),A1
       8 00000008 00006000          NOP     4
       9 0000000c 010401E0          ADD     A0,A1,A2
      10
      11                            .asg    0,x
      12                            .loop   5
      13                            .word   100*x
      14                            .eval   x+1,x
      15                            .endloop
1        00000010 00000000          .word   100*x
#                                   .word   100*0
1                                   .eval   x+1,x
#                                   .eval   0+1,x
1        00000014 00000064          .word   100*x
#                                   .word   100*1
1                                   .eval   x+1,x
#                                   .eval   1+1,x
1        00000018 000000C8          .word   100*x
#                                   .word   100*2
1                                   .eval   x+1,x
#                                   .eval   2+1,x
1        0000001c 0000012C          .word   100*x
#                                   .word   100*3
1                                   .eval   x+1,x
#                                   .eval   3+1,x
1        00000020 00000190          .word   100*x
#                                   .word   100*4
1                                   .eval   x+1,x
#                                   .eval   4+1,x
```

.asmfunc/.endasmfunc *Mark Function Boundaries*

Syntax

symbol **.asmfunc** [**stack_usage(***num***)**]

.endasmfunc

Description

The **.asmfunc** and **.endasmfunc** directives mark function boundaries. These directives are used with the compiler -g option (--symdebug:dwarf) to allow assembly code sections to be debugged in the same manner as C/C++ functions.

You should not use the same directives generated by the compiler (see Appendix A) to accomplish assembly debugging; those directives should be used only by the compiler to generate symbolic debugging information for C/C++ source files.

The .asmfunc and .endasmfunc directives cannot be used when invoking the compiler with the backwards-compatibility --symdebug:coff option. This option instructs the compiler to use the obsolete COFF symbolic debugging format, which does not support these directives.

The *symbol* is a label that must appear in the label field.

The .asmfunc directive has an optional parameter, stack_usage, which indicates that the function may use up to *num* bytes.

Consecutive ranges of assembly code that are not enclosed within a pair of .asmfunc and .endasmfunc directives are given a default name in the following format:

$ *filename* **:** *beginning source line* **:** *ending source line* **$**

Example

This example generates debug information for the user_func section.

```
00000000                      .sect   ".text"
                              .global userfunc
                              .global _printf

                   userfunc:  .asmfunc stack_usage(16)
00000000 00000010!            CALL    .S1     _printf
00000004 01BC94F6             STW     .D2T2   B3,*B15--(16)
00000008 01800E2A'            MVKL    .S2     RL0,B3
0000000c 01800028+            MVKL    .S1     SL1+0,A3
00000010 01800068+            MVKH    .S1     SL1+0,A3

00000014 01BC22F5             STW     .D2T1   A3,*+B15(4)
00000018 0180006A' ||         MVKH    .S2     RL0,B3

0000001c 01BC92E6  RL0:       LDW     .D2T2   *++B15(16),B3
00000020 020008C0             ZERO    .D1     A4
00000024 00004000             NOP             3
00000028 000C0362             RET     .S2     B3
0000002c 00008000             NOP             5
                              .endasmfunc

00000000                      .sect   ".const"
00000000 00000048  SL1:       .string "Hello World!",10,0
00000001 00000065
00000002 0000006C
00000003 0000006C
00000004 0000006F
00000005 00000020
00000006 00000057
00000007 0000006F
00000008 00000072
00000009 0000006C
0000000a 00000064
0000000b 00000021
0000000c 0000000A
0000000d 00000000
```

.bits *Initialize Bits*

Syntax

.bits *value*$_1$[**, ... ,** *value*$_n$]

Description

The **.bits** directive places one or more values into consecutive bits of the current section.

The .bits directive is similar to the .field directive (see .field topic). However, the .bits directive does not allow you to specify the number of bits to fill or increment the SPC.

.bss — *Reserve Space in the .bss Section*

Syntax **.bss** *symbol***,***size in bytes*[**,** *alignment*[**,** *bank offset*]]

Description The **.bss** directive reserves space for variables in the .bss section. This directive is usually used to allocate space in RAM.

- The *symbol* is a required parameter. It defines a symbol that points to the first location reserved by the directive. The symbol name must correspond to the variable that you are reserving space for.
- The *size in bytes* is a required parameter; it must be an absolute constant expression. The assembler allocates size bytes in the .bss section. There is no default size.
- The *alignment* is an optional parameter that ensures that the space allocated to the symbol occurs on the specified boundary. This must be set to a power of 2. If the SPC is already aligned to the specified boundary, it is not incremented.
- The *bank offset* is an optional parameter that ensures that the space allocated to the symbol occurs on a specific memory bank boundary. The bank offset value measures the number of bytes to offset from the alignment specified before assigning the symbol to that location.

For more information about sections, see Chapter 2.

Example In this example, the .bss directive allocates space for a variable, array. The symbol array points to 100 bytes of uninitialized space (at .bss SPC = 0). Symbols declared with the .bss directive can be referenced in the same manner as other symbols and can also be declared global.

```
                   *******************************************
                   **  Start assembling into .text section. **
                   *******************************************
00000000                   .text
00000000 008001A0          MV      A0,A1

                   *******************************************
                   **  Allocate 100 bytes in .bss.          **
                   *******************************************
00000000                   .bss    array,100

                   *******************************************
                   **  Still in .text                       **
                   *******************************************
00000004 010401A0          MV      A1,A2

                   *******************************************
                   **  Declare external .bss symbol         **
                   *******************************************
                           .global array
```

.byte/.ubyte/.char/.uchar *Initialize Byte*

Syntax

.byte *value*$_1$**[, ... ,** *value*$_n$]

.ubyte *value*$_1$**[, ... ,** *value*$_n$]

.char *value*$_1$**[, ... ,** *value*$_n$]

.uchar *value*$_1$**[, ... ,** *value*$_n$]

Description

The **.byte**, **.ubyte**, **.char**, and **.uchar** directives place one or more values into consecutive bytes of the current section. A *value* can be one of the following:

- An expression that the assembler evaluates and treats as an 8-bit signed number
- A character string enclosed in double quotes. Each character in a string represents a separate value, and values are stored in consecutive bytes. The entire string *must* be enclosed in quotes.

With little-endian ordering, the first byte occupies the eight least significant bits of a full 32-bit word. The second byte occupies bits eight through 15 while the third byte occupies bits 16 through 23. The assembler truncates values greater than eight bits.

If you use a label, it points to the location of the first byte that is initialized.

When you use these directives in a .struct/.endstruct sequence, they define a member's size; they do not initialize memory. For more information, see the .struct/.endstruct/.tag topic.

Example

In this example, 8-bit values (10, -1, abc, and a) are placed into consecutive bytes in memory with .byte. Also, 8-bit values (8, -3, def, and b) are placed into consecutive bytes in memory with .char. The label STRX has the value 0h, which is the location of the first initialized byte. The label STRY has the value 6h, which is the first byte initialized by the .char directive.

```
1 00000000 0000000A  STRX    .byte    10,-1,"abc",'a'
  00000001 000000FF
  00000002 00000061
  00000003 00000062
  00000004 00000063
  00000005 00000061
2 00000006 00000008  STRY    .char    8,-3,"def",'b'
```

.cdecls *Share C Headers Between C and Assembly Code*

Syntax **Single Line:**

.cdecls [*options* **,**] **"** *filename* **"**[**, "** *filename2* **"**[**,**...]]

Syntax **Multiple Lines:**

.cdecls [*options*]

%{

/---*/*

/ C/C++ code - Typically a list of #includes and a few defines */*

/---*/*

%}

Description The **.cdecls** directive allows programmers in mixed assembly and C/C++ environments to share C headers containing declarations and prototypes between the C and assembly code. Any legal C/C++ can be used in a .cdecls block and the C/C++ declarations cause suitable assembly to be generated automatically, allowing you to reference the C/C++ constructs in assembly code; such as calling functions, allocating space, and accessing structure members; using the equivalent assembly mechanisms. While function and variable definitions are ignored, most common C/C++ elements are converted to assembly, for instance: enumerations, (non-function-like) macros, function and variable prototypes, structures, and unions.

The .cdecls options control whether the code is treated as C or C++ code; and how the .cdecls block and converted code are presented. Options must be separated by commas; they can appear in any order:

C Treat the code in the .cdecls block as C source code (default).

CPP Treat the code in the .cdecls block as C++ source code. This is the opposite of the C option.

NOLIST Do not include the converted assembly code in any listing file generated for the containing assembly file (default).

LIST Include the converted assembly code in any listing file generated for the containing assembly file. This is the opposite of the NOLIST option.

NOWARN Do not emit warnings on STDERR about C/C++ constructs that cannot be converted while parsing the .cdecls source block (default).

WARN Generate warnings on STDERR about C/C++ constructs that cannot be converted while parsing the .cdecls source block. This is the opposite of the NOWARN option.

In the single-line format, the options are followed by one or more filenames to include. The filenames and options are separated by commas. Each file listed acts as if #include "filename" was specified in the multiple-line format.

In the multiple-line format, the line following .cdecls must contain the opening .cdecls block indicator %{. Everything after the %{, up to the closing block indicator %}, is treated as C/C++ source and processed. Ordinary assembler processing then resumes on the line following the closing %}.

The text within %{ and %} is passed to the C/C++ compiler to be converted into assembly language. Much of C language syntax, including function and variable definitions as well as function-like macros, is not supported and is ignored during the conversion. However, all of what traditionally appears in C header files is supported, including function and variable prototypes; structure and union declarations; non-function-like macros; enumerations; and #defines.

The resulting assembly language is included in the assembly file at the point of the .cdecls directive. If the LIST option is used, the converted assembly statements are printed in the listing file.

The assembly resulting from the .cdecls directive is treated similarly to a .include file. Therefore the .cdecls directive can be nested within a file being copied or included. The assembler limits nesting to ten levels; the host operating system may set additional restrictions. The assembler precedes the line numbers of copied files with a letter code to identify the level of copying. An A indicates the first copied file, B indicates a second copied file, etc.

The .cdecls directive can appear anywhere in an assembly source file, and can occur multiple times within a file. However, the C/C++ environment created by one .cdecls is **not** inherited by a later .cdecls; the C/C++ environment starts new for each .cdecls.

See Chapter 13 for more information on setting up and using the .cdecls directive with C header files.

Example In this example, the .cdecls directive is used call the C header.h file.

C header file:

```
#define WANT_ID 10
#define NAME "John\n"

extern int a_variable;
extern float cvt_integer(int src);

struct myCstruct { int member_a; float member_b; };

enum status_enum { OK = 1, FAILED = 256, RUNNING = 0 };
```

Source file:

```
         .cdecls C,LIST,"myheader.h"

size:    .int $sizeof(myCstruct)
aoffset: .int myCstruct.member_a
boffset: .int myCstruct.member_b
okvalue: .int status_enum.OK
failval: .int status_enum.FAILED
         .if $defined(WANT_ID)
id       .cstring NAME
         .endif
```

Listing File:

```
       1                           .cdecls C,LIST,"myheader.h"
A      1                   ; ------------------------------------------
A      2                   ; Assembly Generated from C/C++ Source Code
A      3                   ; ------------------------------------------
A      4
A      5                   ; =========== MACRO DEFINITIONS ===========
A      6                              .define "10",WANT_ID
A      7                              .define """John\n""",NAME
A      8
A      9                   ; =========== TYPE DEFINITIONS ===========
A     10                   status_enum      .enum
A     11          00000001 OK               .emember 1
A     12          00000100 FAILED           .emember 256
A     13          00000000 RUNNING          .emember 0
A     14                                    .endenum
A     15
A     16                   myCstruct        .struct 0,4
      17                   ; struct size=(8 bytes|64 bits), alignment=4
A     18          00000000 member_a         .field 32
      19                   ; int member_a - offset 0 bytes, size (4 bytes|32 bits)
A     20          00000004 member_b         .field 32
      21                   ; float member_b - offset 4 bytes, size (4 bytes|32 bits)
A     22          00000008                  .endstruct
      23                   ; final size=(8 bytes|64 bits)
A     24
A     25                   ; =========== EXTERNAL FUNCTIONS ===========
A     26                                    .global _cvt_integer
A     27
A     28                   ; =========== EXTERNAL VARIABLES ===========
A     29                                    .global _a_variable
       2 00000000 00000008 size:    .int $sizeof(myCstruct)
       3 00000004 00000000 aoffset: .int myCstruct.member_a
       4 00000008 00000004 boffset: .int myCstruct.member_b
       5 0000000c 00000001 okvalue: .int status_enum.OK
       6 00000010 00000100 failval: .int status_enum.FAILED
       7                            .if $defined(WANT_ID)
       8 00000014 0000004A id       .cstring NAME
         00000015 0000006F
         00000016 00000068
         00000017 0000006E
         00000018 0000000A
         00000019 00000000
       9                            .endif
```

.clink *Conditionally Leave Section Out of Object Module Output*

Syntax

.clink[**"***section name***"**]

Description

The **.clink** directive enables conditional linking by telling the linker to leave a section out of the final object module output of the linker if there are no references found to any symbol in that section. The .clink directive can be applied to initialized or uninitialized sections.

The *section name* identifies the section. If the directive is used without a section name, it applies to the current initialized section. If the directive is applied to an uninitialized section, the section name is required. The section name must be enclosed in double quotes. A section name can contain a subsection name in the form *section name***:***subsection name*.

The .clink directive is useful only with the COFF object file format. Under the COFF ABI model, the linker assumes that all sections are ineligible for removal via conditional linking by default. If you want to make a section eligible for removal, you must apply a .clink directive to it. In contrast, under the ELF EABI model, the linker assumes that all sections are eligible for removal via conditional linking. Therefore, the .clink directive has no effect under EABI.

A section in which the entry point of a C program is defined cannot be marked as a conditionally linked section.

Example

In this example, the Vars and Counts sections are set for conditional linking.

```
 1 00000000                   .sect "Vars"
 2                            .clink
 3                    ; Vars section is conditionally linked
 4
 5 00000000 0000001A  X:      .word 01Ah
 6 00000004 0000001A  Y:      .word 01Ah
 7 00000008 0000001A  Z:      .word 01Ah
 8 00000000                   .sect "Counts"
 9                            .clink
10                     ; Counts section is conditionally linked
11
12 00000000 0000001A  XCount: .word 01Ah
13 00000004 0000001A  YCount: .word 01Ah
14 00000008 0000001A  ZCount: .word 01Ah
15 00000000                   .text
16                    ; By default, .text is unconditionally linked
17
18 00000000 00B802C4          LDH    *B14,A1
19 00000004 00000028+         MVKL    X,A0
20 00000008 00000068+         MVKH   X,A0
21                    ; These references to symbol X cause the Vars
22                    ; section to be linked into the object output
23 0000000c 00040AF8          CMPLT  A0,A1,A0
```

.common Create a Common Symbol

Syntax

.common *symbol*,*size in bytes*[, *alignment*]

.common *symbol*,*structure tag*[, *alignment*]

Description

(ELF only) The **.common** directive creates a common symbol in a common block, rather than placing the variable in a memory section.

This directive is used by the compiler when the --common option is enabled (the default), which causes uninitialized file scope variables to be emitted as common symbols when using ELF. The benefit of common symbols 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.) This optimization happens for C/C++ code by default unless you use the --common=off compiler option.

- The *symbol* is a required parameter. It defines a name for the symbol created by this directive. The symbol name must correspond to the variable that you are reserving space for.
- The *size in bytes* is a required parameter; it must be an absolute expression. The assembler allocates size bytes in the section used for common symbols. There is no default size.
- A *structure tag* can be used in place of a size to specify a structure created with the .struct directive. Either a size or a structure tag is required for this argument.
- The *alignment* is an optional parameter that ensures that the space allocated to the symbol occurs on the specified boundary. The boundary must be set to a power of 2 between 2^0 and 2^{15}, inclusive. If the SPC is already aligned at the specified boundary, it is not incremented.

Common symbols are symbols that are placed in the symbol table of an ELF object file. They represent an uninitialized variable. Common symbols do not reference a section. (In contrast, initialized variables need to reference a section that contains the initialized data.) The value of a common symbol is its required alignment; it has no address and stores no address. While symbols for an uninitialized common block can appear in executable object files, common symbols may only appear in relocatable object files. Common symbols are preferred over weak symbols. See the section on the "Symbol Table" in the System V ABI specification for more about common symbols.

When object files containing common symbols are linked, space is reserved in an uninitialized section for each common symbol. A symbol is created in place of the common symbol to refer to its reserved location.

.copy/.include *Copy Source File*

Syntax

.copy "*filename***"**

.include "*filename***"**

Description

The **.copy** and **.include** directives tell the assembler to read source statements from a different file. The statements that are assembled from a copy file are printed in the assembly listing. The statements that are assembled from an included file are *not* printed in the assembly listing, regardless of the number of .list/.nolist directives assembled.

When a .copy or .include directive is assembled, the assembler:

1. Stops assembling statements in the current source file
2. Assembles the statements in the copied/included file
3. Resumes assembling statements in the main source file, starting with the statement that follows the .copy or .include directive

The *filename* is a required parameter that names a source file. It is enclosed in double quotes and must follow operating system conventions.

You can specify a full pathname (for example, /320tools/file1.asm). If you do not specify a full pathname, the assembler searches for the file in:

1. The directory that contains the current source file
2. Any directories named with the --include_path assembler option
3. Any directories specified by the C6X_A_DIR environment variable
4. Any directories specified by the C6X_C_DIR environment variable

For more information about the --include_path option and C6X_A_DIR, see Section 4.5. For more information about C6X_C_DIR, see the *TMS320C6000 Optimizing Compiler User's Guide*.

The .copy and .include directives can be nested within a file being copied or included. The assembler limits nesting to 32 levels; the host operating system may set additional restrictions. The assembler precedes the line numbers of copied files with a letter code to identify the level of copying. A indicates the first copied file, B indicates a second copied file, etc.

Example 1

In this example, the .copy directive is used to read and assemble source statements from other files; then, the assembler resumes assembling into the current file.

The original file, copy.asm, contains a .copy statement copying the file byte.asm. When copy.asm assembles, the assembler copies byte.asm into its place in the listing (note listing below). The copy file byte.asm contains a .copy statement for a second file, word.asm.

When it encounters the .copy statement for word.asm, the assembler switches to word.asm to continue copying and assembling. Then the assembler returns to its place in byte.asm to continue copying and assembling. After completing assembly of byte.asm, the assembler returns to copy.asm to assemble its remaining statement.

copy.asm (source file)	byte.asm (first copy file)	word.asm (second copy file)
.space 29 .copy "byte.asm" ** Back in original file .string "done"	** In byte.asm .byte 32,1+ 'A' .copy "word.asm" ** Back in byte.asm .byte 67h + 3q	** In word.asm .word 0ABCDh, 56q

Listing file:

```
         1 00000000                .space 29
         2                         .copy "byte.asm"
 A       1                     ** In byte.asm
 A       2 0000001d 00000020       .byte 32,1+ 'A'
           0000001e 00000042
 A       3                         .copy "word.asm"
 B       1                     ** In word.asm
 B       2 00000020 0000ABCD       .word 0ABCDh, 56q
           00000024 0000002E
 A       4                     ** Back in byte.asm
 A       5 00000028 0000006A       .byte 67h + 3q
         3
         4                     ** Back in original file
         5 00000029 00000064       .string "done"
           0000002a 0000006F
           0000002b 0000006E
           0000002c 00000065
```

Example 2

In this example, the .include directive is used to read and assemble source statements from other files; then, the assembler resumes assembling into the current file. The mechanism is similar to the .copy directive, except that statements are not printed in the listing file.

include.asm (source file)	byte2.asm (first copy file)	word2.asm (second copy file)
.space 29 .include "byte2.asm" ** Back in original file .string "done"	** In byte2.asm .byte 32,1+ 'A' .include "word2.asm" ** Back in byte2.asm .byte 67h + 3q	** In word2.asm .word 0ABCDh, 56q

Listing file:

```
         1 00000000                .space 29
         2                         .include "byte2.asm"
         3
         4                     ** Back in original file
         5 00000029 00000064       .string "done"
           0000002a 0000006F
           0000002b 0000006E
           0000002c 00000065
```

.cstruct/.cunion/.endstruct/.endunion/.tag *Declare C Structure Type*

Syntax

[*stag*]	**.cstruct|.cunion**	[*expr*]
[*mem*$_0$]	*element*	[*expr*$_0$]
[*mem*$_1$]	*element*	[*expr*$_1$]
.	.	.
.	.	.
[*mem*$_n$]	**.tag** *stag*	[*expr*$_n$]
[*mem*$_N$]	*element*	[*expr*$_N$]
[*size*]	**.endstruct|.endunion**	
label	**.tag**	*stag*

Description

The **.cstruct** and **.cunion** directives have been added to support ease of sharing of common data structures between assembly and C code. The .cstruct and .cunion directives can be used exactly like the existing .struct and .union directives except that they are guaranteed to perform data layout matching the layout used by the C compiler for C struct and union data types.

In particular, the .cstruct and .cunion directives force the same alignment and padding as used by the C compiler when such types are nested within compound data structures.

The **.endstruct** directive terminates the structure definition. The **.endunion** directive terminates the union definition.

The **.tag** directive gives structure characteristics to a *label*, simplifying the symbolic representation and providing the ability to define structures that contain other structures. The .tag directive does not allocate memory. The structure tag (*stag*) of a .tag directive must have been previously defined.

Following are descriptions of the parameters used with the .struct, .endstruct, and .tag directives:

- The *stag* is the structure's tag. Its value is associated with the beginning of the structure. If no stag is present, the assembler puts the structure members in the global symbol table with the value of their absolute offset from the top of the structure. The stag is optional for .struct, but is required for .tag.
- The *element* is one of the following descriptors: .byte, .char, .int, .long, .word, .double, .half, .short, .string, .float, and .field. All of these except .tag are typical directives that initialize memory. Following a .struct directive, these directives describe the structure element's size. They do not allocate memory. A .tag directive is a special case because stag must be used (as in the definition of stag).
- The *expr* is an optional expression indicating the beginning offset of the structure. The default starting point for a structure is 0.
- The *expr*$_{n/N}$ is an optional expression for the number of elements described. This value defaults to 1. A .string element is considered to be one byte in size, and a .field element is one bit.
- The *mem*$_{n/N}$ is an optional label for a member of the structure. This label is absolute and equates to the present offset from the beginning of the structure. A label for a structure member cannot be declared global.
- The *size* is an optional label for the total size of the structure.

Example

This example illustrates a structure in C that will be accessed in assembly code.

```
typedef struct STRUCT1
; {     int i0;      /* offset 0 */
;       short s0;    /* offset 4 */
; } struct1;         /* size 8, alignment 4 */
;
; typedef struct STRUCT2
; {     struct1 st1; /* offset 0 */
;       short s1;    /* offset 8 */
; } struct2;         /* size 12, alignment 4 */
;
; The structure will get the following offsets once the C compiler lays out the structure
; elements according to the C standard rules:
;
; offsetof(struct1, i0) = 0
; offsetof(struct1, s0) = 4
; sizeof(struct1)       = 8
; offsetof(struct2, s1) = 0
; offsetof(struct2, i1) = 8
; sizeof(struct2)       = 12
;
; Attempts to replicate this structure in assembly using the .struct/.union directives will not
; create the correct offsets because the assembler tries to use the most compact arrangement:

struct1     .struct
i0          .int                ; bytes 0-3
s0          .short        ; bytes 4-5
struct1len  .endstruct          ; size 6, alignment 4

struct2     .struct
st1         .tag struct1        ; bytes 0-5
s1          .short              ; bytes 6-7
endstruct2  .endstruct          ; size 8, alignment 4

        .sect "data1"
        .word struct1.i0        ; 0
        .word struct1.s0        ; 4
        .word struct1len        ; 6

        .sect "data2"
        .word struct2.st1       ; 0
        .word struct2.s1        ; 6
        .word endstruct2        ; 8
;
; The .cstruct/.cunion directives calculate offsets in the same manner as the C compiler. The resulting
; assembly structure can be used to access the elements of the C structure. Compare the difference
; in the offsets of those structures defined via .struct above and the offsets for the C code.

cstruct1    .cstruct
i0          .int                ; bytes 0-3
s0          .short        ; bytes 4-5
cstruct1len .endstruct          ; size 8, alignment 4

cstruct2    .cstruct
st1         .tag cstruct1       ; bytes 0-7
s1          .short        ; bytes 8-9
cendstruct2 .endstruct          ; size 12, alignment 4

        .sect "data3"
        .word cstruct1.i0, struct1.i0   ; 0
        .word cstruct1.s0, struct1.s0   ; 4
        .word cstruct1len, struct1len   ; 8

        .sect "data4"
        .word cstruct2.st1, struct2.st1 ; 0
        .word cstruct2.s1, struct2.s1   ; 8
        .word cendstruct2, endstruct2   ; 12
```

.data

Assemble Into the .data Section

Syntax

.data

Description

The **.data** directive sets .data as the current section; the lines that follow will be assembled into the .data section. The .data section is normally used to contain tables of data or preinitialized variables.

For more information about sections, see Chapter 2.

Example

In this example, code is assembled into the .data and .text sections.

```
 1                    ***********************************************
 2                    **      Reserve space in .data               **
 3                    ***********************************************
 4 00000000                   .data
 5 00000000                   .space  0CCh
 6
 7                    ***********************************************
 8                    **      Assemble into .text                  **
 9                    ***********************************************
10 00000000                   .text
11 00000000 00800358          ABS     A0,A1
12
13                    ***********************************************
14                    **      Assemble into .data                  **
15                    ***********************************************
16 000000cc           table:  .data
17 000000cc FFFFFFFF          .word   -1
18 000000d0 000000FF          .byte   0FFh
19
20                    ***********************************************
21                    **      Assemble into .text                  **
22                    ***********************************************
23 00000004                   .text
24 00000004 008001A0          MV      A0,A1
25
26                    ***********************************************
27                    **  Resume assembling into the .data section **
28                    ***********************************************
29 000000d1                   .data
30 000000d4 00000000  coeff   .word   00h,0ah,0bh
   000000d8 0000000A
   000000dc 0000000B
```

.double — *Initialize Double-Precision Floating-Point Value*

Syntax

.double *value*$_1$ [, ... , *value*$_n$]

Description

The **.double** directive places the IEEE double-precision floating-point representation of one or more floating-point values into the current section. Each *value* must be an absolute constant expression with an arithmetic type or a symbol equated to an absolute constant expression with an arithmetic type. Each constant is converted to a floating-point value in IEEE double-precision 64-bit format. Double-precision floating point constants are aligned to a double word boundary.

The 64-bit value is stored in the format shown in Figure 5-5.

Figure 5-5. Double-Precision Floating-Point Format

S	E E E E E E E E E E E	M M M M M M M M M M M M M M M M M M M M
31	20	0

M M M M M M M M M M M M M M M M M M M M M M M M M M M M M M M M	
31	0

Legend: S = sign
E = exponent (11-bit biased)
M = mantissa (52-bit fraction)

When you use .double in a .struct/.endstruct sequence, .double defines a member's size; it does not initialize memory. For more information, see the .struct/.endstruct/.tag topic.

Example

This example shows the .double directive.

```
1 00000000 2C280291          .double -2.0e25
  00000004 C5308B2A
2 00000008 00000000          .double 6
  0000000c 40180000
3 00000010 00000000          .double 456
  00000014 407C8000
```

.drlist/.drnolist *Control Listing of Directives*

Syntax

.drlist

.drnolist

Description

Two directives enable you to control the printing of assembler directives to the listing file:

The **.drlist** directive enables the printing of all directives to the listing file.

The **.drnolist** directive suppresses the printing of the following directives to the listing file. The .drnolist directive has no affect within macros.

- .asg
- .break
- .emsg
- .eval
- .fclist
- .fcnolist
- .mlist
- .mmsg
- .mnolist
- .sslist
- .ssnolist
- .var
- .wmsg

By default, the assembler acts as if the .drlist directive had been specified.

Example

This example shows how .drnolist inhibits the listing of the specified directives.

Source file:

```
     .length 65
     .width  85
     .asg    0, x
     .loop   2
     .eval   x+1, x
     .endloop

     .drnolist
     .length 55
     .width  95
     .asg    1, x
     .loop   3
     .eval   x+1, x
     .endloop
```

Listing file:

```
       3                          .asg    0, x
       4                          .loop   2
       5                          .eval   x+1, x
       6                          .endloop
1                                 .eval   0+1, x
1                                 .eval   1+1, x
       7
       8                          .drnolist
      12                          .loop   3
      13                          .eval   x+1, x
      14                          .endloop
```

.elfsym *ELF Symbol Information*

Syntax **.elfsym** *name*, **SYM_SIZE(***size***)**

Description The .elfsym directive provides additional information for symbols in the ELF format. This directive is designed to convey different types of information, so the *type*, *data* pair is used to represent each type. Currently, this directive only supports the SYM_SIZE type.

SYM_SIZE indicates the allocation size (in bytes) of the symbol indicated by *name*.

Example This example shows the use of the ELF symbol information directive.

```
         .sect      ".examp"
         .alignment 4
         .elfsym    ex_sym, SYM_SIZE(4)
ex_sym:
          .word     0
```

.emsg/.mmsg/.wmsg *Define Messages*

Syntax

.emsg *string*

.mmsg *string*

.wmsg *string*

Description

These directives allow you to define your own error and warning messages. When you use these directives, the assembler tracks the number of errors and warnings it encounters and prints these numbers on the last line of the listing file.

The **.emsg** directive sends an error message to the standard output device in the same manner as the assembler. It increments the error count and prevents the assembler from producing an object file.

The **.mmsg** directive sends an assembly-time message to the standard output device in the same manner as the .emsg and .wmsg directives. It does not, however, set the error or warning counts, and it does not prevent the assembler from producing an object file.

The **.wmsg** directive sends a warning message to the standard output device in the same manner as the .emsg directive. It increments the warning count rather than the error count, however. It does not prevent the assembler from producing an object file.

Example

This example sends the message ERROR -- MISSING PARAMETER to the standard output device.

Source file:

```
        .global PARAM
MSG_EX  .macro  parm1
        .if     $symlen(parm1) = 0
        .emsg   "ERROR -- MISSING PARAMETER"
        .else
        MVK     parm1, A1
        .endif
        .endm

        MSG_EX PARAM

        MSG_EX
```

Listing file:

```
       1                            .global PARAM
       2                     MSG_EX .macro  parm1
       3                            .if     $symlen(parm1) = 0
       4                            .emsg   "ERROR -- MISSING PARAMETER"
       5                            .else
       6                            MVK  parm1, A1
       7                            .endif
       8                            .endm
       9
      10 00000000                   MSG_EX PARAM
1                                   .if     $symlen(parm1) = 0
1                                   .emsg   "ERROR -- MISSING PARAMETER"
1                                   .else
1        00000000 00800028!         MVK  PARAM, A1
1                                   .endif
      11
      12 00000004                   MSG_EX
1                                   .if     $symlen(parm1) = 0
1                                   .emsg   "ERROR -- MISSING PARAMETER"
  ***** USER ERROR ***** - : ERROR -- MISSING PARAMETER
1                                   .else
1                                   MVK  parm1, A1
1                                   .endif
```

```
1 Error, No Warnings
```

In addition, the following messages are sent to standard output by the assembler:

```
"t.asm", ERROR!   at line 10: [ ***** USER ERROR ***** - ] ERROR --
 MISSING PARAMETER
                .emsg   "ERROR -- MISSING PARAMETER"

1 Assembly Error, No Assembly Warnings
Errors in Source - Assembler Aborted
```

.end *End Assembly*

Syntax

.end

Description

The **.end** directive is optional and terminates assembly. The assembler ignores any source statements that follow a .end directive. If you use the .end directive, it must be the last source statement of a program.

This directive has the same effect as an end-of-file character. You can use .end when you are debugging and you want to stop assembling at a specific point in your code.

Ending a Macro

NOTE: Do not use the .end directive to terminate a macro; use the .endm macro directive instead.

Example

This example shows how the .end directive terminates assembly. If any source statements follow the .end directive, the assembler ignores them.

Source file:

```
start:  .text
        ZERO    A0
        ZERO    A1
        ZERO    A3
        .end
        ZERO    A4
```

Listing file:

```
       1 00000000           start:   .text
       2 00000000 000005E0           ZERO    A0
       3 00000004 008425E0           ZERO    A1
       4 00000008 018C65E0           ZERO    A3
       5                             .end
```

.farcommon/.nearcommon *Create a Common Symbol*

Syntax

.farcommon *symbol*,*size in bytes*[**,** *alignment*]

.farcommon *symbol*,*structure tag*[**,** *alignment*]

.nearcommon *symbol*,*size in bytes*[**,** *alignment*]

.nearcommon *symbol*,*structure tag*[**,** *alignment*]

Description

The **.farcommon** and **.nearcommon** directives create a common symbol in a common block, rather than placing variables in a section. The .farcommon directive places the symbol in far memory, and the .nearcommon directive places the symbol in near memory.

A common symbol cannot be created for a symbol that has a memory bank specification, for example because the DATA_MEM_BANK pragma was used to align the variable.

These directives are used by the compiler when the --common option is enabled (the default), which causes uninitialized file scope variables to be emitted as common symbols when using ELF. The benefit of common symbols 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.) This optimization happens for C/C++ code by default unless you use the --common=off compiler option.

- The *symbol* is a required parameter. It defines a name for the symbol created by this directive. The symbol name must correspond to the variable that you are reserving space for.
- The *size in bytes* is a required parameter; it must be an absolute expression. The assembler allocates size bytes in the section used for common symbols. There is no default size.
- A *structure tag* can be used in place of a size to specify a structure created with the .struct directive. Either a size or a structure tag is required for this argument.
- The *alignment* is an optional parameter that ensures that the space allocated to the symbol occurs on the specified boundary. This boundary must be set to a power of 2. If the SPC is already aligned to the specified boundary, it is not incremented.

.fclist/.fcnolist *Control Listing of False Conditional Blocks*

Syntax

.fclist

.fcnolist

Description

Two directives enable you to control the listing of false conditional blocks:

The **.fclist** directive allows the listing of false conditional blocks (conditional blocks that do not produce code).

The **.fcnolist** directive suppresses the listing of false conditional blocks until a .fclist directive is encountered. With .fcnolist, only code in conditional blocks that are actually assembled appears in the listing. The .if, .elseif, .else, and .endif directives do not appear.

By default, all conditional blocks are listed; the assembler acts as if the .fclist directive had been used.

Example

This example shows the assembly language and listing files for code with and without the conditional blocks listed.

Source file:

```
a    .set    0
b    .set    1
     .fclist   ; list false conditional blocks
     .if     a
     MVK     5,A0
     .else
     MVK     0,A0
     .endif
     .fcnolist ; do not list false conditional blocks
     .if     a
     MVK     5,A0
     .else
     MVK     0,A0
     .endif
```

Listing file:

```
       1          00000000  a    .set    0
       2          00000001  b    .set    1
       3                         .fclist   ; list false conditional blocks
       4                         .if     a
       5                         MVK     5,A0
       6                         .else
       7 00000000 00000028       MVK     0,A0
       8                         .endif
       9                         .fcnolist ; do not list false conditional blocks
      13 00000004 00000028       MVK     0,A0
```

.field Initialize Field

Syntax

.field *value*[**,** *size in bits*]

Description

The **.field** directive initializes a multiple-bit field within a single word (32 bits) of memory. This directive has two operands:

- The *value* is a required parameter; it is an expression that is evaluated and placed in the field. The value must be absolute.
- The *size in bits* is an optional parameter; it specifies a number from 1 to 32, which is the number of bits in the field. The default size is 32 bits. If you specify a value that cannot fit in *size in bits*, the assembler truncates the value and issues a warning message. For example, .field 3,1 causes the assembler to truncate the value 3 to 1; the assembler also prints the message:

```
"t.asm", WARNING! at line 1: [W0001] Value truncated to 1
                .field  3, 1
```

Successive .field directives pack values into the specified number of bits starting at the current 32-bit location. Fields are packed starting at the least significant bit (bit 0), moving toward the most significant bit (bit 31) as more fields are added. If the assembler encounters a field size that does not fit in the current 32-bit word, it fills the remaining bits of the current byte with 0s, increments the SPC to the next word boundary, and begins packing fields into the next word.

The .field directive is similar to the .bits directive (see the .bits topic). However, the .bits directive does not allow you to specify the number of bits in the field and does not automatically increment the SPC when a word boundary is reached.

Use the .align directive to force the next .field directive to begin packing a new word.

If you use a label, it points to the byte that contains the specified field.

When you use .field in a .struct/.endstruct sequence, .field defines a member's size; it does not initialize memory. For more information, see the .struct/.endstruct/.tag topic.

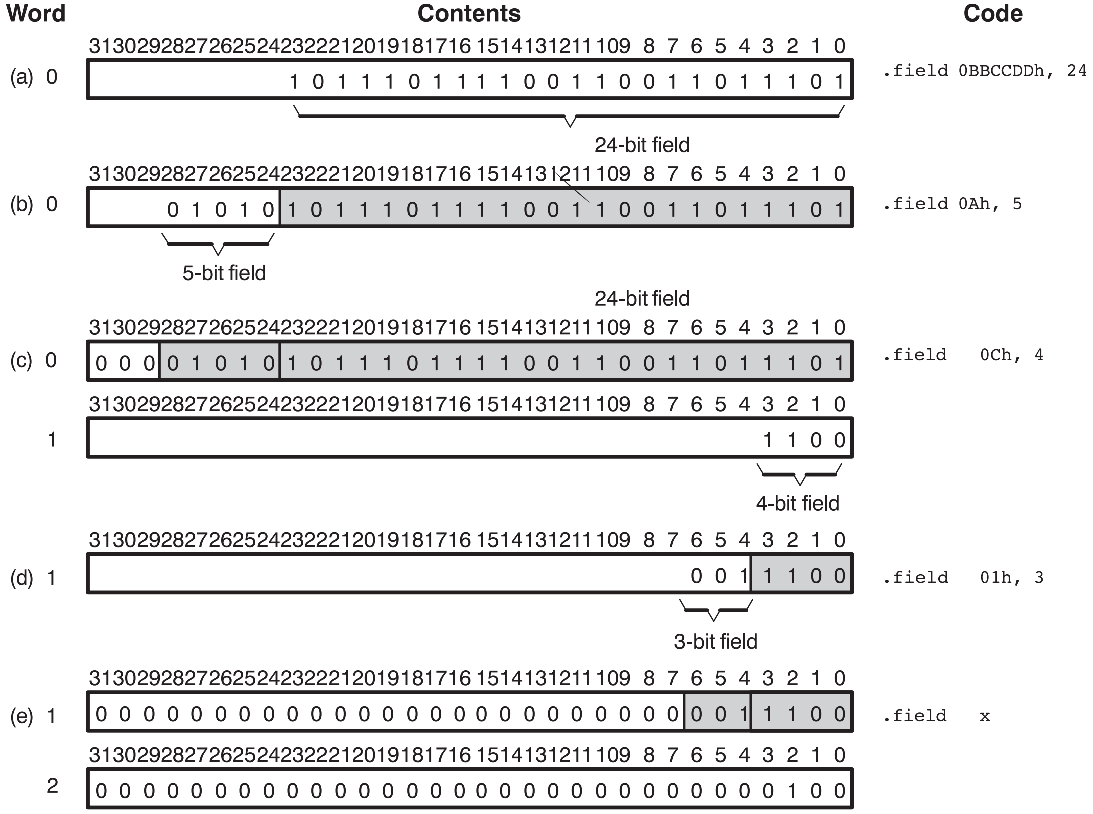
Example

This example shows how fields are packed into a word. The SPC does not change until a word is filled and the next word is begun.

```
 1                      ************************************
 2                      **    Initialize a 24-bit field.  **
 3                      ************************************
 4 00000000 00BBCCDD            .field  0BBCCDDh, 24
 5
 6                      ************************************
 7                      **    Initialize a 5-bit field    **
 8                      ************************************
 9 00000000 0ABBCCDD            .field  0Ah, 5
10
11                      ***********************************
12                      **    Initialize a 4-bit field    **
13                      **        in a new word.          **
14                      ************************************
15 00000004 0000000C           .field  0Ch, 4
16
17                      ************************************
18                      **    Initialize a 3-bit field    **
19                      ************************************
20 00000004 0000001C  x:       .field  01h, 3
21
22                      ************************************
23                      **   Initialize a 32-bit field    **
24                      **   relocatable field in the     **
25                      **   next word                    **
26                      ************************************
27 00000008 00000004'          .field  x
```

Figure 5-6 shows how the directives in this example affect memory.

Figure 5-6. The .field Directive



```
.field 0BBCCDDh, 24
.field 0Ah, 5
.field   0Ch, 4
.field   01h, 3
.field   x
```

.float *Initialize Single-Precision Floating-Point Value*

Syntax **.float** *value*[**, ... ,** *value*$_n$]

Description The **.float** directive places the IEEE single-precision floating-point representation of a single floating-point constant into a word in the current section. The *value* must be an absolute constant expression with an arithmetic type or a symbol equated to an absolute constant expression with an arithmetic type. Each constant is converted to a floating-point value in IEEE single-precision 32-bit format.

With big-endian ordering, the 32-bit value is stored exponent byte first, most significant byte of fraction second, and least significant byte of fraction third, in the format shown in Figure 5-7.

Figure 5-7. Single-Precision Floating-Point Format

S	E	E	E	E	E	E	E	E	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
31								23																							0

value = $(-1)^S$ x (1.0 + mantissa) x $(2)^{\text{exponent-127}}$

Legend: S = sign (1 bit)
E = exponent (8-bit biased)
M = mantissa (23-bit fraction)

When you use .float in a .struct/.endstruct sequence, .float defines a member's size; it does not initialize memory. For more information, see the .struct/.endstruct/.tag topic.

Example Following are examples of the .float directive:

```
1 00000000 E9045951       .float  -1.0e25
2 00000004 40400000       .float  3
3 00000008 42F60000       .float  123
```

.global/.def/.ref *Identify Global Symbols*

Syntax

.global *symbol*$_1$[**, ... ,** *symbol*$_n$]

.def *symbol*$_1$[**, ... ,** *symbol*$_n$]

.ref *symbol*$_1$[**, ... ,** *symbol*$_n$]

Description

Three directives identify global symbols that are defined externally or can be referenced externally:

The **.def** directive identifies a symbol that is defined in the current module and can be accessed by other files. The assembler places this symbol in the symbol table.

The **.ref** directive identifies a symbol that is used in the current module but is defined in another module. The linker resolves this symbol's definition at link time.

The **.global** directive acts as a .ref or a .def, as needed.

A *global symbol* is defined in the same manner as any other symbol; that is, it appears as a label or is defined by the .set, .equ, .bss, or .usect directive. If a global symbol is defined more than once, the linker issues a multiple-definition error. (The assembler can provide a similar multiple-definition error for local symbols.) The .ref directive always creates a symbol table entry for a symbol, whether the module uses the symbol or not; .global, however, creates an entry only if the module actually uses the symbol.

A symbol can be declared global for either of two reasons:

- If the symbol is *not defined in the current module* (which includes macro, copy, and include files), the .global or .ref directive tells the assembler that the symbol is defined in an external module. This prevents the assembler from issuing an unresolved reference error. At link time, the linker looks for the symbol's definition in other modules.
- If the symbol is *defined in the current module*, the .global or .def directive declares that the symbol and its definition can be used externally by other modules. These types of references are resolved at link time.

Example

This example shows four files. The file1.lst and file2.lst refer to each other for all symbols used; file3.lst and file4.lst are similarly related.

The **file1.lst** and **file3.lst** files are equivalent. Both files define the symbol INIT and make it available to other modules; both files use the external symbols X, Y, and Z. Also, file1.lst uses the .global directive to identify these global symbols; file3.lst uses .ref and .def to identify the symbols.

The **file2.lst** and **file4.lst** files are equivalent. Both files define the symbols X, Y, and Z and make them available to other modules; both files use the external symbol INIT. Also, file2.lst uses the .global directive to identify these global symbols; file4.lst uses .ref and .def to identify the symbols.

file1.lst

```
 1                     ; Global symbol defined in this file
 2                              .global INIT
 3                     ; Global symbols defined in file2.lst
 4                              .global X, Y, Z
 5 00000000            INIT:
 6 00000000 00902058            ADD.L1 0x01,A4,A1
 7 00000004 00000000!           .word   X
 8                     ;        .
 9                     ;        .
10                     ;        .
11                              .end
```

file2.lst

```
 1                    ; Global symbols defined in this file
 2                             .global X, Y, Z
 3                    ; Global symbol defined in file1.lst
 4                             .global INIT
 5          00000001  X:       .set    1
 6          00000002  Y:       .set    2
 7          00000003  Z:       .set    3
 8 00000000 00000000!          .word   INIT
 9                    ;        .
10                    ;        .
11                    ;        .
12                             .end
```

file3.lst

```
 1                    ; Global symbol defined in this file
 2                             .def    INIT
 3                    ; Global symbols defined in file4.lst
 4                             .ref    X, Y, Z
 5 00000000           INIT:
 6 00000000 00902058           ADD.L1 0x01,A4,A1
 7 00000004 00000000!          .word   X
 8                    ;        .
 9                    ;        .
10                    ;        .
11                             .end
```

file4.lst

```
 1                    ; Global symbols defined in this file
 2                             .def    X, Y, Z
 3                    ; Global symbol defined in file3.lst
 4                             .ref    INIT
 5          00000001  X:       .set    1
 6          00000002  Y:       .set    2
 7          00000003  Z:       .set    3
 8 00000000 00000000!          .word   INIT
 9                    ;        .
10                    ;        .
11                    ;        .
12                             .end
```

.group/.gmember/.endgroup *Define Common Data Section*

Syntax

.group *group section name group type*

.gmember *section name*

.endgroup

Description

Three directives instruct the assembler to make certain sections members of an ELF group section (see the ELF specification for more information on group sections).

The **.group** directive begins the group declaration. The *group section name* designates the name of the group section. The *group type* designates the type of the group. The following types are supported:

0x0	Regular ELF group
0x1	COMDAT ELF group

Duplicate COMDAT (common data) groups are allowed in multiple modules; the linker keeps only one. Creating such duplicate groups is useful for late instantiation of C++ templates and for providing debugging information.

The **.gmember** directive designates *section name* as a member of the group.

The **.endgroup** directive ends the group declaration.

.half/.short/.uhalf/.ushort *Initialize 16-Bit Integers*

Syntax

.half *value*$_1$**[, ... ,** *value*$_n$]

.short *value*$_1$**[, ... ,** *value*$_n$]

.uhalf *value*$_1$**[, ... ,** *value*$_n$]

.ushort *value*$_1$**[, ... ,** *value*$_n$]

Description

The **.half**, **.uhalf**, **.short**, and **.ushort** directives place one or more values into consecutive halfwords in the current section. Each value is placed in a 2-byte memory location by itself. A *value* can be either:

- An expression that the assembler evaluates and treats as a 16-bit signed or unsigned number
- A character string enclosed in double quotes. Each character in a string represents a separate value and is stored alone in the least significant eight bits of a 16-bit field, which is padded with 0s.

The assembler truncates values greater than 16 bits.

If you use a label with .half, .short, .uhalf, or .ushort; it points to the location where the assembler places the first byte.

These directives perform a halfword (16-bit) alignment before data is written to the section. This guarantees that data resides on a 16-bit boundary.

When you use .half, .short, .uhalf, or .ushort in a .struct/.endstruct sequence, they define a member's size; they do not initialize memory. For more information, see the .struct/.endstruct/.tag topic.

Example

In this example, .half is used to place 16-bit values (10, -1, abc, and a) into consecutive halfwords in memory; .short is used to place 16-bit values (8, -3, def, and b) into consecutive halfwords in memory. The label STRN has the value 100ch, which is the location of the first initialized halfword for .short.

```
1 00000000                     .space  100h * 16
2 00001000 0000000A            .half   10, -1, "abc", 'a'
  00001002 0000FFFF
  00001004 00000061
  00001006 00000062
  00001008 00000063
  0000100a 00000061
3 0000100c 00000008  STRN      .short   8, -3, "def", 'b'
  0000100e 0000FFFD
  00001010 00000064
  00001012 00000065
  00001014 00000066
  00001016 00000062
```

.if/.elseif/.else/.endif *Assemble Conditional Blocks*

Syntax

.if *condition*

[**.elseif** *condition*]

[**.else**]

.endif

Description

These directives provide conditional assembly:

The **.if** directive marks the beginning of a conditional block. The *condition* is a required parameter.

- If the expression evaluates to true (nonzero), the assembler assembles the code that follows the expression (up to a .elseif, .else, or .endif).
- If the expression evaluates to false (0), the assembler assembles code that follows a .elseif (if present), .else (if present), or .endif (if no .elseif or .else is present).

The **.elseif** directive identifies a block of code to be assembled when the .if expression is false (0) and the .elseif expression is true (nonzero). When the .elseif expression is false, the assembler continues to the next .elseif (if present), .else (if present), or .endif (if no .elseif or .else is present). The .elseif is optional in a conditional block, and more than one .elseif can be used. If an expression is false and there is no .elseif, the assembler continues with the code that follows a .else (if present) or a .endif.

The **.else** directive identifies a block of code that the assembler assembles when the .if expression and all .elseif expressions are false (0). The .else directive is optional in the conditional block; if an expression is false and there is no .else statement, the assembler continues with the code that follows the .endif. The .elseif and .else directives can be used in the same conditional assembly block.

The **.endif** directive terminates a conditional block.

See Section 4.9.2 for information about relational operators.

Example

This example shows conditional assembly:

```
 1          00000001  SYM1    .set    1
 2          00000002  SYM2    .set    2
 3          00000003  SYM3    .set    3
 4          00000004  SYM4    .set    4
 5
 6                    If_4:   .if     SYM4 = SYM2 * SYM2
 7 00000000 00000004          .byte   SYM4            ; Equal values
 8                            .else
 9                            .byte   SYM2 * SYM2     ; Unequal values
10                            .endif
11
12                    If_5:   .if     SYM1 <;= 10
13 00000001 0000000A          .byte   10              ; Less than / equal
14                            .else
15                            .byte   SYM1            ; Greater than
16                            .endif
17
18                    If_6:   .if     SYM3 * SYM2 != SYM4 + SYM2
19                            .byte   SYM3 * SYM2     ; Unequal value
20                            .else
21 00000002 00000008          .byte   SYM4 + SYM4     ; Equal values
22                            .endif
23
24                    If_7:   .if     SYM1 = SYM2
25                            .byte   SYM1
26                            .elseif SYM2 + SYM3 = 5
27 00000003 00000005          .byte   SYM2 + SYM3
28                            .endif
```

.import/.export/.hidden/.protected *Set Dynamic Visibility of Global Symbol*

Syntax

.import "*symbolname***"**

.export "*symbolname***"**

.hidden "*symbolname***"**

.protected "*symbolname***"**

Description

These directives set the dynamic visibility of a global symbol. Each takes a single symbol name, optionally enclosed in double-quotes.

- The **.import** directive sets the visibility of *symbolname* to STV_IMPORT.
- The **.export** directive sets the visibility of *symbolname* to STV_EXPORT.
- The **.hidden** directive sets the visibility of *symbolname* to STV_HIDDEN.
- The **.protected** directive sets the visibility of *symbolname* to STV_PROTECTED.

See Section 8.12 for an explanation of symbol visibility.

Theses directives are commonly used in the context of dynamic linking, for more detail see the Dynamic Linking wiki site (http://processors.wiki.ti.com/index.php/C6000_Dynamic_Linking).

.int/.unint/.long/.ulong/.word/.uword *Initialize 32-Bit Integers*

Syntax

.int *value*$_1$**[, ... ,** *value*$_n$]

.uint *value*$_1$**[, ... ,** *value*$_n$]

.long *value*$_1$**[, ... ,** *value*$_n$]

.ulong *value*$_1$**[, ... ,** *value*$_n$]

.word *value*$_1$**[, ... ,** *value*$_n$]

.uword *value*$_1$**[, ... ,** *value*$_n$]

Description

The **.int**, **.unint**, **.long**, **.ulong**, **.word**, and **.uword** directives place one or more values into consecutive words in the current section. Each value is placed in a 32-bit word by itself and is aligned on a word boundary. A *value* can be either:

- An expression that the assembler evaluates and treats as a 32-bit signed or unsigned number
- A character string enclosed in double quotes. Each character in a string represents a separate value and is stored alone in the least significant eight bits of a 32-bit field, which is padded with 0s.

A value can be either an absolute or a relocatable expression. If an expression is relocatable, the assembler generates a relocation entry that refers to the appropriate symbol; the linker can then correctly patch (relocate) the reference. This allows you to initialize memory with pointers to variables or labels.

If you use a label with these directives, it points to the first word that is initialized.

When you use these directives in a .struct/.endstruct sequence, they define a member's size; they do not initialize memory. See the .struct/.endstruct/.tag topic.

Example 1

This example uses the .int directive to initialize words. Notice that the symbol SYMPTR puts the symbol's address in the object code and generates a relocatable reference (indicated by the - character appended to the object word).

```
1 00000000                   .space 73h
2 00000000                   .bss   PAGE, 128
3 00000080                   .bss   SYMPTR, 3
4 00000074 003C12E4  INST:   LDW.D2 *++B15[0],A0
5 00000078 0000000A          .int   10, SYMPTR, -1, 35 + 'a', INST
  0000007c 00000080-
  00000080 FFFFFFFF
  00000084 00000084
  00000088 00000074'
```

Example 2

This example initializes two 32-bit fields and defines DAT1 to point to the first location. The contents of the resulting 32-bit fields are FFFABCDh and 141h.

```
1 00000000 FFFFABCD  DAT1:   .long   0FFFFABCDh,'A'+100h
  00000004 00000141
```

Example 3

This example initializes five words. The symbol WordX points to the first word.

```
1 00000000 00000C80  ;WordX   .word   3200,1+'AB',-'AF',0F410h,'A'
  00000004 00004242
  00000008 FFFFB9BF
  0000000c 0000F410
  00000010 00000041
```

.label *Create a Load-Time Address Label*

Syntax

.label *symbol*

Description

The **.label** directive defines a special *symbol* that refers to the load-time address rather than the run-time address within the current section. Most sections created by the assembler have relocatable addresses. The assembler assembles each section as if it started at 0, and the linker relocates it to the address at which it loads and runs.

For some applications, it is desirable to have a section load at one address and run at a *different* address. For example, you may want to load a block of performance-critical code into slower memory to save space and then move the code to high-speed memory to run it. Such a section is assigned two addresses at link time: a load address and a run address. 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. See Section 3.5 for more information about run-time relocation.

The .label directive creates a special label that refers to the *load-time* address. This function is useful primarily to designate where the section was loaded for purposes of the code that relocates the section.

Example

This example shows the use of a load-time address label.

```
sect  ".examp"
       .label examp_load ; load address of section
start:                   ; run address of section
       <code>
finish:                  ; run address of section end
       .label examp_end  ; load address of section end
```

See Section 8.5.5 for more information about assigning run-time and load-time addresses in the linker.

.length/.width *Set Listing Page Size*

Syntax

.length [*page length*]

.width [*page width*]

Description

Two directives allow you to control the size of the output listing file.

The **.length** directive sets the page length of the output listing file. It affects the current and following pages. You can reset the page length with another .length directive.

- Default length: 60 lines. If you do not use the .length directive or if you use the .length directive without specifying the *page length*, the output listing length defaults to 60 lines.
- Minimum length: 1 line
- Maximum length: 32 767 lines

The **.width** directive sets the page width of the output listing file. It affects the next line assembled and the lines following. You can reset the page width with another .width directive.

- Default width: 132 characters. If you do not use the .width directive or if you use the .width directive without specifying a *page width*, the output listing width defaults to 132 characters.
- Minimum width: 80 characters
- Maximum width: 200 characters

The width refers to a full line in a listing file; the line counter value, SPC value, and object code are counted as part of the width of a line. Comments and other portions of a source statement that extend beyond the page width are truncated in the listing.

The assembler does not list the .width and .length directives.

Example

The following example shows how to change the page length and width.

```
********************************************
**        Page length = 65 lines          **
**        Page width = 85 characters      **
********************************************
          .length    65
          .width     85

********************************************
**        Page length = 55 lines          **
**        Page width = 100 characters     **
********************************************
          .length    55
          .width     100
```

.list/.nolist *Start/Stop Source Listing*

Syntax

.list

.nolist

Description

Two directives enable you to control the printing of the source listing:

The **.list** directive allows the printing of the source listing.

The **.nolist** directive suppresses the source listing output until a .list directive is encountered. The .nolist directive can be used to reduce assembly time and the source listing size. It can be used in macro definitions to suppress the listing of the macro expansion.

The assembler does not print the .list or .nolist directives or the source statements that appear after a .nolist directive. However, it continues to increment the line counter. You can nest the .list/.nolist directives; each .nolist needs a matching .list to restore the listing.

By default, the source listing is printed to the listing file; the assembler acts as if the .list directive had been used. However, if you do not request a listing file when you invoke the assembler by including the --asm_listing option on the command line (see Section 4.3), the assembler ignores the .list directive.

Example

This example shows how the .list and .nolist directives turn the output listing on and off. The .nolist, the table: .data through .byte lines, and the .list directives do not appear in the listing file. Also, the line counter is incremented even when source statements are not listed.

Source file:

```
        .data
        .space  0CCh
        .text
        ABS     A0,A1

        .nolist

table:  .data
        .word   -1
        .byte   0FFh

        .list

        .text
        MV      A0,A1
        .data
coeff   .word   00h,0ah,0bh
```

Listing file:

```
  1 00000000                    .data
  2 00000000                    .space  0CCh
  3 00000000                    .text
  4 00000000 00800358           ABS     A0,A1
  5
 13
 14 00000004                    .text
 15 00000004 008001A0           MV      A0,A1
 16 000000d1                    .data
 17 000000d4 00000000  coeff    .word   00h,0ah,0bh
    000000d8 0000000A
    000000dc 0000000B
```

.loop/.endloop/.break *Assemble Code Block Repeatedly*

Syntax

.loop [*count*]

.break [*end-condition*]

.endloop

Description

Three directives allow you to repeatedly assemble a block of code:

The **.loop** directive begins a repeatable block of code. The optional *count* operand, if used, must be a well-defined integer expression. The *count* indicates the number of loops to be performed (the loop count). If *count* is omitted, it defaults to 1024. The loop will be repeated count number of times, unless terminated early by a .break directive.

The optional **.break** directive terminates a .loop early. You may use .loop without using .break. The .break directive terminates a .loop only if the *end-condition* expression is true (evaluates to nonzero). If the optional *end-condition* operand is omitted, it defaults to true. If *end-condition* is true, the assembler stops repeating the .loop body immediately; any remaining statements after .break and before .endloop are not assembled. The assembler resumes assembling with the statement after the .endloop directive. If *end-condition* is false (evaluates to 0), the loop continues.

The **.endloop** directive marks the end of a repeatable block of code. When the loop terminates, whether by a .break directive with a true *end-condition* or by performing the loop count number of iterations, the assembler stops repeating the loop body and resumes assembling with the statement after the .endloop directive.

Example

This example illustrates how these directives can be used with the .eval directive. The code in the first six lines expands to the code immediately following those six lines.

```
       1                          .eval       0,x
       2                    COEF  .loop
       3                          .word       x*100
       4                          .eval       x+1, x
       5                          .break      x = 6
       6                          .endloop
1        00000000 00000000        .word       0*100
1                                 .eval       0+1, x
1                                 .break      1 = 6
1        00000004 00000064        .word       1*100
1                                 .eval       1+1, x
1                                 .break      2 = 6
1        00000008 000000C8        .word       2*100
1                                 .eval       2+1, x
1                                 .break      3 = 6
1        0000000c 0000012C        .word       3*100
1                                 .eval       3+1, x
1                                 .break      4 = 6
1        00000010 00000190        .word       4*100
1                                 .eval       4+1, x
1                                 .break      5 = 6
1        00000014 000001F4        .word       5*100
1                                 .eval       5+1, x
1                                 .break      6 = 6
```

.macro/.endm *Define Macro*

Syntax

macname **.macro** [*parameter*$_1$[**, ... ,** *parameter*$_n$]]

model statements or macro directives

.endm

Description

The **.macro** and **.endm** directives are used to define macros.

You can define a macro anywhere in your program, but you must define the macro before you can use it. Macros can be defined at the beginning of a source file, in an .include/.copy file, or in a macro library.

macname	names the macro. You must place the name in the source statement's label field.
.macro	identifies the source statement as the first line of a macro definition. You must place .macro in the opcode field.
[*parameters*]	are optional substitution symbols that appear as operands for the .macro directive.
model statements	are instructions or assembler directives that are executed each time the macro is called.
macro directives	are used to control macro expansion.
.endm	marks the end of the macro definition.

Macros are explained in further detail in Chapter 6.

.map/.clearmap *Assign a Variable to a Register*

Syntax

.map *symbol$_1$* **/** *register$_1$* [**,** *symbol$_2$* **/** *register$_2$* , ...]

.clearmap

Description

The **.map** directive is used by the compiler when the input is linear assembly. The compiler tries to keep your symbolic names for registers defined with .reg by creating substitution symbols with .map.

The .map directive is similar to .asg, but uses a forward slash instead of a comma; and allows single quote characters in the symbolic names. For example, this linear assembly input:

The **.clearmap** directive is used by the compiler to undefine all current .map substitution symbols.

See the *TMS320C6000 Optimizing Compiler User's Guide* for details on using the .map directive in linear assembly code.

Example

The .map directive is similar to .asg, but uses a forward slash instead of a comma; and allows single quote characters in the symbolic names. For example, this linear assembly input:

```
fn:     .cproc a, b, c
        .reg x, y, z

        ADD a, b, z
        ADD z, c, z
        .return z
        .endproc
```

Becomes this assembly code output:

```
fn:
        .map    a/A4
        .map    b/B4
        .map    c/A6
        .map    z/A4
        .map    z'/A3
        RET     .S2     B3
        ADD     .L1X    a,b,z'
        ADD     .L1     z',c,z
        NOP             3
```

.mlib — *Define Macro Library*

Syntax

.mlib "*filename*"

Description

The **.mlib** directive provides the assembler with the *filename* of a macro library. A macro library is a collection of files that contain macro definitions. The macro definition files are bound into a single file (called a library or archive) by the archiver.

Each file in a macro library contains one macro definition that corresponds to the name of the file. The *filename* of a macro library member must be the same as the macro name, and its extension must be .asm. The filename must follow host operating system conventions; it can be enclosed in double quotes. You can specify a full pathname (for example, c:\320tools\macs.lib). If you do not specify a full pathname, the assembler searches for the file in the following locations in the order given:

1. The directory that contains the current source file
2. Any directories named with the --include_path assembler option
3. Any directories specified by the C6X_A_DIR environment variable
4. Any directories specified by the C6X_C_DIR environment variable

See Section 4.5 for more information about the --include_path option.

A .mlib directive causes the assembler to open the library specified by *filename* and create a table of the library's contents. The assembler stores names of individual library members in the opcode table as library entries. This redefines any existing opcodes or macros with the same name. If one of these macros is called, the assembler extracts the library entry and loads it into the macro table. The assembler expands the library entry as it does other macros, but it does not place the source code in the listing. Only macros called from the library are extracted, and they are extracted only once.

See Chapter 6 for more information on macros and macro libraries.

Example

The code creates a macro library that defines two macros, inc1.asm and dec1.asm. The file inc1.asm contains the definition of inc1 and dec1.asm contains the definition of dec1.

inc1.asm	dec1.asm

* Macro for incrementing
 inc1 .macro A
     ADD A,1,A
     .endm
	* Macro for decrementing
	 dec1 .macro A
	     SUB A,1,A
	     .endm

Use the archiver to create a macro library:

```
ar6x -a mac inc1.asm dec1.asm
```

Now you can use the .mlib directive to reference the macro library and define the inc1.asm and dec1.asm macros:

```
       1                          .mlib    "mac.lib"
       2
       3                   * Macro Call
       4 00000000                 inc1     A0
1        00000000 000021A0        ADD      A0,1,A0
       5
       6                   * Macro Call
       7 00000004                 dec1     B0
1        00000004 0003E1A2        SUB      B0,1,B0
```

.mlist/.mnolist *Start/Stop Macro Expansion Listing*

Syntax

.mlist

.mnolist

Description

Two directives enable you to control the listing of macro and repeatable block expansions in the listing file:

The **.mlist** directive allows macro and .loop/.endloop block expansions in the listing file.

The **.mnolist** directive suppresses macro and .loop/.endloop block expansions in the listing file.

By default, the assembler behaves as if the .mlist directive had been specified.

See Chapter 6 for more information on macros and macro libraries. See the .loop/.break/.endloop topic for information on conditional blocks.

Example

This example defines a macro named STR_3. The first time the macro is called, the macro expansion is listed (by default). The second time the macro is called, the macro expansion is not listed, because a .mnolist directive was assembled. The third time the macro is called, the macro expansion is again listed because a .mlist directive was assembled.

```
       1                   STR_3  .macro   P1, P2, P3
       2                          .string ":p1:", ":p2:", ":p3:"
       3                          .endm
       4
       5 00000000                 STR_3 "as", "I", "am"
1        00000000 0000003A        .string ":p1:", ":p2:", ":p3:"
         00000001 00000070
         00000002 00000031
         00000003 0000003A
         00000004 0000003A
         00000005 00000070
         00000006 00000032
         00000007 0000003A
         00000008 0000003A
         00000009 00000070
         0000000a 00000033
         0000000b 0000003A
       6                          .mnolist
       7 0000000c                 STR_3 "as", "I", "am"
       8                          .mlist
       9 00000018                 STR_3 "as", "I", "am"
1        00000018 0000003A        .string ":p1:", ":p2:", ":p3:"
         00000019 00000070
         0000001a 00000031
         0000001b 0000003A
         0000001c 0000003A
         0000001d 00000070
         0000001e 00000032
         0000001f 0000003A
         00000020 0000003A
         00000021 00000070
         00000022 00000033
         00000023 0000003A
```

.newblock — *Terminate Local Symbol Block*

Syntax

.newblock

Description

The **.newblock** directive undefines any local labels currently defined. Local labels, by nature, are temporary; the .newblock directive resets them and terminates their scope.

A local label is a label in the form $*n*, where *n* is a single decimal digit, or *name*?, where *name* is a legal symbol name. Unlike other labels, local labels are intended to be used locally, and cannot be used in expressions. They can be used only as operands in 8-bit jump instructions. Local labels are not included in the symbol table.

After a local label has been defined and (perhaps) used, you should use the .newblock directive to reset it. The .text, .data, and .sect directives also reset local labels. Local labels that are defined within an include file are not valid outside of the include file.

See Section 4.8.3 for more information on the use of local labels.

Example

This example shows how the local label $1 is declared, reset, and then declared again.

```
 1                            .global table1, table2
 2
 3 00000000 00000028!         MVKL     table1,A0
 4 00000004 00000068!                  MVKH    table1,A0
 5 00000008 008031A9          MVK     99, A1
 6 0000000c 010848C0  ||      ZERO    A2
 7
 8 00000010 80000212  $1:[A1] B       $1
 9 00000014 01003674          STW     A2, *A0++
10 00000018 0087E1A0          SUB     A1,1,A1
11 0000001c 00004000          NOP     3
12
13                            .newblock ; undefine $1
14
15 00000020 00000028!         MVKL     table2,A0
16 00000024 00000068!         MVKH    table2,A0
17 00000028 008031A9          MVK     99, A1
18 0000002c 010829C0  ||      SUB     A2,1,A2
19
20 00000030 80000212  $1:[A1] B       $1
21 00000034 01003674          STW     A2, *A0++
22 00000038 0087E1A0          SUB     A1,1,A1
23 0000003c 00004000          NOP     3
```

.nocmp *Do Not Utilize 16-Bit Instructions in Section*

Syntax

.nocmp

Description

The C6400+, C6740, and C6600 **.nocmp** directive instructs the compiler to not utilize 16-bit instructions for the code section .nocmp appears in. The .nocmp directive can appear anywhere in the section.

Example

In the example, the section *one* is not compressed, whereas section *two* is compressed.

```
.sect "one"
LDW *A4, A5
LDW *B4, A5
.nocmp
NOP 4
ADD A4, A5, A6
ADD B4, B5, B6
NOP
...

.sect "two"
ADD A4, A5, A6
NOP
NOP
...
```

.noremark/.remark *Control Remarks*

Syntax

.noremark *num*

.remark [*num*]

Description

The **.noremark** directive suppresses the assembler remark identified by num. A remark is an informational assembler message that is less severe than a warning.

This directive is equivalent to using the -ar[*num*] assembler option.

The **.remark** directive re-enables the remark(s) previously suppressed.

Example

This example shows how to suppress the R5002 remark:

Partial source file:

```
;;; cl6x -mv6700+ usenoremark.asm
.noremark 5002
ADDSP A4, A4, A4
```

Resulting listing file:

```
"usenoremark.asm", REMARK   at line 4: [R5002] An ADDSP/SUBSP, ADDDP/SUBDP
                                               instruction has no unit
                                               specifier, but the assembler can
                                                place it on the .L or .S unit
                                               on C6700+. On C6700+, the lack
                                               of unit specifier may cause  an
                                               unintended functional unit
                                               conflict in 4/7th cycle on the
                                               .L or .S unit. Please check and
                                               add unit specifiers to these
                                               instructions to avoid this
                                               hazard. Details can be found in
                                               section "Constrains on
                                               Floating-Point Instructions" and
                                               "Functional Unit Constraints" in
                                               document SPRU733
                ADDSP A4, A4, A4
```

.option *Select Listing Options*

Syntax

.option *option*$_1$[, *option*$_2$,. . .]

Description

The **.option** directive selects options for the assembler output listing. The *options* must be separated by commas; each option selects a listing feature. These are valid options:

A turns on listing of all directives and data, and subsequent expansions, macros, and blocks.

B limits the listing of .byte and .char directives to one line.

D turns off the listing of certain directives (same effect as .drnolist).

H limits the listing of .half and .short directives to one line.

L limits the listing of .long directives to one line.

M turns off macro expansions in the listing.

N turns off listing (performs .nolist).

O turns on listing (performs .list).

R resets any B, H, L, M, T, and W (turns off the limits of B, H, L, M, T, and W).

T limits the listing of .string directives to one line.

W limits the listing of .word and .int directives to one line.

X produces a cross-reference listing of symbols. You can also obtain a cross-reference listing by invoking the assembler with the --cross_reference option (see Section 4.3).

Options *are not* case sensitive.

Example

This example shows how to limit the listings of the .byte, .char, .int, long, .word, and .string directives to one line each.

```
 1                      ****************************************
 2                      ** Limit the listing of .byte, .char, **
 3                      **   .int, .word, and .string  **
 4                      **     directives to 1 line each.     **
 5                      ****************************************
 6                              .option B, W, T
 7 00000000 000000BD          .byte   -'C', 0B0h, 5
 8 00000003 000000BC          .char   -'D', 0C0h, 6
 9 00000008 0000000A          .int    10, 35 + 'a', "abc"
10 0000001c AABBCCDD          .long   0AABBCCDDh, 536 + 'A'
11 00000024 000015AA          .word   5546, 78h
12 0000002c 00000052          .string "Registers"
13
14                      ****************************************
15                      **     Reset the listing options.     **
16                      ****************************************
17                              .option R
18 00000035 000000BD          .byte   -'C', 0B0h, 5
   00000036 000000B0
   00000037 00000005
19 00000038 000000BC          .char   -'D', 0C0h, 6
   00000039 000000C0
   0000003a 00000006
20 0000003c 0000000A          .int    10, 35 + 'a', "abc"
   00000040 00000084
   00000044 00000061
   00000048 00000062
   0000004c 00000063
21 00000050 AABBCCDD          .long   0AABBCCDDh, 536 + 'A'
   00000054 00000259
22 00000058 000015AA          .word   5546, 78h
   0000005c 00000078
```

```
      23 00000060 00000052          .string "Registers"
         00000061 00000065
         00000062 00000067
         00000063 00000069
         00000064 00000073
         00000065 00000074
         00000066 00000065
         00000067 00000072
         00000068 00000073
```

.page *Eject Page in Listing*

Syntax

.page

Description

The **.page** directive produces a page eject in the listing file. The .page directive is not printed in the source listing, but the assembler increments the line counter when it encounters the .page directive. Using the .page directive to divide the source listing into logical divisions improves program readability.

Example

This example shows how the .page directive causes the assembler to begin a new page of the source listing.

Source file:

```
Source file (generic)
        .title   "**** Page Directive Example ****"
;         .
;         .
;         .
        .page
```

Listing file:

```
TMS320C6000 Assembler    Version x.xx         Day    Time    Year
Copyright (c) 1996-2011 Texas Instruments Incorporated
**** Page Directive Example ****                                    PAGE    1

       2                    ;        .
       3                    ;        .
       4                    ;        .
TMS320C6000 Assembler    Version x.xx     Day    Time    Year
Copyright (c) 1996-2011 Texas Instruments Incorporated
**** Page Directive Example ****                                    PAGE    2


 No Errors, No Warnings
```

.retain / .retainrefs *Conditionally Retain Sections In Object Module Output*

Syntax

.retain[**"***section name***"**]

.retainrefs[**"***section name***"**]

Description

The **.retain** directive indicates that the current or specified section is not eligible for removal via conditional linking. You can also override conditional linking for a given section with the --retain linker option. You can disable conditional linking entirely with the --unused_section_elimination=off linker option.

The **.retainrefs** directive indicates that any sections that refer to the current or specified section are not eligible for removal via conditional linking. For example, applications may use an .intvecs section to set up interrupt vectors. Under EABI, the .intvecs section is eligible for removal during conditional linking by default. You can force the .intvecs section and any sections that reference it to be retained by applying the .retain and .retainrefs directives to the .intvecs section. This directive is ignored if the COFF model is used.

The *section name* identifies the section. If the directive is used without a section name, it applies to the current initialized section. If the directive is applied to an uninitialized section, the section name is required. The section name must be enclosed in double quotes. A section name can contain a subsection name in the form *section name***:***subsection name*.

Under the ELF EABI model, the linker assumes that all sections by default are eligible for removal via conditional linking. (However, the linker does automatically retain the .reset section.) The .retain directive is useful for overriding this default conditional linking behavior for sections that you want to keep included in the link, even if the section is not referenced by any other section in the link. For example, you could apply a .retain directive to an interrupt function that you have written in assembly language, but which is not referenced from any normal entry point in the application.

Under the COFF ABI model, the linker assumes that all sections are not eligible for removal via conditional linking by default. So under the COFF ABI mode, the .retain directive does not have any real effect on the section.

Example 1 This example of an interrupt function that has a .retain directive applied to it.

```
        .sect   ".text:interrupts:retain"
        .retain
        .global _int_func1

;******************************************************************************
;* FUNCTION NAME: int_func1                                                   *
;******************************************************************************
_int_func1:
           STW     .D2     FP,*SP++(-88)     ; [B_D] |31|
           STW     .D2     B3,*SP(80)        ; [B_D] |31|
           STW     .D2     A4,*SP(24)        ; [B_D] |31|
           STW     .D2     B2,*SP(84)        ; [B_D] |31|
           STW     .D2     B9,*SP(76)        ; [B_D] |31|
           STW     .D2     B8,*SP(72)        ; [B_D] |31|
           STW     .D2     B7,*SP(68)        ; [B_D] |31|
           STW     .D2     B6,*SP(64)        ; [B_D] |31|
           STW     .D2     B5,*SP(60)        ; [B_D] |31|
           STW     .D2     B4,*SP(56)        ; [B_D] |31|
           STW     .D2     B1,*SP(52)        ; [B_D] |31|
           STW     .D2     B0,*SP(48)        ; [B_D] |31|
           STW     .D2     A7,*SP(36)        ; [B_D] |31|
           STW     .D2     A6,*SP(32)        ; [B_D] |31|
           STW     .D2     A5,*SP(28)        ; [B_D] |31|

           CALL    .S1     _foo              ; [A_S] |32|
||         STW     .D2     A8,*SP(40)        ; [B_D] |31|

        ...

           STW     .D2     B4,*+DP(_a_i)     ; [B_D] |33|

           RET     .S2     IRP               ; [B_Sb] |34|
||         LDW     .D2     *SP(56),B4        ; [B_D] |34|

           LDW     .D2     *++SP(88),FP      ; [B_D] |34|
           NOP             4                 ; [A_L]
```

.sect — *Assemble Into Named Section*

Syntax

.sect " *section name* **"**

.sect " *section name* **"** [,{RO|RW}] [,{ALLOC|NOALLOC}]

Description

The **.sect** directive defines a named section that can be used like the default .text and .data sections. The .sect directive sets *section name* to be the current section; the lines that follow are assembled into the *section name* section.

The *section name* identifies the section. The section name must be enclosed in double quotes. A section name can contain a subsection name in the form *section name* **:** *subsection name*.

In ELF mode the sections can be marked read-only (RO) or read-write (RW). Also, the sections can be marked for allocation (ALLOC) or no allocation (NOALLOC). These attributes can be specified in any order, but only one attribute from each set can be selected. RO conflicts with RW, and ALLOC conflicts with NOALLOC. If conflicting attributes are specified the assembler generates an error, for example:

```
"t.asm", ERROR!  at line 1:[E0000] Attribute RO cannot be combined with attr RW
          .sect "illegal_sect",RO,RW
```

The extra operands are allowed only in ELF mode. They are ignored but generate a warning in COFF mode. For example:

```
"t.asm", WARNING!  at line 1:[W0000] Trailing operands ignored
          .sect "cosnt_sect",RO
```

See Chapter 2 for more information about sections.

Example

This example defines two special-purpose sections, Sym_Defs and Vars, and assembles code into them.

```
                       **********************************************
                       **   Begin assembling into .text section.   **
                       **********************************************
00000000                       .text
00000000 000005E0              ZERO    A0
00000004 008425E0              ZERO    A1

                       **********************************************
                       **   Begin assembling into vars section.    **
                       **********************************************
00000000                       .sect   "vars"
00000000 4048F5C3      pi      .float  3.14
00000004 000007D0      max     .int    2000
00000008 00000001      min     .int    1

                       **********************************************
                       **   Resume assembling into .text section.  **
                       **********************************************
00000008                       .text
00000008 010000A8              MVK     1,A2
0000000c 018000A8              MVK     1,A3

                       **********************************************
                       **   Resume assembling into vars section.   **
                       **********************************************
0000000c                       .sect   "vars"
0000000c 00000019      count   .short  25
```

.set/.equ *Define Assembly-Time Constant*

Syntax

symbol **.set** *value*

symbol **.equ** *value*

Description

The **.set** and **.equ** directives equate a constant value to a .set/.equ symbol. The symbol can then be used in place of a value in assembly source. This allows you to equate meaningful names with constants and other values. The .set and .equ directives are identical and can be used interchangeably.

- The *symbol* is a label that must appear in the label field.
- The *value* must be a well-defined expression, that is, all symbols in the expression must be previously defined in the current source module.

Undefined external symbols and symbols that are defined later in the module cannot be used in the expression. If the expression is relocatable, the symbol to which it is assigned is also relocatable.

The value of the expression appears in the object field of the listing. This value is not part of the actual object code and is not written to the output file.

Symbols defined with .set or .equ can be made externally visible with the .def or .global directive (see the .global/.def/.ref topic). In this way, you can define global absolute constants.

Example

This example shows how symbols can be assigned with .set and .equ.

```
 1                     **********************************************
 2                     **   Equate symbol AUX_R1 to register A1    **
 3                     **   and use it instead of the register.    **
 4                     **********************************************
 5          00000001  AUX_R1  .set    A1
 6 00000000 00B802D4          STH     AUX_R1,*+B14
 7
 8                     **********************************************
 9                     **   Set symbol index to an integer expr.   **
10                     **    and use it as an immediate operand.   **
11                     **********************************************
12          00000035  INDEX   .equ    100/2 +3
13 00000004 01001AD0          ADDK    INDEX, A2
14
15                     **********************************************
16                     ** Set symbol SYMTAB to a relocatable expr. **
17                     **   and use it as a relocatable operand.   **
18                     **********************************************
19 00000008 0000000A  LABEL   .word   10
20          00000009' SYMTAB  .set    LABEL + 1
21
22                     **********************************************
23                     **   Set symbol NSYMS equal to the symbol   **
24                     **   INDEX and use it as you would INDEX.   **
25                     **********************************************
26          00000035  NSYMS   .set    INDEX
27 0000000c 00000035          .word   NSYMS
```

.space/.bes *Reserve Space*

Syntax

[*label*] **.space** *size in bytes*

[*label*] **.bes** *size in bytes*

Description

The **.space** and **.bes** directives reserve the number of bytes given by *size in bytes* in the current section and fill them with 0s. The section program counter is incremented to point to the word following the reserved space.

When you use a label with the .space directive, it points to the *first* byte reserved. When you use a label with the .bes directive, it points to the *last* byte reserved.

Example

This example shows how memory is reserved with the .space and .bes directives.

```
                   *****************************************************
                   **     Begin assembling into the .text section.    **
                   *****************************************************
00000000                   .text
                   *****************************************************
                   **  Reserve 0F0 bytes (60 words in .text section). **
                   *****************************************************
00000000                   .space  0F0h
000000f0 00000100          .word   100h, 200h
000000f4 00000200
                   *****************************************************
                   **     Begin assembling into the .data section.    **
                   *****************************************************
00000000                   .data
00000000 00000049          .string "In .data"
00000001 0000006E
00000002 00000020
00000003 0000002E
00000004 00000064
00000005 00000061
00000006 00000074
00000007 00000061
                   *****************************************************
                   **     Reserve 100 bytes in the .data section;     **
                   **         RES_1 points to the first word          **
                   **          that contains reserved bytes.          **
                   *****************************************************
00000008           RES_1:  .space  100
0000006c 0000000F          .word   15
00000070 00000008"         .word   RES_1
                   *****************************************************
                   **     Reserve 20 bytes in the .data section;      **
                   **          RES_2 points to the last word          **
                   **          that contains reserved bytes.          **
                   *****************************************************
00000087           RES_2:  .bes    20
00000088 00000036          .word   36h
0000008c 00000087"         .word   RES_2
```

.sslist/.ssnolist *Control Listing of Substitution Symbols*

Syntax

.sslist

.ssnolist

Description

Two directives allow you to control substitution symbol expansion in the listing file:

The **.sslist** directive allows substitution symbol expansion in the listing file. The expanded line appears below the actual source line.

The **.ssnolist** directive suppresses substitution symbol expansion in the listing file.

By default, all substitution symbol expansion in the listing file is suppressed; the assembler acts as if the .ssnolist directive had been used.

Lines with the pound (#) character denote expanded substitution symbols.

Example

This example shows code that, by default, suppresses the listing of substitution symbol expansion, and it shows the .sslist directive assembled, instructing the assembler to list substitution symbol code expansion.

```
       1 00000000                   .bss    x,4
       2 00000004                   .bss    y,4
       3 00000008                   .bss    z,4
       4
       5                    addm    .macro  src1,src2,dst
       6                            LDW     *+B14(:src1:), A0
       7                            LDW     *+B14(:src2:), A1
       8                            NOP     4
       9                            ADD     A0,A1,A0
      10                            STW     A0,*+B14(:dst:)
      11                            .endm
      12
      13 00000000                   addm    x,y,z
1        00000000 0000006C-         LDW     *+B14(x), A0
1        00000004 0080016C-         LDW     *+B14(y), A1
1        00000008 00006000          NOP     4
1        0000000c 000401E0          ADD     A0,A1,A0
1        00000010 0000027C-         STW     A0,*+B14(z)
      14
      15                            .sslist
      16 00000014                   addm    x,y,z
1        00000014 0000006C-         LDW     *+B14(:src1:), A0
#                                   LDW     *+B14(x), A0
1        00000018 0080016C-         LDW     *+B14(:src2:), A1
#                                   LDW     *+B14(y), A1
1        0000001c 00006000          NOP     4
1        00000020 000401E0          ADD     A0,A1,A0
1        00000024 0000027C-         STW     A0,*+B14(:dst:)
#                                   STW     A0,*+B14(z)
      17
```

.string/.cstring

Initialize Text

Syntax

.string {*expr*$_1$ **|** **"***string*$_1$**"**} [**,** **...** **,** {*expr*$_n$ **|** **"***string*$_n$**"**}]

.cstring {*expr*$_1$ **|** **"***string*$_1$**"**} [**,** **...** **,** {*expr*$_n$ **|** **"***string*$_n$**"**}]

Description

The **.string** and **.cstring** directives place 8-bit characters from a character string into the current section. The *expr* or *string* can be one of the following:

- An expression that the assembler evaluates and treats as an 8-bit signed number.
- A character string enclosed in double quotes. Each character in a string represents a separate value, and values are stored in consecutive bytes. The entire string *must* be enclosed in quotes.

The .cstring directive adds a NUL character needed by C; the .string directive does not add a NUL character. In addition, .cstring interprets C escapes (\\ \a \b \f \n \r \t \v \<octal>).

The assembler truncates any values that are greater than eight bits. Operands must fit on a single source statement line.

If you use a label, it points to the location of the first byte that is initialized.

When you use .string and .cstring in a .struct/.endstruct sequence, the directive only defines a member's size; it does not initialize memory. For more information, see the .struct/.endstruct/.tag topic.

Example

In this example, 8-bit values are placed into consecutive bytes in the current section. The label Str_Ptr has the value 0h, which is the location of the first initialized byte.

```
1 00000000 00000041  Str_Ptr:   .string  "ABCD"
  00000001 00000042
  00000002 00000043
  00000003 00000044
2 00000004 00000041             .string  41h, 42h, 43h, 44h
  00000005 00000042
  00000006 00000043
  00000007 00000044
3 00000008 00000041             .string  "Austin", "Houston"
  00000009 00000075
  0000000a 00000073
  0000000b 00000074
  0000000c 00000069
  0000000d 0000006E
  0000000e 00000048
  0000000f 0000006F
  00000010 00000075
  00000011 00000073
  00000012 00000074
  00000013 0000006F
  00000014 0000006E
4 00000015 00000030             .string  36 + 12
```

.struct/.endstruct/.tag *Declare Structure Type*

Syntax

[*stag*]	**.struct**	[*expr*]
[mem_0]	*element*	[$expr_0$]
[mem_1]	*element*	[$expr_1$]
.	.	.
.	.	.
.	.	.
[mem_n]	**.tag** *stag*	[$expr_n$]
.	.	.
.	.	.
.	.	.
[mem_N]	*element*	[$expr_N$]
[*size*]	**.endstruct**	
label	**.tag**	*stag*

Description

The **.struct** directive assigns symbolic offsets to the elements of a data structure definition. This allows you to group similar data elements together and let the assembler calculate the element offset. This is similar to a C structure or a Pascal record. The .struct directive does not allocate memory; it merely creates a symbolic template that can be used repeatedly.

The **.endstruct** directive terminates the structure definition.

The **.tag** directive gives structure characteristics to a *label*, simplifying the symbolic representation and providing the ability to define structures that contain other structures. The .tag directive does not allocate memory. The structure tag (*stag*) of a .tag directive must have been previously defined.

Following are descriptions of the parameters used with the .struct, .endstruct, and .tag directives:

- The *stag* is the structure's tag. Its value is associated with the beginning of the structure. If no stag is present, the assembler puts the structure members in the global symbol table with the value of their absolute offset from the top of the structure. The stag is optional for .struct, but is required for .tag.
- The *expr* is an optional expression indicating the beginning offset of the structure. The default starting point for a structure is 0.
- The $mem_{n/N}$ is an optional label for a member of the structure. This label is absolute and equates to the present offset from the beginning of the structure. A label for a structure member cannot be declared global.
- The *element* is one of the following descriptors: .byte, .char, .int, .long, .word, .double, .half, .short, .string, .float, .field, and .tag. All of these except .tag are typical directives that initialize memory. Following a .struct directive, these directives describe the structure element's size. They do not allocate memory. The .tag directive is a special case because stag must be used (as in the definition of stag).
- The $expr_{n/N}$ is an optional expression for the number of elements described. This value defaults to 1. A .string element is considered to be one byte in size, and a .field element is one bit.
- The *size* is an optional label for the total size of the structure.

Directives that Can Appear in a .struct/.endstruct Sequence

NOTE: The only directives that can appear in a .struct/.endstruct sequence are element descriptors, conditional assembly directives, and the .align directive, which aligns the member offsets on word boundaries. Empty structures are illegal.

The following examples show various uses of the .struct, .tag, and .endstruct directives.

Example 1

```
 1                    real_rec  .struct                 ; stag
 2          00000000  nom       .int                    ; member1 = 0
 3          00000004  den       .int                    ; member2 = 1
 4          00000008  real_len  .endstruct              ; real_len = 2
 5
 6 00000000 0080016C-           LDW  *+B14(real+real_rec.den), A1
 7                                                      ; access structure
 8
 9 00000000                     .bss real, real_len     ; allocate mem rec
10
```

Example 2

```
11                    cplx_rec  .struct                 ; stag
12          00000000  reali     .tag real_rec           ; member1  = 0
13          00000008  imagi     .tag real_rec           ; member2  = 2
14          00000010  cplx_len  .endstruct              ; cplx_len = 4
15
16                    complex   .tag cplx_rec           ; assign structure
17                                                      ; attribute
18 00000008                     .bss complex, cplx_len  ; allocate mem rec
19
20 00000004 0100046C-           LDW  *+B14(complex.imagi.nom), A2
21                                                      ; access structure
22 00000008 0100036C-           LDW  *+B14(complex.reali.den), A2
23                                                      ; access structure
24 0000000c 018C4A78            CMPEQ A2, A3, A3
```

Example 3

```
 1                              .struct                 ; no stag puts
 2                                                      ; mems into global
 3                                                      ; symbol table
 4
 5          00000000  X         .byte                   ; create 3 dim
 6          00000001  Y         .byte                   ; templates
 7          00000002  Z         .byte
 8          00000003            .endstruct
```

Example 4

```
 1                    bit_rec   .struct                 ; stag
 2          00000000  stream    .string 64
 3          00000040  bit7      .field  7               ; bit7 = 64
 4          00000040  bit1      .field  9               ; bit9 = 64
 5          00000042  bit5      .field  10              ; bit5 = 64
 6          00000044  x_int     .byte                   ; x_int = 68
 7          00000045  bit_len   .endstruct              ; length = 72
 8
 9                    bits      .tag bit_rec
10 00000000                     .bss bits, bit_len
11
12 00000000 0100106C-           LDW  *+B14(bits.bit7), A2
13                                                     ; load field
14 00000004 0109E7A0            AND  0Fh, A2, A2       ; mask off garbage
```

.symdepend/.weak *Affect Symbol Linkage and Visibility*

Syntax

.symdepend *dst symbol name*[**,** *src symbol name*]

.weak *symbol name*

Description

These directives are used to affect symbol linkage and visibility. The .weak directive is only valid when ELF mode is used.

The **.symdepend** directive creates an artificial reference from the section defining *src symbol name* to the symbol *dst symbol name*. This prevents the linker from removing the section containing *dst symbol name* if the section defining *src symbol name* is included in the output module. If *src symbol name* is not specified, a reference from the current section is created.

The **.weak** directive identifies a symbol that is used in the current module but is defined in another module. The linker resolves this symbol's definition at link time. The .weak directive is equivalent to the .ref directive, except that the reference has weak linkage.

A global *symbol* is defined in the same manner as any other symbol; that is, it appears as a label or is defined by the .set, .equ, .bss, or .usect directive. If a global symbol is defined more than once, the linker issues a multiple-definition error. (The assembler can provide a similar multiple-definition error for local symbols.) The .weak directive always creates a symbol table entry for a symbol, whether the module uses the symbol or not; .symdepend, however, creates an entry only if the module actually uses the symbol.

A symbol can be declared global for either of two reasons:

- If the symbol is *not defined in the current module* (which includes macro, copy, and include files), the .weak directive tells the assembler that the symbol is defined in an external module. This prevents the assembler from issuing an unresolved reference error. At link time, the linker looks for the symbol's definition in other modules.
- If the symbol is *defined in the current module*, the .symdepend directive declares that the symbol and its definition can be used externally by other modules. These types of references are resolved at link time.

.tab *Define Tab Size*

Syntax

.tab *size*

Description

The **.tab** directive defines the tab size. Tabs encountered in the source input are translated to *size* character spaces in the listing. The default tab size is eight spaces.

Example

In this example, each of the lines of code following a .tab statement consists of a single tab character followed by an NOP instruction.

Source file:

```
; default tab size
    NOP
    NOP
    NOP
      .tab 4
    NOP
    NOP
    NOP
      .tab 16
    NOP
    NOP
    NOP
```

Listing file:

```
 1                    ; default tab size
 2 00000000 00000000          NOP
 3 00000004 00000000          NOP
 4 00000008 00000000          NOP
 5                               .tab4
 7 0000000c 00000000      NOP
 8 00000010 00000000      NOP
 9 00000014 00000000      NOP
10                               .tab 16
12 00000018 00000000                  NOP
13 0000001c 00000000                  NOP
14 00000020 00000000                  NOP
```

.text Assemble Into the .text Section

Syntax

.text

Description

The **.text** sets .text as the current section. Lines that follow this directive will be assembled into the .text section, which usually contains executable code. The section program counter is set to 0 if nothing has yet been assembled into the .text section. If code has already been assembled into the .text section, the section program counter is restored to its previous value in the section.

The .text section is the default section. Therefore, at the beginning of an assembly, the assembler assembles code into the .text section unless you use a .data or .sect directive to specify a different section.

For more information about sections, see Chapter 2.

Example

This example assembles code into the .text and .data sections.

```
 1                       ******************************************
 2                       ** Begin assembling into .data section. **
 3                       ******************************************
 4 00000000                      .data
 5 00000000 00000005             .byte   5,6
   00000001 00000006
 6
 7                       ******************************************
 8                       ** Begin assembling into .text section. **
 9                       ******************************************
10 00000000                      .text
11 00000000 00000001             .byte   1
12 00000001 00000002             .byte   2,3
   00000002 00000003
13
14                       ******************************************
15                       ** Resume assembling into .data section.**
16                       ******************************************
17 00000002                      .data
18 00000002 00000007             .byte   7,8
   00000003 00000008
19
20                       ******************************************
21                       ** Resume assembling into .text section.**
22                       ******************************************
23 00000003                      .text
24 00000003 00000004             .byte   4
```

.title *Define Page Title*

Syntax

.title "*string***"**

Description

The **.title** directive supplies a title that is printed in the heading on each listing page. The source statement itself is not printed, but the line counter is incremented.

The *string* is a quote-enclosed title of up to 64 characters. If you supply more than 64 characters, the assembler truncates the string and issues a warning:

```
*** WARNING! line x: W0001: String is too long - will be truncated
```

The assembler prints the title on the page that follows the directive and on subsequent pages until another .title directive is processed. If you want a title on the first page, the first source statement must contain a .title directive.

Example

In this example, one title is printed on the first page and a different title is printed on succeeding pages.

Source file:

```
       .title  "**** Fast Fourier Transforms ****"
;        .
;        .
;        .
       .title  "**** Floating-Point Routines ****"
       .page
```

Listing file:

```
TMS320C6000 Assembler    Version x.xx        Day    Time    Year
Copyright (c) 1996-2011 Texas Instruments Incorporated
**** Fast Fourier Transforms ****                                    PAGE    1

       2                    ;        .
       3                    ;        .
       4                    ;        .
TMS320C6000 Assembler    Version x.xx        Day    Time    Year
Copyright (c) 1996-2011 Texas Instruments Incorporated
**** Floating-Point Routines ****                                    PAGE    2


 No Errors, No Warnings
```

.union/.endunion/.tag *Declare Union Type*

Syntax

[*stag*] **.union** [*expr*]

[*mem*$_0$] *element* [*expr*$_0$]

[*mem*$_1$] *element* [*expr*$_1$]

. . .

. . .

. . .

[*mem*$_n$] **.tag** *stag* [*expr*$_n$]

. . .

. . .

. . .

[*mem*$_N$] *element* [*expr*$_N$]

[*size*] **.endunion**

label **.tag** *stag*

Description

The **.union** directive assigns symbolic offsets to the elements of alternate data structure definitions to be allocated in the same memory space. This enables you to define several alternate structures and then let the assembler calculate the element offset. This is similar to a C union. The .union directive does not allocate any memory; it merely creates a symbolic template that can be used repeatedly.

A .struct definition can contain a .union definition, and .structs and .unions can be nested.

The **.endunion** directive terminates the union definition.

The **.tag** directive gives structure or union characteristics to a *label*, simplifying the symbolic representation and providing the ability to define structures or unions that contain other structures or unions. The .tag directive does not allocate memory. The structure or union tag of a .tag directive must have been previously defined.

Following are descriptions of the parameters used with the .struct, .endstruct, and .tag directives:

- The *utag* is the union's tag. is the union's tag. Its value is associated with the beginning of the union. If no utag is present, the assembler puts the union members in the global symbol table with the value of their absolute offset from the top of the union. In this case, each member must have a unique name.
- The *expr* is an optional expression indicating the beginning offset of the union. Unions default to start at 0. This parameter can only be used with a top-level union. It cannot be used when defining a nested union.
- The *mem*$_{n/N}$ is an optional label for a member of the union. This label is absolute and equates to the present offset from the beginning of the union. A label for a union member cannot be declared global.
- The *element* is one of the following descriptors: .byte, .char, .int, .long, .word, .double, .half, .short, .string, .float, and .field. An element can also be a complete declaration of a nested structure or union, or a structure or union declared by its tag. Following a .union directive, these directives describe the element's size. They do not allocate memory.
- The *expr*$_{n/N}$ is an optional expression for the number of elements described. This value defaults to 1. A .string element is considered to be one byte in size, and a .field element is one bit.
- The *size* is an optional label for the total size of the union.

Directives that Can Appear in a .union/.endunion Sequence

NOTE: The only directives that can appear in a .union/.endunion sequence are element descriptors, structure and union tags, and conditional assembly directives. Empty structures are illegal.

These examples show unions with and without tags.

Example 1

```
 1                         .global employid
 2              xample     .union                 ; utag
 3        0000  ival       .word                  ; member1 = int
 4        0000  fval       .float                 ; member2 = float
 5        0000  sval       .string                ; member3 = string
 6        0002  real_len   .endunion              ; real_len = 2
 7
 8 000000                  .bss  employid, real_len  ;allocate memory
 9
10              employid   .tag  xample           ; name an instance
11 000000 0000-            ADD   employid.fval, A  ; access union element
```

Example 2

```
 1
 2                                        ; utag
 3        0000  x          .long                ; member1 = long
 4        0000  y          .float               ; member2 = float
 5        0000  z          .word                ; member3 = word
 6        0002  size_u     .endunion            ; real_len = 2
 7
```

.usect *Reserve Uninitialized Space*

Syntax *symbol* **.usect "***section name***",** *size in bytes*[**,** *alignment*[, *bank offset*]]

Description The **.usect** directive reserves space for variables in an uninitialized, named section. This directive is similar to the .bss directive; both simply reserve space for data and that space has no contents. However, .usect defines additional sections that can be placed anywhere in memory, independently of the .bss section.

- The *symbol* points to the first location reserved by this invocation of the .usect directive. The symbol corresponds to the name of the variable for which you are reserving space.
- The *section name* must be enclosed in double quotes. This parameter names the uninitialized section. A section name can contain a subsection name in the form *section name* **:** *subsection name*.
- The *size in bytes* is an expression that defines the number of bytes that are reserved in *section name*.
- The *alignment* is an optional parameter that ensures that the space allocated to the symbol occurs on the specified boundary. This boundary must be set to a power of 2.
- The *bank offset* is an optional parameter that ensures that the space allocated to the symbol occurs on a specific memory bank boundary. The bank offset value measures the number of bytes to offset from the alignment specified before assigning the symbol to that location.

Initialized sections directives (.text, .data, and .sect) tell the assembler to pause assembling into the current section and begin assembling into another section. A .usect or .bss directive encountered in the current section is simply assembled, and assembly continues in the current section.

Variables that can be located contiguously in memory can be defined in the same specified section; to do so, repeat the .usect directive with the same section name and the subsequent symbol (variable name).

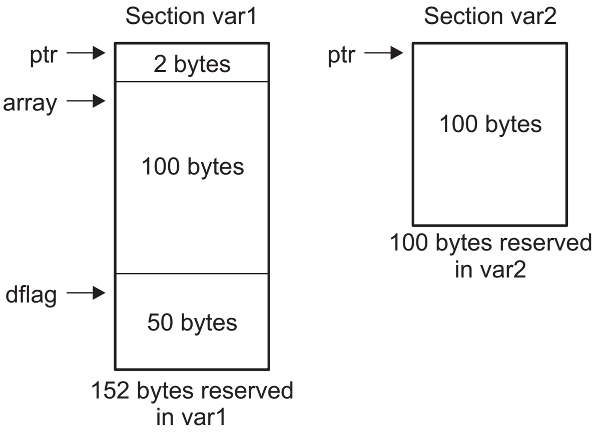
For more information about sections, see Chapter 2.

Example This example uses the .usect directive to define two uninitialized, named sections, var1 and var2. The symbol ptr points to the first byte reserved in the var1 section. The symbol array points to the first byte in a block of 100 bytes reserved in var1, and dflag points to the first byte in a block of 50 bytes in var1. The symbol vec points to the first byte reserved in the var2 section.

Figure 5-8 shows how this example reserves space in two uninitialized sections, var1 and var2.

```
                   ***************************************************
                   **   Assemble into .text section                 **
                   ***************************************************
00000000                   .text
00000000 008001A0          MV      A0,A1

                   ***************************************************
                   **   Reserve 2 bytes in var1.                    **
                   ***************************************************
00000000           ptr     .usect  "var1",2
00000004 0100004C-         LDH     *+B14(ptr),A2   ; still in .text

                   ***************************************************
                   **   Reserve 100 bytes in var1                   **
                   ***************************************************
00000002           array   .usect  "var1",100
00000008 01800128-         MVK     array,A3        ; still in .text
0000000c 01800068-         MVKH    array,A3

                   ***************************************************
                   **   Reserve 50 bytes in var1                    **
                   ***************************************************
00000066           dflag   .usect  "var1",50
00000010 02003328-         MVK     dflag,A4
00000014 02000068-         MVKH    dflag,A4

                   ***************************************************
                   **   Reserve 100 bytes in var1                   **
                   ***************************************************
00000000           vec     .usect  "var2",100
00000018 0000002A-         MVK     vec,B0          ; still in .text
0000001c 0000006A-         MVKH    vec,B0
```

Figure 5-8. The .usect Directive



.unasg/.undefine *Turn Off Substitution Symbol*

Syntax

.unasg *symbol*

.undefine *symbol*

Description

The **.unasg** and **.undefine** directives remove the definition of a substitution symbol created using .asg or .define. The named *symbol* will removed from the substitution symbol table from the point of the .undefine or .unasg to the end of the assembly file. See Section 4.8.10 for more information on substitution symbols.

These directives can be used to remove from the assembly environment any C/C++ macros that may cause a problem. See Chapter 13 for more information about using C/C++ headers in assembly source.

.var *Use Substitution Symbols as Local Variables*

Syntax

.var sym_1 [**,** sym_2 **, ... ,** sym_n]

Description

The **.var** directive allows you to use substitution symbols as local variables within a macro. With this directive, you can define up to 32 local macro substitution symbols (including parameters) per macro.

The .var directive creates temporary substitution symbols with the initial value of the null string. These symbols are not passed in as parameters, and they are lost after expansion.

See Section 4.8.10 for more information on substitution symbols .See Chapter 6 for information on macros.

Chapter 6

SPRU186X – March 2014

Macro Language Description

The TMS320C6000 assembler supports a macro language that enables you to create your own instructions. This is especially useful when a program executes a particular task several times. The macro language lets you:

- Define your own macros and redefine existing macros
- Simplify long or complicated assembly code
- Access macro libraries created with the archiver
- Define conditional and repeatable blocks within a macro
- Manipulate strings within a macro
- Control expansion listing

Topic **Page**

6.1 Using Macros

Programs often contain routines that are executed several times. Instead of repeating the source statements for a routine, you can define the routine as a macro, then call the macro in the places where you would normally repeat the routine. This simplifies and shortens your source program.

If you want to call a macro several times but with different data each time, you can assign parameters within a macro. This enables you to pass different information to the macro each time you call it. The macro language supports a special symbol called a *substitution symbol*, which is used for macro parameters. See Section 6.3 for more information.

Using a macro is a 3-step process.

Step 1. **Define the macro.** You must define macros before you can use them in your program. There are two methods for defining macros:

(a) Macros can be defined at the beginning of a *source file* or in a copy/include file. See Section 6.2, *Defining Macros*, for more information.

(b) Macros can also be defined in a *macro library*. A macro library is a collection of files in archive format created by the archiver. Each member of the archive file (macro library) may contain one macro definition corresponding to the member name. You can access a macro library by using the .mlib directive. For more information, see Section 6.4.

Step 2. **Call the macro.** After you have defined a macro, call it by using the macro name as a mnemonic in the source program. This is referred to as a *macro call*.

Step 3. **Expand the macro.** The assembler expands your macros when the source program calls them. During expansion, the assembler passes arguments by variable to the macro parameters, replaces the macro call statement with the macro definition, then assembles the source code. By default, the macro expansions are printed in the listing file. You can turn off expansion listing by using the .mnolist directive. For more information, see Section 6.8.

When the assembler encounters a macro definition, it places the macro name in the opcode table. This redefines any previously defined macro, library entry, directive, or instruction mnemonic that has the same name as the macro. This allows you to expand the functions of directives and instructions, as well as to add new instructions.

6.2 Defining Macros

You can define a macro anywhere in your program, but you must define the macro before you can use it. Macros can be defined at the beginning of a source file or in a .copy/.include file (see Copy Source File); they can also be defined in a macro library. For more information about macro libraries, see Section 6.4.

Macro definitions can be nested, and they can call other macros, but all elements of the macro must be defined in the same file. Nested macros are discussed in Section 6.9.

A macro definition is a series of source statements in the following format:

macname **.macro** [*parameter*$_1$] [**,** ... **,** *parameter*$_n$]
model statements or macro directives
[**.mexit**]
.endm

macname names the macro. You must place the name in the source statement's label field. Only the first 128 characters of a macro name are significant. The assembler places the macro name in the internal opcode table, replacing any instruction or previous macro definition with the same name.

.macro is the directive that identifies the source statement as the first line of a macro definition. You must place .macro in the opcode field.

parameter $_1$,
parameter $_n$ are optional substitution symbols that appear as operands for the .macro directive. Parameters are discussed in Section 6.3.

model statements are instructions or assembler directives that are executed each time the macro is called.

macro directives are used to control macro expansion.

.mexit is a directive that functions as a *goto .endm*. The .mexit directive is useful when error testing confirms that macro expansion fails and completing the rest of the macro is unnecessary.

.endm is the directive that terminates the macro definition.

If you want to include comments with your macro definition but *do not* want those comments to appear in the macro expansion, use an exclamation point to precede your comments. If you *do* want your comments to appear in the macro expansion, use an asterisk or semicolon. See Section 6.7 for more information about macro comments.

Example 6-1 shows the definition, call, and expansion of a macro.

Example 6-1. Macro Definition, Call, and Expansion

Macro definition: The following code defines a macro, sadd4, with four parameters:

```
      1                    sadd4   .macro  r1,r2,r3,r4
      2                    !
      3                    !  sadd4  r1, r2 ,r3, r4
      4                    !  r1 = r1 + r2 + r3 + r4 (saturated)
      5                    !
      6                            SADD    r1,r2,r1
      7                            SADD    r1,r3,r1
      8                            SADD    r1,r4,r1
      9                            .endm
```

Macro call: The following code calls the sadd4 macro with four arguments:

```
     10
     11 00000000                   sadd4   A0,A1,A2,A3
```

Macro expansion: The following code shows the substitution of the macro definition for the macro call. The assembler substitutes A0, A1, A2, and A3 for the r1, r2, r3, and r4 parameters of sadd4.

```
1        00000000 00040278         SADD    A0,A1,A0
1        00000004 00080278         SADD    A0,A2,A0
1        00000008 000C0278         SADD    A0,A3,A0
```

6.3 Macro Parameters/Substitution Symbols

If you want to call a macro several times with different data each time, you can assign parameters within the macro. The macro language supports a special symbol, called a *substitution symbol*, which is used for macro parameters.

Macro parameters are substitution symbols that represent a character string. These symbols can also be used outside of macros to equate a character string to a symbol name (see Section 4.8.10).

Valid substitution symbols can be up to 128 characters long and *must begin with a letter*. The remainder of the symbol can be a combination of alphanumeric characters, underscores, and dollar signs.

Substitution symbols used as macro parameters are local to the macro they are defined in. You can define up to 32 local substitution symbols (including substitution symbols defined with the .var directive) per macro. For more information about the .var directive, see Section 6.3.6.

During macro expansion, the assembler passes arguments by variable to the macro parameters. The character-string equivalent of each argument is assigned to the corresponding parameter. Parameters without corresponding arguments are set to the null string. If the number of arguments exceeds the number of parameters, the last parameter is assigned the character-string equivalent of all remaining arguments.

If you pass a list of arguments to one parameter or if you pass a comma or semicolon to a parameter, you must surround these terms with quotation marks.

At assembly time, the assembler replaces the macro parameter/substitution symbol with its corresponding character string, then translates the source code into object code.

Example 6-2 shows the expansion of a macro with varying numbers of arguments.

Example 6-2. Calling a Macro With Varying Numbers of Arguments

Macro definition:

```
Parms    .macro      a,b,c
;                 a = :a:
;                 b = :b:
;                 c = :c:
      .endm
```

Calling the macro:

```
      Parms   100,label             Parms   100,label,x,y
;         a = 100                           ;   a = 100
;         b = label                         ;   b = label
;         c = ""                            ;   c = x,y

      Parms   100, , x              Parms   "100,200,300",x,y
;         a = 100                           ;   a = 100,200,300
;         b = ""                            ;   b = x
;         c = x                             ;   c = y

      Parms   """string""",x,y
;         a = "string"
;         b = x
;         c = y
```

6.3.1 Directives That Define Substitution Symbols

You can manipulate substitution symbols with the **.asg** and **.eval** directives.

- The **.asg** directive assigns a character string to a substitution symbol.

  For the .asg directive, the quotation marks are optional. If there are no quotation marks, the assembler reads characters up to the first comma and removes leading and trailing blanks. In either case, a character string is read and assigned to the *substitution symbol*. The syntax of the .asg directive is:

.asg[**"**]*character string*[**"**], *substitution symbol*

Example 6-3 shows character strings being assigned to substitution symbols.

Example 6-3. The .asg Directive

```
      .asg   "A4", RETVAL       ; return value
```

- The **.eval** directive performs arithmetic on numeric substitution symbols.

  The .eval directive evaluates the *expression* and assigns the string value of the result to the *substitution symbol*. If the expression is not well defined, the assembler generates an error and assigns the null string to the symbol. The syntax of the .eval directive is:

.eval *well-defined expression* **,** *substitution symbol*

Example 6-4 shows arithmetic being performed on substitution symbols.

Example 6-4. The .eval Directive

```
      .asg   1,counter
      .loop  100
      .word  counter
      .eval  counter + 1,counter
      .endloop
```

In Example 6-4, the .asg directive could be replaced with the .eval directive (.eval 1, counter) without changing the output. In simple cases like this, you can use .eval and .asg interchangeably. However, you must use .eval if you want to calculate a *value* from an expression. While .asg only assigns a character string to a substitution symbol, .eval evaluates an expression and then assigns the character string equivalent to a substitution symbol.

See Assign a Substitution Symbol for more information about the .asg and .eval assembler directives.

6.3.2 Built-In Substitution Symbol Functions

The following built-in substitution symbol functions enable you to make decisions on the basis of the string value of substitution symbols. These functions always return a value, and they can be used in expressions. Built-in substitution symbol functions are especially useful in conditional assembly expressions. Parameters of these functions are substitution symbols or character-string constants.

In the function definitions shown in Table 6-1, *a* and *b* are parameters that represent substitution symbols or character-string constants. The term *string* refers to the string value of the parameter. The symbol *ch* represents a character constant.

Table 6-1. Substitution Symbol Functions and Return Values

Function	Return Value
$symlen *(a)*	Length of string *a*
$symcmp *(a,b)*	< 0 if *a* < *b;* 0 if *a* = *b;* > 0 if *a* > *b*
$firstch *(a,ch)*	Index of the first occurrence of character constant *ch* in string *a*
$lastch *(a,ch)*	Index of the last occurrence of character constant *ch* in string *a*
$isdefed *(a)*	1 if string *a* is defined in the symbol table 0 if string *a* is not defined in the symbol table
$ismember *(a,b)*	Top member of list *b* is assigned to string *a* 0 if *b* is a null string
$iscons *(a)*	1 if string *a* is a binary constant 2 if string *a* is an octal constant 3 if string *a* is a hexadecimal constant 4 if string *a* is a character constant 5 if string *a* is a decimal constant
$isname *(a)*	1 if string *a* is a valid symbol name 0 if string *a* is not a valid symbol name
$isreg *(a)* [1]	1 if string *a* is a valid predefined register name 0 if string *a* is not a valid predefined register name

[1] For more information about predefined register names, see Section 4.8.6.

Example 6-5 shows built-in substitution symbol functions.

Example 6-5. Using Built-In Substitution Symbol Functions

```
pushx .macro list
!
! Push more than one item
! $ismember removes the first item in the list

   .var      item
   .loop
   .break    ($ismember(item, list) = 0)
   STW       item,*B15--[1]
   .endloop
   .endm


   pushx     A0,A1,A2,A3
```

6.3.3 Recursive Substitution Symbols

When the assembler encounters a substitution symbol, it attempts to substitute the corresponding character string. If that string is also a substitution symbol, the assembler performs substitution again. The assembler continues doing this until it encounters a token that is not a substitution symbol or until it encounters a substitution symbol that it has already encountered during this evaluation.

In Example 6-6, the x is substituted for z; z is substituted for y; and y is substituted for x. The assembler recognizes this as infinite recursion and ceases substitution.

Example 6-6. Recursive Substitution

```
    .asg   "x",z  ; declare z and assign z = "x"
    .asg   "z",y  ; declare y and assign y = "z"
    .asg   "y",x  ; declare x and assign x = "y"
    MVKL   x, A1
    MVKH   x, A1

*   MVKL   x, A1  ; recursive expansion
*   MVKH   x, A1  ; recursive expansion
```

6.3.4 Forced Substitution

In some cases, substitution symbols are not recognizable to the assembler. The forced substitution operator, which is a set of colons surrounding the symbol, enables you to force the substitution of a symbol's character string. Simply enclose a symbol with colons to force the substitution. Do not include any spaces between the colons and the symbol.

The syntax for the forced substitution operator is:

:symbol:

The assembler expands substitution symbols surrounded by colons before expanding other substitution symbols.

You can use the forced substitution operator only inside macros, and you cannot nest a forced substitution operator within another forced substitution operator.

Example 6-7 shows how the forced substitution operator is used.

Example 6-7. Using the Forced Substitution Operator

```
force    .macro   x
         .loop    8
PORT:x:  .set     x*4
         .eval    x+1, x
         .endloop
         .endm

         .global  portbase
         force

  PORT0  .set     0
  PORT1  .set     4
    .
    .
    .
  PORT7  .set     28
```

6.3.5 Accessing Individual Characters of Subscripted Substitution Symbols

In a macro, you can access the individual characters (substrings) of a substitution symbol with subscripted substitution symbols. You must use the forced substitution operator for clarity.

You can access substrings in two ways:

- :symbol (*well-defined expression*):

  This method of subscripting evaluates to a character string with one character.

- :symbol (*well-defined expression* $_1$, *well-defined expression* $_2$):

  In this method, expression$_1$ represents the substring's starting position, and expression$_2$ represents the substring's length. You can specify exactly where to begin subscripting and the exact length of the resulting character string. *The index of substring characters begins with 1, not 0.*

Example 6-8 and Example 6-9 show built-in substitution symbol functions used with subscripted substitution symbols.

In Example 6-8, subscripted substitution symbols redefine the STW instruction so that it handles immediates. In Example 6-9, the subscripted substitution symbol is used to find a substring strg1 beginning at position start in the string strg2. The position of the substring strg1 is assigned to the substitution symbol pos.

Example 6-8. Using Subscripted Substitution Symbols to Redefine an Instruction

```
storex  .macro    x
        .var      tmp
        .asg      :x(1):, tmp
        .if       $symcmp(tmp,"A") == 0
        STW       x,*A15--(4)
        .elseif   $symcmp(tmp,"B") == 0
        STW       x,*A15--(4)
        .elseif   $iscons(x)
        MVK       x,A0
        STW       A0,*A15--(4)
        .else
        .emsg     "Bad Macro Parameter"
        .endif
        .endm

        storex    10h
        storex    A15
```

Example 6-9. Using Subscripted Substitution Symbols to Find Substrings

```
substr  .macro    start,strg1,strg2,pos
        .var      len1,len2,i,tmp
        .if       $symlen(start) = 0
        .eval     1,start
        .endif
        .eval     0,pos
        .eval     start,i
        .eval     $symlen(strg1),len1
        .eval     $symlen(strg2),len2
        .loop
        .break    I = (len2 - len1 + 1)
        .asg      ":strg2(i,len1):",tmp
        .if       $symcmp(strg1,tmp) = 0
        .eval     i,pos
        .break
        .else
        .eval     I + 1,i
        .endif
        .endloop
        .endm

        .asg      0,pos
        .asg      "ar1 ar2 ar3 ar4",regs
        substr    1,"ar2",regs,pos
        .word     pos
```

6.3.6 Substitution Symbols as Local Variables in Macros

If you want to use substitution symbols as local variables within a macro, you can use the **.var** directive to define up to 32 local macro substitution symbols (including parameters) per macro. The .var directive creates temporary substitution symbols with the initial value of the null string. These symbols are not passed in as parameters, and they are lost after expansion.

.var sym_1 [,sym_2 , ... ,sym_n]

The .var directive is used in Example 6-8 and Example 6-9.

6.4 Macro Libraries

One way to define macros is by creating a macro library. A macro library is a collection of files that contain macro definitions. You must use the archiver to collect these files, or members, into a single file (called an archive). Each member of a macro library contains one macro definition. The files in a macro library must be unassembled source files. The macro name and the member name must be the same, and the macro filename's extension must be .asm. For example:

Macro Name	Filename in Macro Library
simple	simple.asm
add3	add3.asm

You can access the macro library by using the .mlib assembler directive (described in Define Macro Library). The syntax is:

.mlib *filename*

When the assembler encounters the .mlib directive, it opens the library named by filename and creates a table of the library's contents. The assembler enters the names of the individual members within the library into the opcode tables as library entries; this redefines any existing opcodes or macros that have the same name. If one of these macros is called, the assembler extracts the entry from the library and loads it into the macro table.

The assembler expands the library entry in the same way it expands other macros. See Section 6.1 for how the assembler expands macros. You can control the listing of library entry expansions with the .mlist directive. For more information about the .mlist directive, see Section 6.8 and Start/Stop Macro Expansion Listing. Only macros that are actually called from the library are extracted, and they are extracted only once.

You can use the archiver to create a macro library by including the desired files in an archive. A macro library is no different from any other archive, except that the assembler expects the macro library to contain macro definitions. The assembler expects *only* macro definitions in a macro library; putting object code or miscellaneous source files into the library may produce undesirable results. For information about creating a macro library archive, see Section 7.1.

6.5 Using Conditional Assembly in Macros

The conditional assembly directives are **.if/.elseif/.else/.endif** and **.loop/ .break/.endloop**. They can be nested within each other up to 32 levels deep. The format of a conditional block is:

.if *well-defined expression*
[**.elseif** *well-defined expression*]
[**.else**]
.endif

The **.elseif** and **.else** directives are optional in conditional assembly. The .elseif directive can be used more than once within a conditional assembly code block. When .elseif and .else are omitted and when the .if expression is false (0), the assembler continues to the code following the .endif directive. See Assemble Conditional Blocks for more information on the .if/ .elseif/.else/.endif directives.

The **.loop/.break/.endloop** directives enable you to assemble a code block repeatedly. The format of a repeatable block is:

.loop [*well-defined expression*]
[**.break** [*well-defined expression*]]
.endloop

The **.loop** directive's optional *well-defined expression* evaluates to the loop count (the number of loops to be performed). If the expression is omitted, the loop count defaults to 1024 unless the assembler encounters a .break directive with an expression that is true (nonzero). See Assemble Conditional Blocks Repeatedly for more information on the .loop/.break/.endloop directives.

The **.break** directive and its expression are optional in repetitive assembly. If the expression evaluates to false, the loop continues. The assembler breaks the loop when the .break expression evaluates to true or when the .break expression is omitted. When the loop is broken, the assembler continues with the code after the .endloop directive.

For more information, see Section 5.7.

Example 6-10, Example 6-11, and Example 6-12 show the .loop/.break/ .endloop directives, properly nested conditional assembly directives, and built-in substitution symbol functions used in a conditional assembly code block.

Example 6-10. The .loop/.break/.endloop Directives

```
      .asg    1,x
      .loop

      .break  (x == 10)  ; if x == 10, quit loop/break with expression

      .eval   x+1,x
      .endloop
```

Example 6-11. Nested Conditional Assembly Directives

```
      .asg    1,x
      .loop

      .if     (x == 10)  ; if x == 10, quit loop
      .break  (x == 10)  ; force break
      .endif

      .eval   x+1,x
      .endloop
```

Example 6-12. Built-In Substitution Symbol Functions in a Conditional Assembly Code Block

```
MACK3   .macro src1, src2, sum, k
!
    !   dst = dst + k * (src1 * src2)

        .if       k = 0
        MPY    src1, src2, src2
        NOP
        ADD    src2, sum, sum
        .else
        MPY    src1,src2,src2
        MVK    k,src1
        MPY    src1,src2,src2
        NOP
        ADD    src2,sum,sum
        .endif

        .endm

        MACK3  A0,A1,A3,0
        MACK3  A0,A1,A3,100
```

6.6 Using Labels in Macros

All labels in an assembly language program must be unique. This includes labels in macros. If a macro is expanded more than once, its labels are defined more than once. *Defining a label more than once is illegal*. The macro language provides a method of defining labels in macros so that the labels are unique. Simply follow each label with a question mark, and the assembler replaces the question mark with a period followed by a unique number. When the macro is expanded, *you do not see the unique number in the listing file*. Your label appears with the question mark as it did in the macro definition. You cannot declare this label as global. See Section 4.8.3 for more about labels.

The syntax for a unique label is:

label **?**

Example 6-13 shows unique label generation in a macro. The maximum label length is shortened to allow for the unique suffix. For example, if the macro is expanded fewer than 10 times, the maximum label length is 126 characters. If the macro is expanded from 10 to 99 times, the maximum label length is 125. The label with its unique suffix is shown in the cross-listing file. To obtain a cross-listing file, invoke the assembler with the --cross_reference option (see Section 4.3).

Example 6-13. Unique Labels in a Macro

```
       1                    min     .macro  x,y,z
       2
       3                            MV      y,z
       4                    ||      CMPLT   x,y,y
       5                    [y]     B       l?
       6                            NOP     5
       7                            MV      x,z
       8                    l?
       9                            .endm
      10
      11
      12 00000000                   MIN     A0,A1,A2
1
1        00000000 010401A1          MV      A1,A2
1        00000004 00840AF8  ||      CMPLT   A0,A1,A1
1        00000008 80000292  [A1]    B       l?
1        0000000c 00008000          NOP     5
1        00000010 010001A0          MV      A0,A2
1        00000014           l?


LABEL                                VALUE       DEFN    REF

.TMS320C60                       00000001          0
.tms320C60                       00000001          0
l$1$                             00000014'        12     12
```

6.7 Producing Messages in Macros

The macro language supports three directives that enable you to define your own assembly-time error and warning messages. These directives are especially useful when you want to create messages specific to your needs. The last line of the listing file shows the error and warning counts. These counts alert you to problems in your code and are especially useful during debugging.

.emsg sends error messages to the listing file. The .emsg directive generates errors in the same manner as the assembler, incrementing the error count and preventing the assembler from producing an object file.

.mmsg sends assembly-time messages to the listing file. The .mmsg directive functions in the same manner as the .emsg directive but does not set the error count or prevent the creation of an object file.

.wmsg sends warning messages to the listing file. The .wmsg directive functions in the same manner as the .emsg directive, but it increments the warning count and does not prevent the generation of an object file.

Macro comments are comments that appear in the definition of the macro *but do not show up in the expansion of the macro*. An exclamation point in column 1 identifies a macro comment. If you want your comments to appear in the macro expansion, precede your comment with an asterisk or semicolon.

Example 6-14 shows user messages in macros and macro comments that do not appear in the macro expansion.

For more information about the .emsg, .mmsg, and .wmsg assembler directives, see Define Messages.

Example 6-14. Producing Messages in a Macro

```
TEST   .macro  x,y
!
! This macro checks for the correct number of parameters.
! It generates an error message if x and y are not present.
!
! The first line tests for proper input.
!
    .if     ($symlen(x) + ||$symlen(y) == 0)
    .emsg   "ERROR --missing parameter in call to TEST"
    .mexit
    .else
      .
      .
    .endif
    .if
      .
      .
    .endif
    .endm
```

6.8 Using Directives to Format the Output Listing

Macros, substitution symbols, and conditional assembly directives may hide information. You may need to see this hidden information, so the macro language supports an expanded listing capability.

By default, the assembler shows macro expansions and false conditional blocks in the list output file. You may want to turn this listing off or on within your listing file. Four sets of directives enable you to control the listing of this information:

- **Macro and loop expansion listing**

  .mlist expands macros and .loop/.endloop blocks. The .mlist directive prints all code encountered in those blocks.

  .mnolist suppresses the listing of macro expansions and .loop/ .endloop blocks.

  For macro and loop expansion listing, .mlist is the default.

- **False conditional block listing**

  .fclist causes the assembler to include in the listing file all conditional blocks that do not generate code (false conditional blocks). Conditional blocks appear in the listing exactly as they appear in the source code.

  .fcnolist suppresses the listing of false conditional blocks. Only the code in conditional blocks that actually assemble appears in the listing. The .if, .elseif, .else, and .endif directives do not appear in the listing.

  For false conditional block listing, .fclist is the default.

- **Substitution symbol expansion listing**

  .sslist expands substitution symbols in the listing. This is useful for debugging the expansion of substitution symbols. The expanded line appears below the actual source line.

  .ssnolist turns off substitution symbol expansion in the listing.

  For substitution symbol expansion listing, .ssnolist is the default.

- **Directive listing**

  .drlist causes the assembler to print to the listing file all directive lines.

  .drnolist suppresses the printing of certain directives in the listing file. These directives are .asg, .eval, .var, .sslist, .mlist, .fclist, .ssnolist, .mnolist, .fcnolist, .emsg, .wmsg, .mmsg, .length, .width, and .break.

  For directive listing, .drlist is the default.

6.9 Using Recursive and Nested Macros

The macro language supports recursive and nested macro calls. This means that you can call other macros in a macro definition. You can nest macros up to 32 levels deep. When you use recursive macros, you call a macro from its own definition (the macro calls itself).

When you create recursive or nested macros, you should pay close attention to the arguments that you pass to macro parameters because the assembler uses dynamic scoping for parameters. This means that the called macro uses the environment of the macro from which it was called.

Example 6-15 shows nested macros. The y in the in_block macro hides the y in the out_block macro. The x and z from the out_block macro, however, are accessible to the in_block macro.

Example 6-15. Using Nested Macros

```
in_block  .macro y,a
             .          ; visible parameters are y,a and x,z from the calling macro
          .endm

out_block .macro    x,y,z
             .          ; visible parameters are x,y,z
             .
          in_block x,y  ; macro call with x and y as arguments
             .
             .
          .endm
          out_block     ; macro call
```

Example 6-16 shows recursive and fact macros. The fact macro produces assembly code necessary to calculate the factorial of n, where n is an immediate value. The result is placed in the A1 register . The fact macro accomplishes this by calling fact1, which calls itself recursively.

Example 6-16. Using Recursive Macros

```
       .fcnolist

fact1  .macro n

       .if n == 1
          MVK globcnt, A1               ; Leave the answer in the A1 register.
       .else
          .eval 1, temp               ; Compute the decrement of symbol n.
          .eval globcnt*temp, globcnt   ; Multiply to get a new result.
          fact1 temp                    ; Recursive call.
       .endif
       .endm

fact   .macro n
       .if ! $iscons(n)                 ; Test that input is a constant.
           .emsg "Parm not a constant"


       .elseif n < 1                    ; Type check input.
           MVK 0, A1

       .else
           .var temp
           .asg n, globcnt

           fact1 n                      ; Perform recursive procedure

       .endif
       .endm
```

6.10 Macro Directives Summary

The directives listed in Table 6-2 through Table 6-6 can be used with macros. The .macro, .mexit, .endm and .var directives are valid only with macros; the remaining directives are general assembly language directives.

Table 6-2. Creating Macros

		See	
Mnemonic and Syntax	**Description**	**Macro Use**	**Directive**
.endm	End macro definition	Section 6.2	.endm
macname **.macro** [*parameter*$_1$][**,**... **,** *parameter*$_n$]	Define macro by *macname*	Section 6.2	.macro
.mexit	Go to .endm	Section 6.2	Section 6.2
.mlib *filename*	Identify library containing macro definitions	Section 6.4	.mlib

Table 6-3. Manipulating Substitution Symbols

		See	
Mnemonic and Syntax	**Description**	**Macro Use**	**Directive**
.asg [**"**]*character string*[**"**]*, substitution symbol*	Assign character string to substitution symbol	Section 6.3.1	.asg
.eval *well-defined expression, substitution symbol*	Perform arithmetic on numeric substitution symbols	Section 6.3.1	.eval
.var *sym*$_1$ [**,** *sym*$_2$, ...**,** *sym*$_n$]	Define local macro symbols	Section 6.3.6	.var

Table 6-4. Conditional Assembly

		See	
Mnemonic and Syntax	**Description**	**Macro Use**	**Directive**
.break [*well-defined expression*]	Optional repeatable block assembly	Section 6.5	.break
.endif	End conditional assembly	Section 6.5	.endif
.endloop	End repeatable block assembly	Section 6.5	.endloop
.else	Optional conditional assembly block	Section 6.5	.else
.elseif *well-defined expression*	Optional conditional assembly block	Section 6.5	.elseif
.if *well-defined expression*	Begin conditional assembly	Section 6.5	.if
.loop [*well-defined expression*]	Begin repeatable block assembly	Section 6.5	.loop

Table 6-5. Producing Assembly-Time Messages

		See	
Mnemonic and Syntax	**Description**	**Macro Use**	**Directive**
.emsg	Send error message to standard output	Section 6.7	.emsg
.mmsg	Send assembly-time message to standard output	Section 6.7	.mmsg
.wmsg	Send warning message to standard output	Section 6.7	.wmsg

Table 6-6. Formatting the Listing

		See	
Mnemonic and Syntax	**Description**	**Macro Use**	**Directive**
.fclist	Allow false conditional code block listing (default)	Section 6.8	.fclist
.fcnolist	Suppress false conditional code block listing	Section 6.8	.fcnolist
.mlist	Allow macro listings (default)	Section 6.8	.mlist
.mnolist	Suppress macro listings	Section 6.8	.mnolist
.sslist	Allow expanded substitution symbol listing	Section 6.8	.sslist
.ssnolist	Suppress expanded substitution symbol listing (default)	Section 6.8	.ssnolist

Archiver Description

The TMS320C6000 archiver lets you combine several individual files into a single archive file. For example, you can collect several macros into a macro library. The assembler searches the library and uses the members that are called as macros by the source file. You can also 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.

Topic **Page**

7.1 Archiver Overview

You can build libraries from any type of files. Both the assembler and the linker accept archive libraries as input; the assembler can use libraries that contain individual source files, and the linker can use libraries that contain individual object files.

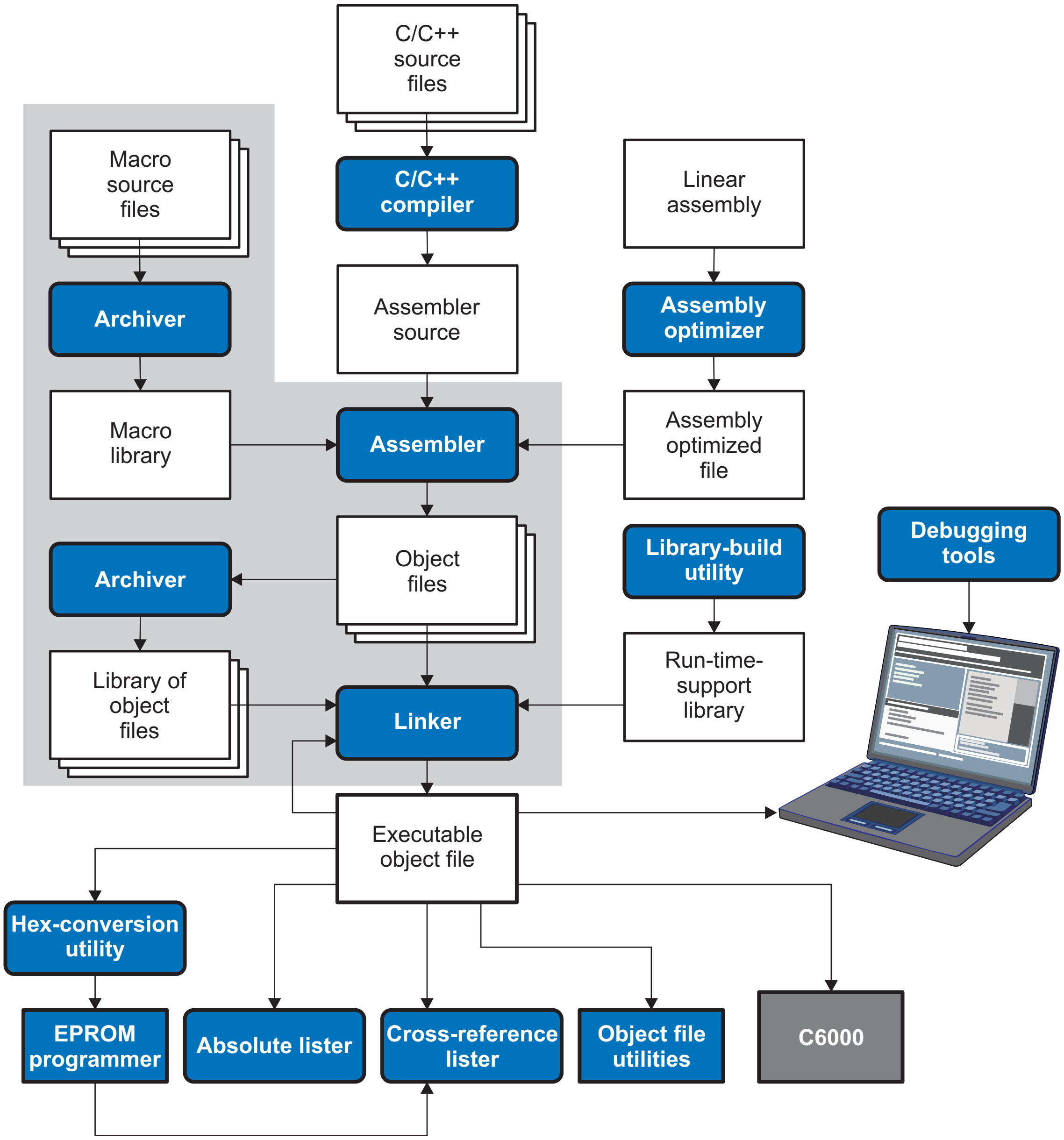
One of the most useful applications of the archiver is building libraries of object modules. For example, you can write several arithmetic routines, assemble them, and use the archiver to collect the object files into a single, logical group. You can then specify the object library as linker input. The linker searches the library and includes members that resolve external references.

You can also use the archiver to build macro libraries. You can create several source files, each of which contains a single macro, and use the archiver to collect these macros into a single, functional group. You can use the .mlib directive during assembly to specify that macro library to be searched for the macros that you call. Chapter 6 discusses macros and macro libraries in detail, while this chapter explains how to use the archiver to build libraries.

7.2 The Archiver's Role in the Software Development Flow

Figure 7-1 shows the archiver's role in the software development process. The shaded portion highlights the most common archiver development path. Both the assembler and the linker accept libraries as input.

Figure 7-1. The Archiver in the TMS320C6000 Software Development Flow



7.3 Invoking the Archiver

To invoke the archiver, enter:

ar6x [-]*command* [*options*] *libname* [*filename$_1$* ... *filename$_n$*]

ar6x 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:

- @ 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 7-1 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 *appends* 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 *does not* remove it from the library.

options In addition to one of the *commands,* 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:

- **-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 *libname,* the archiver uses the default extension *.lib*.

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.

7.4 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:

  ```
  ar6x -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:

  ```
  ar6x -t function
  ```

  The archiver responds as follows:

  ```
           FILE NAME    SIZE   DATE
    ----------------   -----   ------------------------
            sine.obj     300   Wed Jun 15 10:00:24 2011
             cos.obj     300   Wed Jun 15 10:00:30 2011
             flt.obj     300   Wed Jun 15 09:59:56 2011
  ```

- If you want to add new members to the library, enter:

  ```
  ar6x -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 macros.lib that contains the members push.asm, pop.asm, and swap.asm.

  ```
  ar6x -x macros push.asm
  ```

  The archiver makes a copy of push.asm and places it in the current directory; it does not remove push.asm from the library. Now you can edit the extracted file. To replace the copy of push.asm in the library with the edited copy, enter:

  ```
  ar6x -r macros push.asm
  ```

- If you want to use a command file, specify the command filename after the -@ command. For example:

  ```
  ar6x -@modules.cmd
  ```

  The archiver responds as follows:

  ```
    ==>  building archive 'modules.lib'
  ```

  Example 7-1 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 7-1. 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.asm
bss.asm
data.asm
text.asm
sect.asm
clink.asm
copy.asm
double.asm
drnolist.asm
emsg.asm
end.asm
```

7.5 Library Information Archiver Description

Section 7.1 explains 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.

7.5.1 Invoking the Library Information Archiver

To invoke the library information archiver, enter:

libinfo6x [*options*] **-o**=*libname libname*$_1$ [*libname*$_2$ **...** *libname*$_n$]

libinfo6x is the command that invokes the library information archiver.

options changes the default behavior of the library information archiver. These options are:

- **-o** *libname* specifies the name of the index library to create or update. This option is required.
- **-u** updates any existing information in the index library specified with the -o option instead of creating a new index.

libnames names individual object file libraries to be manipulated. When you enter a libname, you must enter a complete filename including extension, if applicable.

7.5.2 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_6200_be.lib	-mv6200 --endian=big
mylib_6200_le.lib	-mv6200 --endian=little
mylib_64plus_be.lib	-mv64plus --endian=big
mylib_64plus_le.lib	-mv64plus --endian=little

Using the library information archiver, you can create an index library called mylib.lib from the above libraries:

```
libinfo62 -o mylib.lib mylib_6200_be.lib mylib_6200_le.lib
     mylib_64plus_be.lib mylib_64plus_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** (ISA 64plus, little endian):

  ```
  cl6x -mv64plus --endian=little --issue_remarks main.c -z -l lnk.cmd ./mylib.lib
  <Linking>
  remark: linking in "mylib_64plus_le.lib" in place of "mylib.lib"
  ```

- **Example 2** (ISA 6700, big endian):

  ```
  cl6x -mv6700 --endian=big --issue_remarks main.c -z -l lnk.cmd ./mylib.lib
  <Linking>
  remark: linking in "mylib_6200_be.lib" in place of "mylib.lib"
  ```

  In Example 2, there was no version of the library for C6700, but a C6200 library was available and is compatible, so it was used.

7.5.3 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:

```
ar6x t mylib.lib
      SIZE   DATE                       FILE NAME
  --------   ------------------------   -----------------
       119   Wed Feb 03 12:45:22 2010   mylib_6200_be.lib
       119   Wed Feb 03 12:45:22 2010   mylib_6200_le.lib
       119   Wed Feb 03 12:45:22 2010   mylib_64plus_be.lib
       119   Wed Feb 03 12:45:22 2010   mylib_64plus_le.lib
         0   Wed Sep 30 12:45:22 2009   __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.

7.5.4 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.

Chapter 8
SPRU186X–March 2014

Linker Description

The TMS320C6000 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 2 includes a detailed discussion of sections.

Topic **Page**

8.1 Linker Overview

The TMS320C6000 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

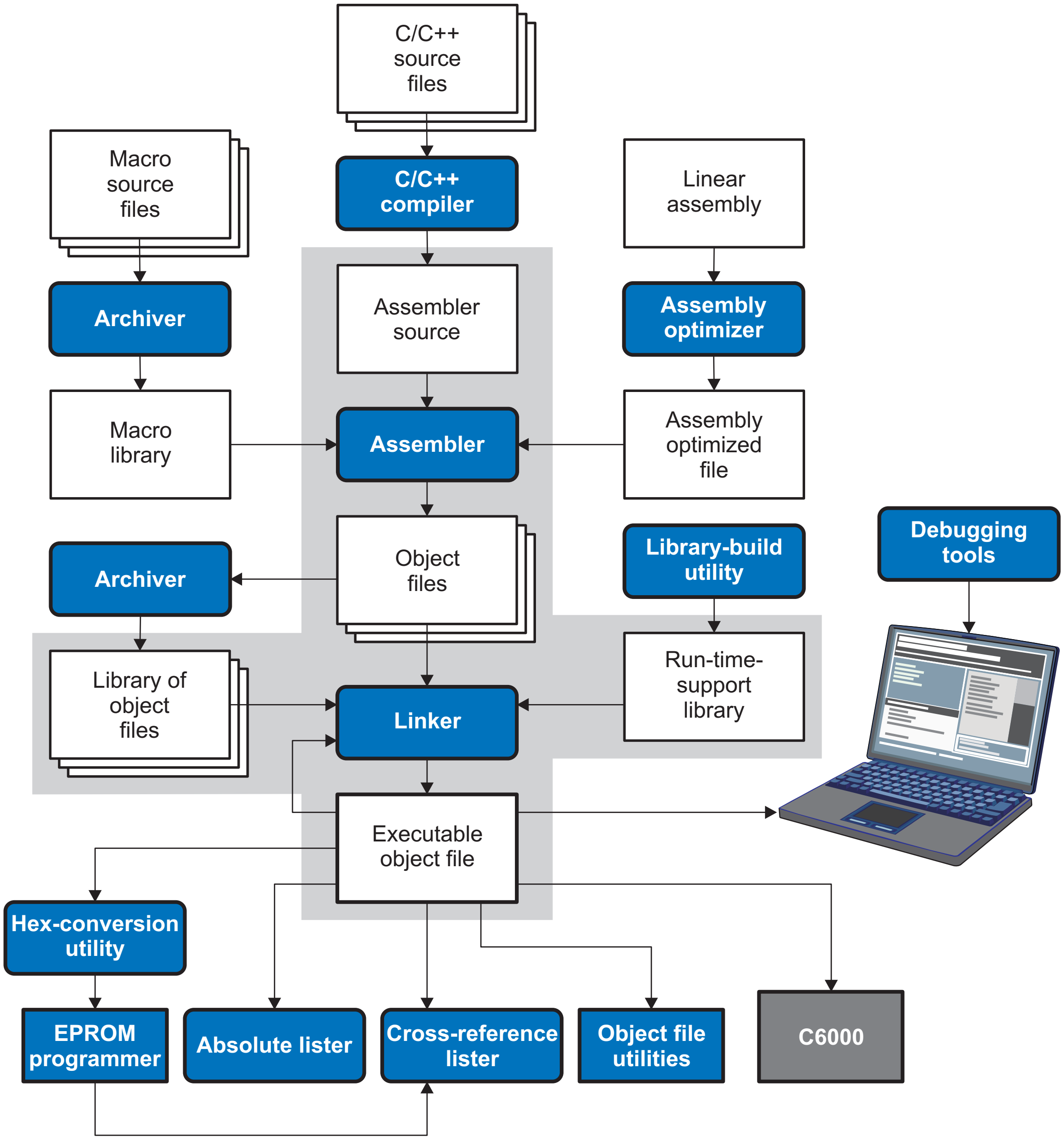
The linker command language controls memory configuration, output section definition, and address binding. The language supports expression assignment and evaluation. You configure system memory by defining and creating a memory model that you design. Two powerful directives, MEMORY and SECTIONS, allow you to:

- Allocate sections into specific areas of memory
- Combine object file sections
- Define or redefine global symbols at link time

8.2 The Linker's Role in the Software Development Flow

Figure 8-1 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 TMS320C6000 device.

Figure 8-1. The Linker in the TMS320C6000 Software Development Flow



8.3 Invoking the Linker

The general syntax for invoking the linker is:

cl6x --run_linker [*options*] *filename*$_1$ .... *filename*$_n$

cl6x --run_linker is the command that invokes the linker. The --run_linker option's short form is -z.

options can appear anywhere on the command line or in a link command file. (Options are discussed in Section 8.4.)

filename $_1$, *filename* $_n$ can be object files, link command files, or archive libraries. The default extension for all input files is *.obj*; 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 *a.out*, unless you use the --output_file option to name the output file.

There are two methods for invoking the linker:

- Specify options and filenames on the command line. This example links two files, file1.obj and file2.obj, and creates an output module named link.out.

  ```
  cl6x --run_linker file1.obj file2.obj --output_file=link.out
  ```

- Put filenames and options in a link command file. Filenames that are specified inside a link command file must begin with a letter. For example, assume the file linker.cmd contains the following lines:

  ```
  --output_file=link.out file1.obj file2.obj
  ```

  Now you can invoke the linker from the command line; specify the command filename as an input file:

  ```
  cl6x --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:

  ```
  cl6x --run_linker --map_file=link.map linker.cmd file3.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.obj, file2.obj, and file3.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 8.10.

8.4 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 8-1. Basic Options Summary

Option	Alias	Description	Section
--run_linker	-z	Enables linking	Section 8.3
--output_file	-o	Names the executable output module. The default filename is a.out.	Section 8.4.23
--map_file	-m	Produces a map or listing of the input and output sections, including holes, and places the listing in *filename*	Section 8.4.18
--stack_size	-stack	Sets C system stack size to *size* bytes and defines a global symbol that specifies the stack size. Default = 1K bytes	Section 8.4.29
--heap_size	-heap	Sets heap size (for the dynamic memory allocation in C) to *size* bytes and defines a global symbol that specifies the heap size. Default = 1K bytes	Section 8.4.14

Table 8-2. File Search Path Options Summary

Option	Alias	Description	Section
--library	-l	Names an archive library or link command *filename* as linker input	Section 8.4.16
--search_path	-i	Alters library-search algorithms to look in a directory named with *pathname* before looking in the default location. This option must appear before the --library option.	Section 8.4.16.1
--priority	-priority	Satisfies unresolved references by the first library that contains a definition for that symbol	Section 8.4.16.3
--reread_libs	-x	Forces rereading of libraries, which resolves back references	Section 8.4.16.3
--disable_auto_rts		Disables the automatic selection of a run-time-support library	Section 8.4.8

Table 8-3. Command File Preprocessing Options Summary

Option	Alias	Description	Section
--define		Predefines *name* as a preprocessor macro.	Section 8.4.10
--undefine		Removes the preprocessor macro *name*.	Section 8.4.10
--disable_pp		Disables preprocessing for command files	Section 8.4.10

Table 8-4. Diagnostic Options Summary

Option	Alias	Description	Section
--diag_error		Categorizes the diagnostic identified by *num* as an error	Section 8.4.7
--diag_remark		Categorizes the diagnostic identified by *num* as a remark	Section 8.4.7
--diag_suppress		Suppresses the diagnostic identified by *num*	Section 8.4.7
--diag_warning		Categorizes the diagnostic identified by *num* as a warning	Section 8.4.7
--display_error_number		Displays a diagnostic's identifiers along with its text	Section 8.4.7
--emit_warnings_as_errors	-pdew	Treats warnings as errors	Section 8.4.7
--issue_remarks		Issues remarks (nonserious warnings)	Section 8.4.7
--no_demangle		Disables demangling of symbol names in diagnostics	Section 8.4.20
--no_warnings		Suppresses warning diagnostics (errors are still issued)	Section 8.4.7
--set_error_limit		Sets the error limit to *num*. The linker abandons linking after this number of errors. (The default is 100.)	Section 8.4.7
--verbose_diagnostics		Provides verbose diagnostics that display the original source with line-wrap	Section 8.4.7
--warn_sections	-w	Displays a message when an undefined output section is created	Section 8.4.34

Table 8-5. 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 8.4.3.1
--ecc:data_error		Inject the specified errors into the output file for testing	Section 8.4.11 Section 8.5.8
--ecc:ecc_error		Inject the specified errors into the Error Correcting Code (ECC) for testing	Section 8.4.11 Section 8.5.8
--mapfile_contents		Controls the information that appears in the map file.	Section 8.4.19
--relocatable	-r	Produces a nonexecutable, relocatable output module	Section 8.4.3.2
--rom	-r	Create a ROM object	
--run_abs	-abs	Produces an absolute listing file	Section 8.4.27
--xml_link_info		Generates a well-formed XML *file* containing detailed information about the result of a link	Section 8.4.35

Table 8-6. 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 8.4.12
--globalize		Changes the symbol linkage to global for symbols that match *pattern*	Section 8.4.17
--hide		Hides global symbols that match *pattern*	Section 8.4.15
--localize		Changes the symbol linkage to local for symbols that match *pattern*	Section 8.4.17
--make_global	-g	Makes *symbol* global (overrides -h)	
--make_static	-h	Makes all global symbols static	Section 8.4.17.1
--no_sym_merge	-b	Disables merge of symbolic debugging information in COFF object files	Section 8.4.21
--no_symtable	-s	Strips symbol table information and line number entries from the output module	Section 8.4.22
--retain		Retains a list of sections that otherwise would be discarded	Section 8.4.26
--scan_libraries	-scanlibs	Scans all libraries for duplicate symbol definitions	Section 8.4.28
--symbol_map		Maps symbol references to a symbol definition of a different name	Section 8.4.31
--undef_sym	-u	Places an unresolved external *symbol* into the output module's symbol table	Section 8.4.33
--unhide		Reveals (un-hides) global symbols that match *pattern*	Section 8.4.15

Table 8-7. Run-Time Environment Options Summary

Option	Alias	Description	Section
--arg_size	--args	Allocates memory to be used by the loader to pass arguments	Section 8.4.4
--fill_value	-f	Sets default fill values for holes within output sections; *fill_value* is a 32-bit constant	Section 8.4.13
--ram_model	-cr	Initializes variables at load time	Section 8.4.25
--rom_model	-c	Autoinitializes variables at run time	Section 8.4.25
--trampolines		Generates far call trampolines; on by default	Section 8.4.32

Table 8-8. Link-Time Optimization Options Summary

Option	Alias	Description	Section
--cinit_compression		Specifies the type of compression to apply to the c auto initialization data (default is rle)	Section 8.4.5
--compress_dwarf		Aggressively reduces the size of DWARF information from input object files	Section 8.4.6
--copy_compression		Compresses data copied by linker copy tables	Section 8.4.5
--unused_section_elimination		Eliminates sections that are not needed in the executable module; on by default	Section 8.4.9.2

Table 8-9. Dynamic Linking Options Summary

Option	Alias	Description	Section
--dsbt_index		Specifies the Data Segment Base Table (DSBT) index to be assumed for the dynamic shared object or dynamic library being linked	Section 8.12.5.3
--dsbt_size		Specifies the number of entries to be reserved for the Data Segment Base Table (DSBT)	Section 8.12.5.3
--dynamic		Generates a bare-metal dynamic executable or library (argument is optional; if no argument is specified, then a dynamic executable (exe) is generated)	Section 8.12.5.3
--export		Exports the specified function symbol (*sym*)	Section 8.12.4.1
--fini		Specifies function symbol (*sym*) of the termination code	Section 8.12.5.3
--import		Imports the specified *symbol*	Section 8.12.5.1
--init		Specifies the function symbol (*sym*) of the initialization code	Section 8.12.5.3
--linux		Generates code for Linux	Section 8.12.5.3
--pic		Generates position independent addressing for a shared object. Default is near.	Section 8.12.5.3
--rpath		Adds specified directory to the beginning of the dynamic library search path	Section 8.12.5.3
--runpath		Adds specified directory to the end of the dynamic library search path	Section 8.12.5.3
--shared		Generates an ELF dynamically shared object (DSO)	Section 8.12.5.3
--soname		Specifies the name to be associated with this linked dynamic output; this name is stored in the file's dynamic table	Section 8.12.5.3
--sysv		Generates SysV ELF output file	Section 8.12.5.3

Table 8-10. Miscellaneous Options Summary

Option	Alias	Description	Section
--disable_clink	-j	Disables conditional linking of COFF object modules	Section 8.4.9.1
--linker_help	-help	Displays information about syntax and available options	–
--minimize_trampolines		Selects the trampoline minimization algorithm (argument is optional; algoriithm is postorder by default)	Section 8.4.32.2
--preferred_order		Prioritizes placement of functions	Section 8.4.24
--strict_compatibility		Performs more conservative and rigorous compatibility checking of input object files	Section 8.4.30
--trampoline_min_spacing		When trampoline reservations are spaced more closely than the specified limit, tries to make them adjacent	Section 8.4.32.3
--zero_init		Controls preinitialization of uninitialized variables. Default is on.	Section 8.4.36

8.4.1 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.obj, taskX.o55, etc. */

SECTIONS
{
   .fast_code: { *.obj(*fast*) }              > FAST_MEM
   .vectors  : { vectors.obj(.vector:part1:*) > 0xFFFFFF00
   .str_code : { rts*.lib<str*.obj>(.text) }  > S1ROM
}
```

8.4.2 Specifying C/C++ Symbols with Linker Options

For COFF ABI, the compiler prepends an underscore _ to the beginning of all C/C++ identifiers. That is, for a function named foo2(), foo2() is prefixed with _ and _foo2 becomes the link-time symbol. For example, the --localize and --globalize options accept link-time symbols. Thus, you specify --localize='_foo2' to localize the C function _foo2(). For more information on linknames see the C/C++ Language Implementation chapter in the *TMS320C6000 Optimizing Compiler User's Guide*.

For EABI, the link-time symbol is the same as the C/C++ identifier name.

8.4.3 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 (Section 2.7).

The linker supports two options (--absolute_exe and --relocatable) that allow you to produce an absolute or a relocatable output module. The linker also supports a third option (-ar) that allows you to produce an executable, 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).

8.4.3.1 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 8.5.9.4)
- An header that describes information such as the program entry point (optional in COFF)
- *No* unresolved references

The following example links file1.obj and file2.obj and creates an absolute output module called a.out:

```
cl6x --run_linker --absolute_exe file1.obj file2.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.

8.4.3.2 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.obj and file2.obj and creates a relocatable output module called a.out:

```
cl6x --run_linker --relocatable file1.obj file2.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 8.9.)

8.4.3.3 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.obj and file2.obj to create an executable, relocatable output module called xr.out:

```
cl6x --run_linker -ar file1.obj file2.obj --output_file=xr.out
```

8.4.4 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 the *TMS320C6000 Optimizing Compiler User's Guide* for information about the loader.

8.4.5 Compression (--cinit_compression and --copy_compression Option)

By default, the linker does not compress data. These two options specify compression through the linker.

The ELF mode --cinit_compression option specifies the compression type the linker applies to the C autoinitialization data. The default is rle.

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 and Symanski compression.

8.4.6 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. 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).

8.4.7 Control Linker Diagnostics

The linker uses certain C/C++ compiler options to control linker-generated diagnostics. The diagnostic options must be specified before the --run_linker option.

--diag_error=*num* Categorizes the diagnostic identified by *num* as an error. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_error=*num* to recategorize the diagnostic as an error. You can only alter the severity of discretionary diagnostics.

--diag_remark=*num* Categorizes the diagnostic identified by *num* as a remark. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_remark=*num* to recategorize the diagnostic as a remark. You can only alter the severity of discretionary diagnostics.

--diag_suppress=*num* Suppresses the diagnostic identified by *num*. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_suppress=*num* to suppress the diagnostic. You can only suppress discretionary diagnostics.

--diag_warning=*num* Categorizes the diagnostic identified by *num* as a warning. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_warning=*num* to recategorize the diagnostic as a warning. You can only alter the severity of discretionary diagnostics.

--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 (--diag_suppress, --diag_error, --diag_remark, and --diag_warning). 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 -D; otherwise, no suffix is present. See the *TMS320C6000 Optimizing Compiler User's Guide* for more information on understanding diagnostic messages.

--emit_warnings_as_errors Treats all warnings as errors. This option cannot be used with the --no_warnings option. The --diag_remark option takes precedence over this option. This option takes precedence over the --diag_warning option.

--issue_remarks Issues remarks (nonserious warnings), which are suppressed by default.

--no_warnings Suppresses warning diagnostics (errors are still issued).

--set_error_limit=*num* Sets the error limit to *num*, which can be any decimal value. The linker abandons linking after this number of errors. (The default is 100.)

--verbose_diagnostics Provides verbose diagnostics that display the original source with line-wrap and indicate the position of the error in the source line

8.4.8 Disable Automatic Library Selection (--disable_auto_rts Option)

The --disable_auto_rts option disables the automatic selection of a run-time-support library. See the *TMS320C6000 Optimizing Compiler User's Guide* for details on the automatic selection process.

8.4.9 Controlling Unreferenced and Unused Sections

8.4.9.1 Disable Conditional Linking (--disable_clink Option)

The --disable_clink option disables removal of unreferenced sections in COFF object modules. Only sections marked as candidates for removal with the .clink assembler directive are affected by conditional linking. See Conditionally Leave Section Out of Object Module Output for details on setting up conditional linking using the .clink directive, which is available under ELF as well as COFF.

8.4.9.2 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.

8.4.10 Link Command File Preprocessing (--disable_pp, --define and --undefine Options)

The linker preprocesses link 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=*name*[=*val*]	Predefines *name* as a preprocessor macro
--undefine=*name*	Removes the macro *name*

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:

```
cl6x --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 8.4.16)

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 has the standard built-in definitions for the macros __FILE__, __DATE__, and __TIME__. It does not, however, have the compiler-specific options for the target (__.TMS320C6000__), version (__TI_COMPILER_VERSION__), run-time model, and so on.

8.4.11 Error Correcting Code Testing (--ecc Options)

Error Correcting Codes (ECC) can be generated and placed in separate sections through the linker command file. ECC uses extra bits to allow errors to be detected and/or corrected by a device. The ECC support provided by the linker is compatible with the ECC support in TI Flash memory on various TI devices. TI Flash memory uses a modified Hamming(72,64) code, which uses 8 parity bits for every 64 bits. Check the documentation for your Flash memory to see if ECC is supported. (ECC for read-write memory is handled completely in hardware at run time.)

See Section 8.5.8 for details on linker command file syntax for ECC support.

To test ECC error detection and handling, you can use two command-line options that inject bit errors into the linked executable. These options let you specify an address where an error should appear and a bitmask of bits in the code/data at that address to flip. You can specify the address of the error absolutely or as an offset from a symbol.

When a data error is injected, the ECC parity bits for the data are calculated as if the error were not present. This simulates bit errors that might actually occur and test ECC's ability to correct different levels of errors.

The **--ecc:data_error option** injects errors into the load image at the specified location. The syntax is:

```
--ecc:data_error=(symbol+offset|address)[,page],bitmask
```

The *address* is the location of the minimum addressable unit where the error is to be injected. A *symbol+offset* can be used to specify the location of the error to be injected with a signed offset from that symbol. The *page* number is needed to make the location non-ambiguous if the address occurs on multiple memory pages. The *bitmask* is a mask of the bits to flip; its width should be the width of an addressable unit.

For example, the following command line flips the least-significant bit in the byte at the address 0x100, making it inconsistent with the ECC parity bits for that byte:

```
cl6x test.c --ecc:data_error=0x100,0x01 -z -o test.out
```

The following command flips two bits in the third byte of the code for main():

```
cl6x test.c --ecc:data_error=main+2,0x42 -z -o test.out
```

The **--ecc:ecc_error option** injects errors into the ECC parity bits that correspond to the specified location. Note that the ecc_error option can therefore only specify locations inside ECC input ranges, whereas the data_error option can also specify errors in the ECC output memory ranges. The syntax is:

```
--ecc:ecc_error=(symbol+offset|address)[,page],bitmask
```

The parameters for this option are the same as for --ecc:data_error, except that the *bitmask* must be exactly 8 bits. Mirrored copies of the affected ECC byte will also contain the same injected error.

An error injected into an ECC byte with --ecc:ecc_error may cause errors to be detected at run time in any of the 8 data bytes covered by that ECC byte.

For example, the following command flips every bit in the ECC byte that contains the parity information for the byte at 0x200:

```
cl6x test.c --ecc:ecc_error=0x200,0xff -z -o test.out
```

The linker disallows injecting errors into memory ranges that are neither an ECC range nor the input range for an ECC range. The compiler can only inject errors into initialized sections.

8.4.12 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; refer to the *TMS320C6000 Optimizing Compiler User's Guide*.
- 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.obj and file2.obj. The symbol begin is the entry point; begin must be defined as external in file1 or file2.

```
cl6x --run_linker --entry_point=begin file1.obj file2.obj
```

8.4.13 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 32-bit constant (up to eight 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:

```
cl6x --run_linker --fill_value=0xABCDABCD file1.obj file2.obj
```

8.4.14 Define Heap Size (--heap_size Option)

The C/C++ compiler uses an uninitialized section called .sysmem 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:

```
cl6x --run_linker --heap_size=0x1000 /* defines a 4k heap (.sysmem section)*/
```

The linker creates the .sysmem section only if there is a .sysmem section in an input file.

The linker also creates a global symbol __SYSMEM_SIZE (COFF) or __TI_SYSMEM_SIZE (EABI) and assigns it a value equal to the size of the heap. The default size is 1K bytes.

For more information about C/C++ linking, see Section 8.10.

8.4.15 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, 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 string with optional wildcards ? or *. Use ? to match a single character and use * to match zero or more characters.

The --hide option hides global symbols which have a linkname matching the *pattern*. It hides the symbols matching the pattern by changing the name to an empty string. A global symbol which 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.

8.4.16 Alter the Library Search Algorithm (--library Option, --search_path Option, and C6X_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. Assume that this library defines symbols that are referenced in the file file1.obj. This is how you link the files:

```
cl6x --run_linker file1.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 link 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 8.5.4.5.

You can augment the linker's directory search algorithm by using the --search_path linker option or the C6X_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 C6X_C_DIR.
3. If C6X_C_DIR is not set, it searches directories named with the assembler's C6X_A_DIR environment variable.
4. It searches the current directory.

8.4.16.1 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)	`cl6x --run_linker f1.obj f2.obj --search_path=/ld --search_path=/ld2 --library=r.lib --library=lib2.lib`
Windows	`cl6x --run_linker f1.obj f2.obj --search_path=\ld --search_path=\ld2 --library=r.lib --library=lib2.lib`

8.4.16.2 Name an Alternate Library Directory (C6X_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 C6X_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)	**C6X_C_DIR="** *pathname$_1$*; *pathname$_2$*; . . . **"; export C6X_C_DIR**
Windows	**set C6X_C_DIR=** *pathname$_1$* **;** *pathname$_2$* **;** . . .

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 link 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 C6X_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 C6X_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)	`C6X_C_DIR="/ld ;/ld2"; export C6X_C_DIR;`
	`cl6x --run linker f1.obj f2.obj --library=r.lib --library=lib2.lib`

Windows	`C6X_C_DIR=\ld;\ld2`
	`cl6x --run linker f1.obj f2.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 C6X_C_DIR`
Windows	`set C6X_C_DIR=`

The assembler uses an environment variable named C6X_A_DIR to name alternate directories that contain copy/include files or macro libraries. If C6X_C_DIR is not set, the linker searches for object libraries in the directories named with C6X_A_DIR. For information about C6X_A_DIR, see Section 4.5.2. For more information about object libraries, see Section 8.6.

8.4.16.3 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:

```
cl6x --run_linker --library=a.lib --library=b.lib --library=a.lib
```

or you can force the linker to do it for you:

```
cl6x --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
```

```
% cl6x --run_linker objfile lib1 lib2
```

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 rts6200.lib without providing a full replacement for rts6200.lib. Using --priority and linking your new library before rts6200.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.

8.4.17 Change Symbol Localization

Symbol localization changes symbol linkage from global to local (static). This is used to obscure global symbols in a library which should not be visible outside the library, 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 string with optional wildcards ? or *. Use ? to match a single character and 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 8.4.2 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 more restrictive than Pattern A.
- These options affect final and partial linking.

In map files these symbols are listed under the Localized Symbols heading.

8.4.17.1 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.obj and file2.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.obj is treated separately from the symbol EXT defined in file2.obj.

```
cl6x --run_linker --make_static file1.obj file2.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*

8.4.18 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 link 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 8.5.3.

- 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 link 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 8.5.4.
- 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.obj and file2.obj and creates a map file called map.out:

```
cl6x --run_linker file1.obj file2.obj --map_file=map.out
```

Example 8-26 shows an example of a map file.

8.4.19 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 new --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
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).

By default, information about static and global symbols defined in an application are included in tables sorted by name, data page, and run address. In addition, 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
```

8.4.20 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.obj

The --no_demangle option disables the demangling of symbol names in diagnostics. For example:

undefined symbol	first referenced in file
_ZN9ANewClass8getValueEv	test.obj

8.4.21 Disable Merge of Symbolic Debugging Information (--no_sym_merge Option)

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.obj and f2.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 COFF only --no_sym_merge option if you want the linker to keep such duplicate entries in COFF 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.

8.4.22 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.obj and file2.obj and creates an output module, stripped of line numbers and symbol table information, named nosym.out:

```
cl6x --run_linker --output_file=nosym.out --no_symtable file1.obj file2.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 strip6x utility as described in Section 11.4.

8.4.23 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.obj and file2.obj and creates an output module named run.out:

```
cl6x --run_linker --output_file=run.out file1.obj file2.obj
```

8.4.24 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*

Refer to the *TMS320C6000 Optimizing Compiler User's Guide* for details on the program cache layout tool, which is impacted by --preferred_option.

8.4.25 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.

- The --ram_model option tells the linker to initialize variables at load time.
- The --rom_model option tells the linker to autoinitialize variables at run time.

For more information, see Section 8.10, Section 8.10.4, and Section 8.10.5.

8.4.26 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 .initvec sections from all input files:

  ```
  --retain='init*'
  ```

  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.obj in the rts64plus_eabi.lib library:

  ```
  --retain=rts64plus_eabi.lib<printf.obj>(.text)
  ```

  If the library is specified with the --library option (--library=rts64plus_eabi.lib) the library search path is used to search for the library. You cannot specify '*<*>(*)'.

8.4.27 Create an Absolute Listing File (--run_abs Option)

The --run_abs option produces an output file for each file that was linked. These files are named with the input filenames and an extension of .abs. Header files, however, do not generate a corresponding .abs file.

8.4.28 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.

8.4.29 Define Stack Size (--stack_size Option)

The TMS320C6000 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 byte stack:

```
cl6x --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_SIZE for COFF and __TI_STACK_SIZE for EABI, and assigns it a value equal to the size of the section. The default software stack size is 1K bytes.

8.4.30 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.

8.4.31 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'
```

8.4.32 Generate Far Call Trampolines (--trampolines Option)

The C6000 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.

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 near calls. The --trampolines 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.

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    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    foo_trampoline  ; 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:

```
foo_trampoline:
      branch_long     foo
```

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.

The syntax for this option is:

--trampolines[=on|off]

The default setting is on. For C6000, trampolines are turned on by default.

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 B15 Contains the Stack Pointer

NOTE: Assembly language programmers must be aware that the linker assumes B15 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 B15 as the stack pointer, you should use the linker option that disables trampolines, --trampolines=off. Otherwise, trampolines could corrupt memory and overwrite register values.

8.4.32.1 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.

8.4.32.2 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.

8.4.32.3 Making Trampoline Reservations Adjacent (--trampoline_min_spacing Option)

When a call is placed and the callee's address is unknown, the linker must provisionally reserve space for a far call trampoline in case the callee turns out to be too far away. Even if the callee ends up being close enough, the trampoline reservation can interfere with optimal placement for very large code sections.

When trampoline reservations are spaced more closely than the specified limit, use the --trampoline_min_spacing option to try to make them adjacent. The syntax is:

--trampoline_min_spacing=*size*

A higher value minimizes fragmentation, but may result in more trampolines. A lower value may reduce trampolines, at the expense of fragmentation and linker running time. Specifying 0 for this option disables coalescing. The default is 16K.

8.4.32.4 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 8.5.9.7). These operators allow you to define symbols to represent the load-time start address and size inside the link 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.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.obj code in .text from its load space to its run space.

8.4.33 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 rts6200.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 rts6200.lib for the member that defines symtab and to link in the member.

```
cl6x --run_linker --undef_sym=symtab file1.obj file2.obj rts6200.lib
```

If you do not use --undef_sym, this member is not included, because there is no explicit reference to it in file1.obj or file2.obj.

8.4.34 Display a Message When an Undefined Output Section Is Created (--warn_sections)

In a link 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 8.5.4. For more information about the default actions of the linker, see Section 8.7.

8.4.35 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 B for specifics on the contents of the generated XML file.

8.4.36 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++ EABI compiler supports preinitialization of uninitialized variables by default. To turn this off, specify the linker option --zero_init=off. COFF ABI does not support zero initialization.

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. In EABI mode, 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.

8.5 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 8.5.3). The SECTIONS directive controls how sections are built and allocated (see Section 8.5.4.)
- Assignment statements, which define and assign values to global symbols

To invoke the linker with a command file, enter the cl6x --run_linker command and follow it with the name of the command file:

cl6x --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 8-1 shows a sample link command file called link.cmd.

Example 8-1. Linker Command File

```
a.obj                     /*  First input filename          */
b.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 8-1 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:

```
cl6x --run_linker link.cmd
```

You can place other parameters on the command line when you use a command file:

```
cl6x --run_linker --relocatable link.cmd c.obj d.obj
```

The linker processes the command file as soon as it encounters the filename, so a.obj and b.obj are linked into the output module before c.obj and d.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:

```
cl6x --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 8-2 shows a sample command file that contains linker directives.

Example 8-2. 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 8.5.3 for the MEMORY directive, and Section 8.5.4 for the SECTIONS directive.

8.5.1 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.

ADDRESS_MASK
ALGORITHM
ALIGN
ATTR
BLOCK
COMPRESSION
COPY
DSECT
ECC
END
f
FILL
GROUP
HAMMING_MASK
HIGH
INPUT_PAGE
INPUT_RANGE
l (lowercase L)
LEN
LENGTH
LOAD
LOAD_END
LOAD_SIZE
LOAD_START
MEMORY
MIRRORING
NOINIT
NOLOAD
o
ORG
ORIGIN
PAGE
PALIGN
PARITY_MASK
RUN
RUN_END
RUN_SIZE
RUN_START
SECTIONS
SIZE
START
TABLE
TYPE
UNION
UNORDERED
VFILL

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.

8.5.2 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 (see Section 4.7) 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

8.5.3 *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 TMS320C6000 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 2.5.

8.5.3.1 Default Memory Model

If you do not use the MEMORY directive, the linker uses a default memory model that is based on the TMS320C6000 architecture. This model assumes that the full 32-bit address space (2^{32} locations) is present in the system and available for use. For more information about the default memory model, see Section 8.7.

8.5.3.2 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 8-3 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 8.5.3.3).

Example 8-3. The MEMORY Directive

```
/********************************************************/
/*      Sample command file with MEMORY directive       */
/********************************************************/
file1.obj file2.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:

- **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 *origin*, *org*, or *o*. The value, specified in bytes, is a 32-bit integer constant expression, which can be decimal, octal, or hexadecimal.

length specifies the length of a memory range; enter as *length*, *len*, or *l*. The value, specified in bytes, is a 32-bit integer constant expression, which can be decimal, octal, or hexadecimal.

fill specifies a fill character for the memory range; enter as *fill* or *f*. Fills are optional. The value is a 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. (See Section 8.5.8.3 for virtual filling of memory ranges when using Error Correcting Code (ECC).)

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 0FFFFFFFFh:

```
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 8.5.4.

8.5.3.3 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 8-4. Origin and Length as Expressions

```
/********************************************************/
/*      Sample command file with MEMORY directive       */
/********************************************************/
file1.obj file2.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
```

8.5.4 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
- Specifies where output sections are placed in memory (in relation to each other and to the entire memory space)
- Permits renaming of output sections

For more information, see Section 2.5, Section 2.7, and Section 2.4.6. 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 8.7 describes this algorithm in detail.

8.5.4.1 SECTIONS Directive Syntax

The SECTIONS directive is specified in a command file by the word SECTIONS (uppercase), followed by a list of output section specifications enclosed in braces.

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 8.5.4.4 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 3.5, Section 3.1.1, and Section 8.5.5.

  Syntax: **load =** *allocation* or
  > *allocation*

- **Run allocation** defines where in memory the section is to be run.

  Syntax: **run =** *allocation* or
  run > *allocation*

- **Input sections** defines the input sections (object files) that constitute the output section. See Section 8.5.4.3.

  Syntax: **{** *input_sections* **}**

- **Section type** defines flags for special section types. See Section 8.5.7.

  Syntax: **type = COPY** or
  type = DSECT or
  type = NOLOAD

- **Fill value** defines the value used to fill uninitialized holes. See Section 8.5.10.

  Syntax: **fill =** *value*

Example 8-5 shows a SECTIONS directive in a sample link command file.

Example 8-5. The SECTIONS Directive

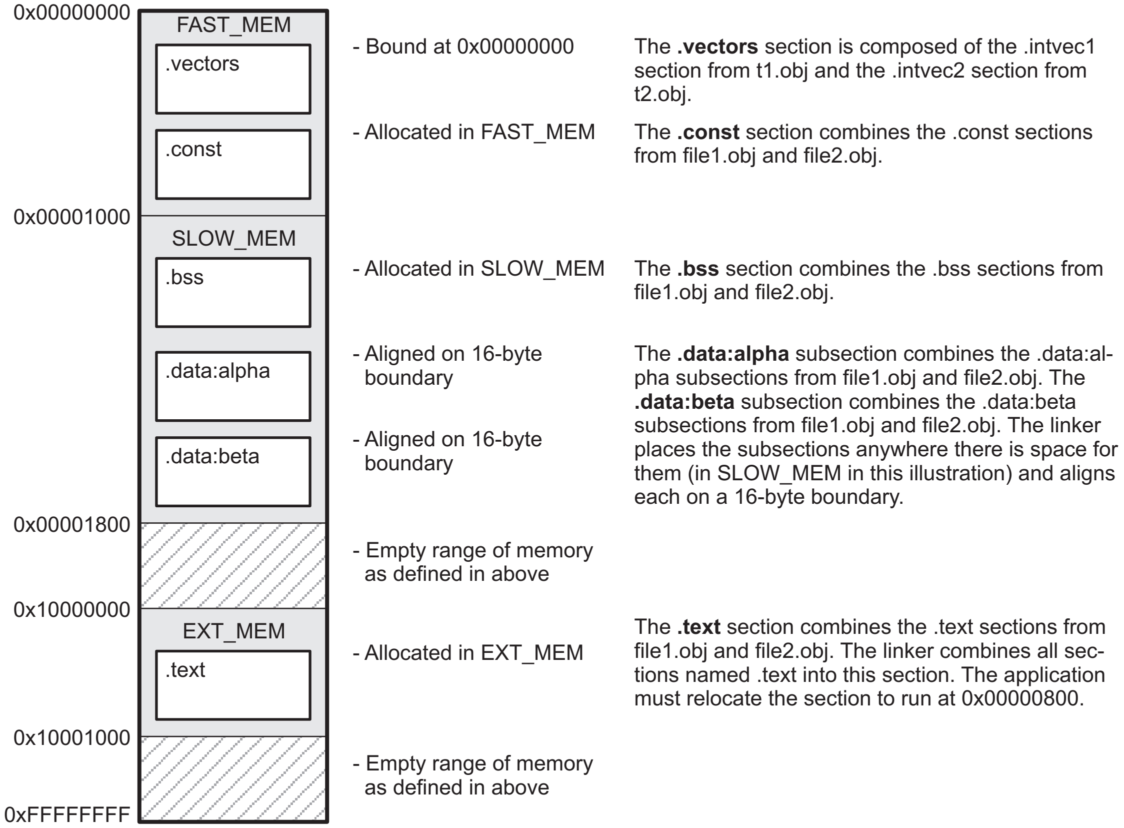
```
/****************************************************/
/*  Sample command file with SECTIONS directive    */
/****************************************************/
file1.obj    file2.obj           /* Input files    */
--output_file=prog.out           /* Options        */

SECTIONS
{
   .text:       load = EXT_MEM, run = 0x00000800
   .const:      load = FAST_MEM
   .bss:        load = SLOW_MEM
   .vectors:    load = 0x00000000
```

Example 8-5. The SECTIONS Directive (continued)

```
       {
          t1.obj(.intvec1)
          t2.obj(.intvec2)
          endvec = .;
       }
    .data:alpha: align = 16
    .data:beta:  align = 16
}
```

Figure 8-2 shows the six output sections defined by the SECTIONS directive in Example 8-5 (.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 8-3.

Figure 8-2. Section Placement Defined by Example 8-5



The **.vectors** section is composed of the .intvec1 section from t1.obj and the .intvec2 section from t2.obj.

The **.const** section combines the .const sections from file1.obj and file2.obj.

The **.bss** section combines the .bss sections from file1.obj and file2.obj.

The **.data:alpha** subsection combines the .data:alpha subsections from file1.obj and file2.obj. The **.data:beta** subsection combines the .data:beta subsections from file1.obj and file2.obj. The linker places the subsections anywhere there is space for them (in SLOW_MEM in this illustration) and aligns each on a 16-byte boundary.

The **.text** section combines the .text sections from file1.obj and file2.obj. The linker combines all sections named .text into this section. The application must relocate the section to run at 0x00000800.

8.5.4.2 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 8.5.5.

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 that the section must start on an address boundary.

```
.text: align = 0x100
```

Blocking uses the block keyword to specify that the section must fit between two address aligned to the blocking factor. If the 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 8.5.4.3.

8.5.4.2.1 Binding

You can supply a specific 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 32-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.

NOTE: Binding is Incompatible With Alignment and Named Memory

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.

8.5.4.2.2 Named Memory

You can allocate a section into a memory range that is defined by the MEMORY directive (see Section 8.5.3). 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.

8.5.4.2.3 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 = 0xEEE0
    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 .sysmem sections are allocated into the lower addresses within RAM. Example 8-6 illustrates a portion of a map file that shows where the given sections are allocated within RAM for a typical program.

Example 8-6. Linker Placement With the HIGH Specifier

```
.bss       0     00000200    00000270     UNINITIALIZED
                   00000200    0000011a     rtsxxx.lib  : defs.obj (.bss)
```

Example 8-6. Linker Placement With the HIGH Specifier (continued)

```
                  0000031a    00000088                 : trgdrv.obj (.bss)
                  000003a2    00000078                 : lowlev.obj (.bss)
                  0000041a    00000046                 : exit.obj (.bss)
                  00000460    00000008                 : memory.obj (.bss)
                  00000468    00000004                 : _lock.obj (.bss)
                  0000046c    00000002                 : fopen.obj (.bss)
                  0000046e    00000002     hello.obj (.bss)

.sysmem    0    00000470    00000120     UNINITIALIZED
                  00000470    00000004     rtsxxx .lib : memory.obj (.sysmem)

.stack     0    000008c0    00000140     UNINITIALIZED
                  000008c0    00000002     rtsxxx .lib : boot.obj (.stack)
```

As shown in Example 8-6 , 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 8-7

The HIGH specifier is ignored if it is used with specific address binding or automatic section splitting (>> operator).

Example 8-7. Linker Placement Without HIGH Specifier

```
.bss       0    00000200    00000270     UNINITIALIZED
                  00000200    0000011a     rtsxxx.lib  : defs.obj (.bss)
                  0000031a    00000088                 : trgdrv.obj (.bss)
                  000003a2    00000078                 : lowlev.obj (.bss)
                  0000041a    00000046                 : exit.obj (.bss)
                  00000460    00000008                 : memory.obj (.bss)
                  00000468    00000004                 : _lock.obj (.bss)
                  0000046c    00000002                 : fopen.obj (.bss)
                  0000046e    00000002     hello.obj (.bss)

.stack     0    00000470    00000140     UNINITIALIZED
                  00000470    00000002     rtsxxx.lib  : boot.obj (.stack)

.sysmem    0    000005b0    00000120     UNINITIALIZED
                  000005b0    00000004     rtsxxx.lib  : memory.obj (.sysmem)
```

8.5.4.2.4 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 block or begins on that boundary:

```
bss: load = block(0x0080)
```

You can use alignment or blocking alone or in conjunction with a memory area, but alignment and blocking cannot be used together.

8.5.4.2.5 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 6 bytes 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
```

8.5.4.3 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 8-8 shows the most common type of section specification; note that no input sections are listed.

Example 8-8. The Most Common Method of Specifying Section Contents

```
SECTIONS
{
   .text:
   .data:
   .bss:
}
```

In Example 8-8, 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.obj(.text)      /* Link .text section from f1.obj    */
    f2.obj(sec1)       /* Link sec1 section from f2.obj     */
    "f3-new.obj"       /* Link ALL sections from f3-new.obj */
    f4.obj"(.text,sec2) /* Link .text and sec2 from f4.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.obj(sec2).

The specifications in Example 8-8 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.obj(xqt)
                   *(.text)
             }
   .data  :  {
                   *(.data)
                   fil.obj(table)
             }
}
```

In this example, the .text output section contains a named section xqt from file abc.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.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.

8.5.4.4 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 link 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:north:sweden
europe:north:finland
europe:north:iceland

europe:central:france
europe:central:germany
europe:central:denmark

europe:south:spain
europe:south:italy
europe:south:malta

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 link 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.

8.5.4.5 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 8-9. Archive Members to Output Sections

```
SECTIONS
{
        boot    >        BOOT1
        {
                --library=rtsXX.lib<boot.obj> (.text)
                --library=rtsXX.lib<exit.obj strcpy.obj> (.text)
        }

        .rts    >        BOOT2
        {
                --library=rtsXX.lib (.text)
        }

        .text    >        RAM
        {
                * (.text)
        }
}
```

In Example 8-9, the .text sections of boot.obj, exit.obj, and strcpy.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 8-9 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 rts6200.lib into the .rtstest section:

```
SECTIONS
{
   .rtstest { --library=rts6200.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.

8.5.4.6 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 link command file, you can let the linker move the section into one of the other areas.

8.5.4.7 Automatic Splitting of Output Sections Among Non-Contiguous Memory Ranges

The linker can split output sections among multiple memory ranges to achieve an efficient allocation. Use the >> operator to indicate that an output section can be split, if necessary, into the specified memory ranges. For example:

```
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.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.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.

8.5.5 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 3.5 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 8.8.4.1.)

8.5.5.1 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. See Section 3.1.1 for an overview of load and run addresses.

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 8.5.6.2.)

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 3.5.

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.

```
.bss: load = FAST_MEM
.bss: run = FAST_MEM
.bss: > FAST_MEM
```

8.5.5.2 Referring to the Load Address by Using the .label Directive

Normally, any reference to a symbol refers to its run-time address. However, it may be necessary at run time to refer to a load-time address. Specifically, the code that copies a section from its load address to its run address must have access to the load address. The .label directive defines a special symbol that refers to the section's load address. Thus, whereas normal symbols are relocated with respect to the run address, .label symbols are relocated with respect to the load address. See Create a Load-Time Address Label for more information on the .label directive.

Example 8-10 and Example 8-11 show the use of the .label directive to copy a section from its load address in SLOW_MEM to its run address in FAST_MEM. Figure 8-3 illustrates the run-time execution of Example 8-10.

If you use the table operator, the .label directive is not needed. See Section 8.8.4.1.

Example 8-10. Moving a Function from Slow to Fast Memory at Run Time

```
       .sect  ".fir"
       .align 4
       .label fir_src
fir
       ; insert code here

       .label fir_end

       .text
       MVKL   fir_src, A4
       MVKH   fir_src, A4
       MVKL   fir_end, A5
       MVKH   fir_end, A5
       MVKL   fir, A6
       MVKH   fir, A6
       SUB    A5, A4, A1

loop:
[!A1]  B      done
       LDW    *A4+ +, B3
       NOP    4
       ; branch occurs
       STW    B3, *A6+ +
       SUB    A1, 4, A1
       B      loop
       NOP    5
       ; branch occurs

done:
       B      fir
       NOP    5
       ; call occurs
```

Example 8-11. Linker Command File for Example 8-10

```
/******************************************************/
/*    PARTIAL LINKER COMMAND FILE FOR FIR EXAMPLE     */
/******************************************************/

MEMORY
{
   FAST_MEM :  origin = 0x00001000, length = 0x00001000
   SLOW_MEM :  origin = 0x10000000, length = 0x00001000
}

SECTIONS
{
```

Example 8-11. Linker Command File for Example 8-10 (continued)

```
    .text: load = FAST_MEM
    .fir:  load = SLOW_MEM, run FAST_MEM
}
```

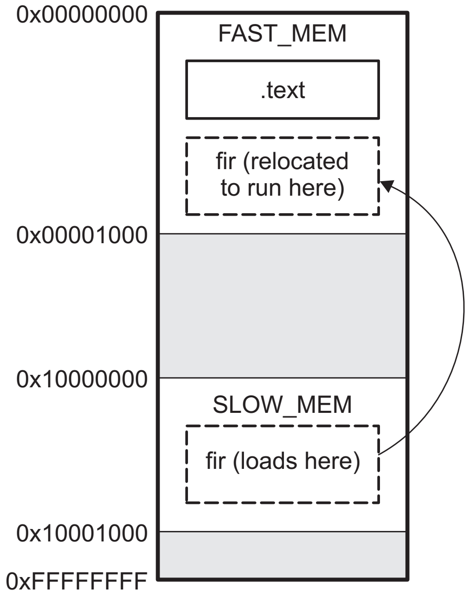


Figure 8-3. Run-Time Execution of Example 8-10

8.5.6 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.

8.5.6.1 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 8-12. Allocate Sections Together

```
SECTIONS
{
   .text           /* Normal output section            */
   .bss            /* Normal output section            */
   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.

8.5.6.2 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 8-13, the .bss sections from file1.obj and file2.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 8-13. The UNION Statement

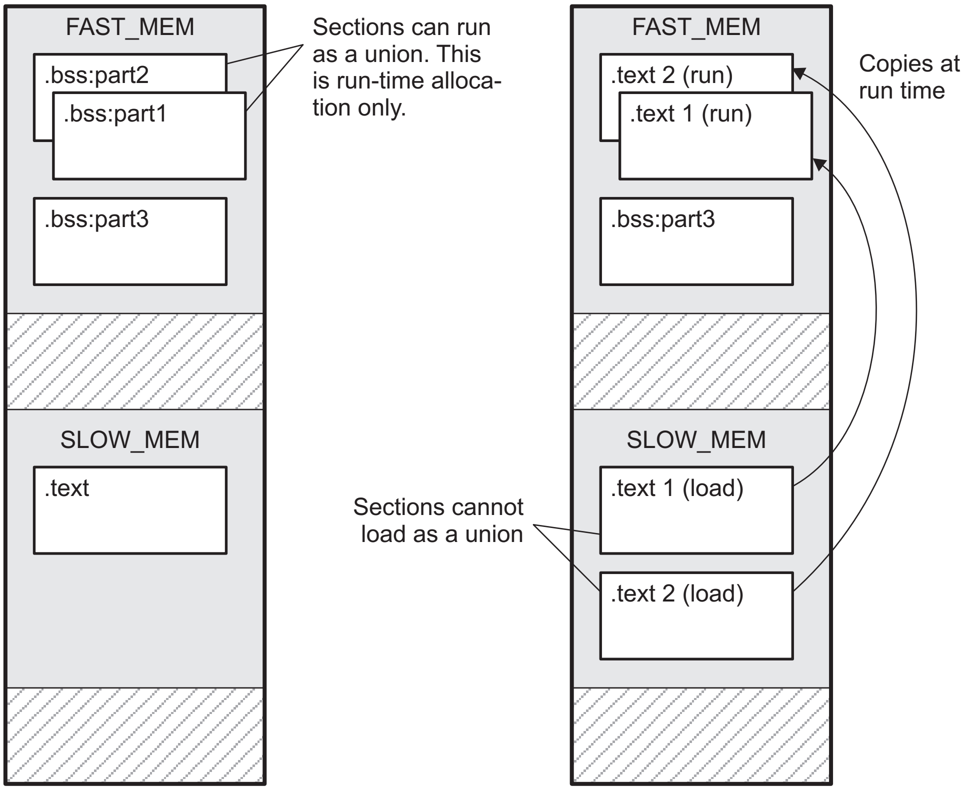
```
SECTIONS
{
   .text: load = SLOW_MEM
   UNION: run  = FAST_MEM
   {
      .bss:part1: { file1.obj(.bss) }
      .bss:part2: { file2.obj(.bss) }
   }
      .bss:part3: run = FAST_MEM { globals.obj(.bss) }
}
```

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 8-14.

Example 8-14. Separate Load Addresses for UNION Sections

```
UNION run = FAST_MEM
{
   .text:part1: load = SLOW_MEM, { file1.obj(.text) }
   .text:part2: load = SLOW_MEM, { file2.obj(.text) }
}
```

Figure 8-4. Memory Allocation Shown in Example 8-13 and Example 8-14



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.

8.5.6.3 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 8-15 shows how two overlays can be grouped together.

Example 8-15. ***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. The name you defined with the .label directive is used in the SLOW_MEM memory region. 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*

In this notation, *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.

8.5.6.4 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.

8.5.6.5 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
```

8.5.7 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.obj}
   sec2: load = 0x00004000, type =  COPY   {f2.obj}
   sec3: load = 0x00006000, type =  NOLOAD {f3.obj}
   sec4: load = 0x00008000, type =  NOINIT {f4.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.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 TMS320C6000 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.

8.5.8 Configuring Error Correcting Code (ECC) with the Linker

Error Correcting Codes (ECC) can be generated and placed in separate sections through the linker command file. ECC uses extra bits to allow errors to be detected and/or corrected by a device. The ECC support provided by the linker is compatible with the ECC support in TI Flash memory on various TI devices. TI Flash memory uses a modified Hamming(72,64) code, which uses 8 parity bits for every 64 bits. Check the documentation for your Flash memory to see if ECC is supported. (ECC for read-write memory is handled completely in hardware at run time.)

See Section 8.4.11 for command-line options that introduce bit errors into code that has a corresponding ECC section or into the ECC parity bits themselves. You can use these options to test your ECC error handling code.

ECC can be generated during linking. The ECC data is included in the resulting object file, alongside code and data, as a data section located at the appropriate address. No extra ECC generation step is required after compilation, and the ECC can be uploaded to the device along with everything else.

You can control the generation of ECC data using the ECC specifier in the memory map (Section 8.5.8.1) and the ECC directive (Section 8.5.8.2).

8.5.8.1 Using the ECC Specifier in the Memory Map

To generate ECC, add a separate memory range to your memory map to hold ECC data and to indicate which memory range contains the Flash data that corresponds to this ECC data. If you have multiple memory ranges for Flash data, you should add a separate ECC memory range for each Flash data range.

The definition of an ECC memory range can also provide parameters for how to generate the ECC data.

The memory map for a device supporting Flash ECC may look something like this:

```
MEMORY {
   VECTORS  : origin=0x00000000 length=0x000020
   FLASH0   : origin=0x00000020 length=0x17FFE0
   FLASH1   : origin=0x00180000 length=0x180000
   STACKS   : origin=0x08000000 length=0x000500
   RAM      : origin=0x08000500 length=0x03FB00
   ECC_VEC  : origin=0xf0400000 length=0x000004 ECC={ input_range=VECTORS }
   ECC_FLA0 : origin=0xf0400004 length=0x02FFFC ECC={ input_range=FLASH0  }
   ECC_FLA1 : origin=0xf0430000 length=0x030000 ECC={ input_range=FLASH1  }
}
```

The "ECC" specifier attached to the ECC memory ranges indicates the data memory range that the ECC range covers. The ECC specifier supports the following parameters:

input_range = <*memory range*>
The data memory range covered by this ECC data range. Required.

input_page = <*page number*>
The page number of the input range. Required only if the input range's name is ambiguous.

algorithm = <*ECC algorithm name*>
The name of an ECC algorithm defined later in the command file using the ECC directive. Optional if only one algorithm is defined. (See Section 8.5.8.2.)

fill = true | false
Whether to generate ECC data for holes in the initialized data of the input range. The default is "true". Using fill=false produces behavior similar to the nowECC tool. The input range can be filled normally or using a virtual fill (see Section 8.5.8.3).

8.5.8.2 Using the ECC Directive

In addition to specifying ECC memory ranges in the memory map, the linker command file must specify parameters for the algorithm that generates ECC data. You might need multiple ECC algorithm specifications if you have multiple Flash devices.

Each TI device supporting Flash ECC has exactly one set of valid values for these parameters. The linker command files provided with Code Composer Studio include the ECC parameters necessary for ECC support on the Flash memory accessible by the device. Documentation is provided here for completeness.

You specify algorithm parameters with the top-level ECC directive in the linker command file. For example:

```
ECC {
   algo_name : address_mask = 0x003ffff8
               hamming_mask = FMC
               parity_mask  = 0xfc
               mirroring    = F021
}
```

This ECC directive accepts the following attributes:

address_mask = <*32-bit mask*>
This mask determines which bits of the address of each 64-bit piece of memory are used in the calculation of the ECC byte for that memory. Default is 0.

hamming_mask = FMC | R4
This setting determines for which data bits the ECC bits encode parity. Default is FMC.

parity_mask = <*8-bit mask*>
This mask determines which ECC bits encode even parity and which bits encode odd parity. Default is 0, meaning that all bits encode even parity.

mirroring = F021 | F035
This setting determines the order of the ECC bytes and their duplication pattern for redundancy. Default is F021.

8.5.8.3 Using the VFILL Specifier in the Memory Map

Normally, specifying a fill value for a MEMORY range creates initialized data sections to cover any previously uninitialized areas of memory. To generate ECC data for an entire memory range, the linker either needs to have initialized data in the entire range, or needs to know what value uninitialized memory areas will have at run time.

In cases where you want to generate ECC for an entire memory range, but do not want to initialize the entire range by specifying a fill value, you can use the "vfill" specifier instead of a "fill" specifier to virtually fill the range:

```
MEMORY {
   FLASH : origin=0x0000  length=0x4000  vfill=0xffffffff
}
```

The vfill specifier is functionally equivalent to omitting a fill specifier, except that it allows ECC data to be generated for areas of the input memory range that remain uninitialized. This has the benefit of reducing the size of the resulting object file.

The vfill specifier has no effect other than in ECC data generation. It cannot be specified along with a fill specifier, since that would introduce ambiguity.

8.5.9 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.

8.5.9.1 Syntax of Assignment Statements

The syntax of assignment statements in the linker is similar to that of assignment statements in the C language:

symbol	**=**	*expression;*	assigns the value of expression to symbol
symbol	+ =	*expression;*	adds the value of expression to symbol
symbol	- =	*expression;*	subtracts the value of expression from symbol
symbol	* =	*expression;*	multiplies symbol by expression
symbol	/ =	*expression;*	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 8.5.9.3. 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 could accomplish this in the assembly code, but you would need to reassemble the program to change tables. Instead, you can use a linker assignment statement to assign cur_tab at link time:

```
prog.obj          /* Input file                        */
cur_tab = Table1; /* Assign cur_tab to one of the tables */
```

8.5.9.2 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 linker's . symbol is analogous to the assembler's $ symbol. 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 8.5.4.)

The . symbol refers to the current run address, not the current load address, of the section.

For example, suppose a program needs to know the address of the beginning of the .data section. By using the .global directive (see Identify Global Symbols), you can create an external undefined variable called Dstart in the program. Then, assign the value of . to Dstart:

```
SECTIONS
{
   .text:    {}
   .data:    {Dstart = .;}
   .bss :    {}
}
```

This defines Dstart to be the first linked address of the .data section. (Dstart is assigned *before* .data is allocated.) The linker relocates all references to Dstart.

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 8.5.10.

8.5.9.3 Assignment Expressions

These rules apply to linker expressions:

- Expressions can contain global symbols, constants, and the C language operators listed in Table 8-11.
- All numbers are treated as long (32-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 8-11 in order of precedence. Operators in the same group have the same precedence. Besides the operators listed in Table 8-11, 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 8-11. Groups of Operators Used in Expressions (Precedence)

Group 1 (Highest Precedence)		Group 6	
! ~ -	Logical NOT Bitwise NOT Negation	&	Bitwise AND
Group 2		**Group 7**	
* / %	Multiplication Division Modulus	|	Bitwise OR
Group 3		**Group 8**	
+ -	Addition Subtraction	&&	Logical AND
Group 4		**Group 9**	
>> <<	Arithmetic right shift Arithmetic left shift	||	Logical OR
Group 5		**Group 10 (Lowest Precedence)**	
== ! = > < < = > =	Equal to Not equal to Greater than Less than Less than or equal to Greater than or equal to	= + = - = * = / =	Assignment A + = B is equivalent to A = A + B A - = B is equivalent to A = A - B A * = B is equivalent to A = A * B A / = B is equivalent to A = A / B

8.5.9.4 Symbols Defined by the Linker

The linker automatically defines several symbols based on which sections are used in your assembly source. A program can use these symbols at run time to determine where a section is linked. Since these symbols are external, they appear in the linker map. Each symbol can be accessed in any assembly language module if it is declared with a .global directive (see Identify Global Symbols). You must have used the corresponding section in a source module for the symbol to be created. Values are assigned to these symbols as follows:

.text is assigned the first address of the .text output section.
(It marks the *beginning* of executable code.)

etext is assigned the first address following the .text output section.
(It marks the *end* of executable code.)

.data is assigned the first address of the .data output section.
(It marks the *beginning* of initialized data tables.)

edata is assigned the first address following the .data output section.
(It marks the *end* of initialized data tables.)

.bss is assigned the first address of the .bss output section.
(It marks the *beginning* of uninitialized data.)

end is assigned the first address following the .bss output section.
(It marks the *end* of uninitialized data.)

The following symbols are defined only for C/C++ support when the --ram_model or --rom_model option is used.

__TI_STACK_END is assigned the end of the .stack size for ELF.

__TI_STACK_SIZE is assigned the size of the .stack section for ELF.

__TI_STATIC_BASE 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.

__STACK_END is assigned the end of the .stack size for COFF.

__STACK_SIZE is assigned the size of the .stack section for COFF.

__SYSMEM_SIZE is assigned the size of the .sysmem section for COFF.

__TI_SYSMEM_SIZE is assigned the size of the .sysmem section for ELF.

8.5.9.5 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 link command file. Then execute a sequence of instructions (the copying code in Example 8-10) 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. A simple example is illustrated Example 8-10.

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.

8.5.9.6 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.obj(.text)
        end_of_s1   = .;
        start_of_s2 = .;
        s2.obj(.text)
        end_of_s2 = .;
}
```

This statement creates three symbols:

- end_of_s1—the end address of .text in s1.obj
- start_of_s2—the start address of .text in s2.obj
- end_of_s2—the end address of .text in s2.obj

Suppose there is padding between s1.obj and s2.obj that is created as a result of alignment. Then start_of_s2 is not really the start address of the .text section in s2.obj, but it is the address before the padding needed to align the .text section in s2.obj. This is due to the linker's interpretation of the dot operator as the current PC. It is also due to the fact that 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; }
}
```

8.5.9.7 Address and Dimension Operators

Six operators allow you to define symbols for load-time and run-time addresses and sizes:

LOAD_START(*sym* **)**
START(*sym* **)**
	Defines *sym* with the load-time start address of related allocation unit

LOAD_END(*sym* **)**
END(*sym* **)**
	Defines *sym* with the load-time end address of related allocation unit

LOAD_SIZE(*sym* **)**
SIZE(*sym* **)**
	Defines *sym* with the load-time size of related allocation unit

RUN_START(*sym* **)**	Defines *sym* with the run-time start address of related allocation unit
RUN_END(*sym* **)**	Defines *sym* with the run-time end address of related allocation unit
RUN_SIZE(*sym* **)**	Defines *sym* 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.

8.5.9.7.1 Input Items

Consider an output section specification within a SECTIONS directive:

```
outsect:
{
        s1.obj(.text)
        end_of_s1   = .;
        start_of_s2 = .;
        s2.obj(.text)
        end_of_s2 = .;
}
```

This can be rewritten using the START and END operators as follows:

```
outsect:
{
        s1.obj(.text) { END(end_of_s1) }
        s2.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.

8.5.9.7.2 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.

8.5.9.7.3 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. This makes the use of .label in the source code unnecessary.

8.5.9.7.4 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.obj(.text) }
        .text2: load = ROM, SIZE(text2_size) { f2.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.

8.5.10 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.

8.5.10.1 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. Named sections defined with the .sect assembler directive also have raw data.

By default, the .bss section (see Reserve Space in the .bss Section) and sections defined with the .usect directive (see Reserve Uninitialized Space) 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.

8.5.10.2 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 8.5.3.2.

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 8.5.9.

The following example uses assignment statements to create holes in output sections:

```
SECTIONS
{
   outsect:
   {
      file1.obj(.text)
     . += 0x0100    /* Create a hole with size 0x0100 */
      file2.obj(.text)
    . = align(16);  /* Create a hole to align the SPC */
      file3.obj(.text)
    }
}
```

The output section outsect is built as follows:

1. The .text section from file1.obj is linked in.
2. The linker creates a 256-byte hole.
3. The .text section from file2.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.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.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.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.obj(.text)
     file1.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.

8.5.10.3 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 32-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 32-bit constant. For example:

```
SECTIONS
{  outsect:
   {
      file1.obj(.text)
      file2.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.obj(.text)
      file1.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 8.4.13). 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:

```
cl6x --run_linker --fill_value=0xFFFFFFFF 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.

8.5.10.4 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 = 0x12341234 /* Fills .bss with 0x12341234 */
}
```

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.

8.6 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 7.1 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 8.4.16.3). 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.obj and f2.obj both reference an external function named *clrscr*.
- Input file f1.obj references the symbol *origin*.
- Input file f2.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:

```
cl6x --run_linker f1.obj f2.obj liba.lib libc.lib
```

then:

- Member 1 of liba.lib satisfies the f1.obj and f2.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:

```
cl6x --run_linker f1.obj f2.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 8.4.33.) The next example creates an undefined symbol rout1 in the linker's global symbol table:

```
cl6x --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 8.5.4.

Section 8.4.16 describes methods for specifying directories that contain object libraries.

8.7 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 default algorithms to build and allocate sections within the specifications you supply.

If you do not use the MEMORY and SECTIONS directives, the linker allocates output sections as though the memory map and section definitions in Example 8-16 were specified.

Example 8-16. Default Allocation for TMS320C6000 Devices

```
MEMORY
{
    RAM     : origin = 0x00000001, length = 0xFFFFFFFE
}

SECTIONS
{
    .text  :  ALIGN(32) {} > RAM
    .const :  ALIGN(8)  {} > RAM
    .data  :  ALIGN(8)  {} > RAM
    .bss   :  ALIGN(8)  {} > RAM
    .cinit :  ALIGN(4)  {} > RAM       ; cflag option only
    .pinit :  ALIGN(4)  {} > RAM       ; cflag option only
    .stack :  ALIGN(8)  {} > RAM       ; cflag option only
    .far   :  ALIGN(8)  {} > RAM       ; cflag option only
    .sysmem:  ALIGN(8)  {} > RAM       ; cflag option only
    .switch:  ALIGN(4)  {} > RAM       ; cflag option only
    .cio   :  ALIGN(4)  {} > RAM       ; cflag option only
}
```

Also see Section 2.5.1 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, the linker performs *no part* of the default allocation. Allocation is performed according to the rules specified by the SECTIONS directive and the general algorithm described next in Section 8.7.1.

8.7.1 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 8.5.4 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.obj and f2.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 8.4.34) 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 as shown in Example 8-16. (See Section 8.5.3 for more information on configuring memory.)

8.7.2 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 have supplied 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.

8.8 Linker-Generated Copy Tables

The linker supports extensions to the link 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

8.8.1 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 you can develop an application like this is to create a copy table in assembly code that contains three elements for each block of code or data that needs to be moved from FLASH into 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.

8.8.2 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 link command file syntax . For example, instead of building the application to generate a .map file, the link command file can be annotated:

```
SECTIONS
{
   .flashcode: { app_tasks.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
_flash_code_ld_start	Load address of .flashcode section
_flash_code_rn_start	Run address of .flashcode section
_flash_code_size	Size of .flashcode 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 8.8.1.

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 link 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 8.5.9.7.

8.8.3 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 link command file as illustrated in Example 8-17:

Example 8-17. Using a UNION for Memory Overlay

```
SECTIONS
{
   ...
   UNION
   {
      GROUP
      {
         .task1: { task1.obj(.text) }
         .task2: { task2.obj(.text) }

      } load = ROM, LOAD_START(_task12_load_start), SIZE(_task12_size)

      GROUP
      {
         .task3: { task3.obj(.text) }
         .task4: { task4.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.

8.8.4 Generating Copy Tables With the table() Operator

The linker supports extensions to the link 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 8-17 can be written as shown in Example 8-18:

Example 8-18. Produce Address for Linker Generated Copy Table

```
SECTIONS
{
   ...

   UNION
   {
      GROUP
      {
         .task1: { task1.obj(.text) }
         .task2: { task2.obj(.text) }

      } load = ROM, table(_task12_copy_table)

      GROUP
      {
         .task3: { task3.obj(.text) }
         .task4: { task4.obj(.text) }

      } load = ROM, table(_task34_copy_table)

   } run = RAM
   ...
}
```

Using the SECTIONS directive from Example 8-18 in the link 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 do not have to 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++ or assembly source code, passing that value to a general purpose copy routine which will process the copy table and affect the actual copy.

8.8.4.1 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 8.8.4. The table operator can be used with compression; see Section 8.8.5.

8.8.4.2 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 link command file for the boot-loaded application described in Section 8.8.2 can be rewritten as follows:

```
SECTIONS
{
   .flashcode: { app_tasks.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 link 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.

8.8.4.3 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 link command file excerpt in Example 8-19:

Example 8-19. Linker Command File to Manage Object Components

```
SECTIONS
{
   UNION
   {
      .first: { a1.obj(.text), b1.obj(.text), c1.obj(.text) }
            load = EMEM, run = PMEM, table(BINIT), table(_first_ctbl)

      .second: { a2.obj(.text), b2.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.

8.8.4.4 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 8-20 illustrates how you can control the placement of the linker-generated copy table sections using the input section names in the link command file.

Example 8-20. Controlling the Placement of the Linker-Generated Copy Table Sections

```
SECTIONS
{
   UNION
   {
      .first: { a1.obj(.text), b1.obj(.text), c1.obj(.text) }
             load = EMEM, run = PMEM, table(BINIT), table(_first_ctbl)

      .second: { a2.obj(.text), b2.obj(.text) }
             load = EMEM, run = PMEM, table(_second_ctbl)
   }

   .extra: load = EMEM, run = PMEM, table(BINIT)

   ...

   .ovly: { } > BMEM
   .binit: { } > BMEM
}
```

For the link command file in Example 8-20, 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.

8.8.4.5 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 8-21. Example 8-22 illustrates a possible driver for such an application.

Example 8-21. 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 8-22. Split Object Component Driver

```
#include <cpy_tbl.h>

extern far COPY_TABLE task13_ctbl;
extern far 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();
   ...
}
```

You must declare a COPY_TABLE object as *far* to allow the overlay copy table section placement to be independent from the other sections containing data objects (such as .bss).

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.

8.8.5 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.

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.

8.8.5.1 Compressed Copy Table Format

The copy table format is the same irrespective of the compression. The size field of the copy record is overloaded to support compression. Figure 8-5 illustrates the compressed copy table layout.

Figure 8-5. Compressed Copy Table

<table>
<tr><td>Rec size</td><td>Rec cnt</td><td></td><td></td></tr>
<tr><td colspan="2">Load address</td><td>Run address</td><td>Size (0 if load data is compressed)</td></tr>
</table>

In Figure 8-5, 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.

8.8.5.2 Compressed Section Representation in the Object File

When the load data is not compressed, the object file can have only one section with a different load and run address.

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 a 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.

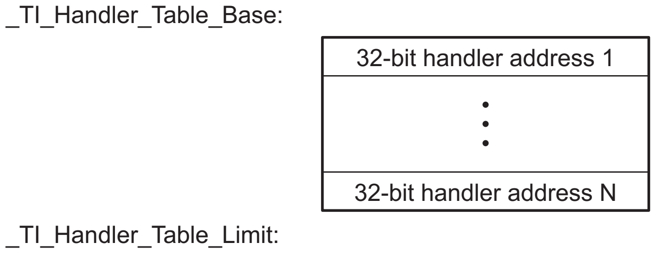
8.8.5.3 Compressed Data Layout

The compressed load data has the following layout:

8-bit index	Compressed data

The first eight 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 32-bit function pointers as shown in Figure 8-6.

Figure 8-6. Handler Table



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().

8.8.5.4 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 byte from load address. Call this index.
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.

8.8.5.5 Compression Algorithms

Run Length Encoding (RLE):

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. C6000 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 != 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).
        - (i) If L == 0, length is a 24-bit value or the end of the data is reached, read next byte (L).
            - (i) If L == 0, the end of the data is reached, go to step 7.
            - (ii) Else L <<= 16, read next two bytes into lower 16 bits of L to complete 24-bit value for L.
        - (ii) Else L <<= 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 C6000 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 that are generated by older versions of the linker.

Lempel-Ziv-Storer-Szymanski Compression (LZSS):

8-bit index	Data compressed using LZSS

The data following the 8-bit index is compressed using LZSS compression. The C6000 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, and the second argument is the run address from the C auto initialization record.

8.8.6 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 8-23 shows the copy table header file.

Example 8-23. TMS320C6000 cpy_tbl.h File

```
/****************************************************************************/
/* cpy_tbl.h                                                                */
/*                                                                          */
/* Copyright (c) 2011 Texas Instruments Incorporated                        */
/*                                                                          */
/* Specification of copy table data structures which can be automatically   */
/* generated by the linker (using the table() operator in the LCF).      */
/*                                                                          */
/****************************************************************************/

/****************************************************************************/
/* Copy Record Data Structure                                               */
/****************************************************************************/
typedef struct copy_record
{
   unsigned int load_addr;
   unsigned int run_addr;
   unsigned int size;
} COPY_RECORD;

/****************************************************************************/
/* Copy Table Data Structure                                                */
/****************************************************************************/
typedef struct copy_table
{
   unsigned short rec_size;
   unsigned short 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" namespace std */

#ifndef _CPP_STYLE_HEADER
using std::COPY_RECORD;
using std::COPY_TABLE;
using std::copy_in;
#endif /* _CPP_STYLE_HEADER */
#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 8.8.4.2, 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> } };
```

8.8.7 General Purpose Copy Routine

The cpy_tbl.h file in Example 8-23 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 8-24.

Example 8-24. 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);
      }
#ifdef __TI_EABI__
      else if (HANDLER_TABLE)
      {
         /*-------------------------------------------------------------------*/
```

Example 8-24. Run-Time-Support cpy_tbl.c File (continued)

```
         /* 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
   }
}
```

8.9 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 8.4.3.2.)
- 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 8.4.22.)
- 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.

  When 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 8.4.17.1).
- 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 8.4.25.)

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.

```
cl6x --run_linker --relocatable --output_file=tempout1 file1.com
```

file1.com contains:

```
SECTIONS
{
    ss1:   {
          f1.obj
          f2.obj
           .
           .
           .
          fn.obj
          }
}
```

Step 2: Link the file file2.com; use the --relocatable option to retain relocation information in the output file tempout2.out.

```
cl6x --run_linker --relocatable --output_file=tempout2 file2.com
```

file2.com contains:

```
SECTIONS
{
   ss2:   {
          g1.obj
          g2.obj
           .
           .
           .
          gn.obj
          }
}
```

Step 3: Link tempout1.out and tempout2.out.

```
cl6x --run_linker --map_file=final.map --
output_file=final.out tempout1.out tempout2.out
```

8.10 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:

```
cl6x --run_linker --rom_model --
output_file prog.out prog1.obj prog2.obj ... rts6200.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.

For more information about the TMS320C6000 C/C++ language, including the run-time environment and run-time-support functions, see the *TMS320C6000 Optimizing Compiler User's Guide*.

8.10.1 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.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.obj; referencing _c_int00 ensures that boot.obj is automatically linked in from the run-time-support library. When a program begins running, it executes boot.obj first. The boot.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.obj. You can:

- Use the archiver to extract boot.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.obj when you use the --ram_model or --rom_model option).

8.10.2 Object Libraries and Run-Time Support

The *TMS320C6000 Optimizing Compiler User's Guide* 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.

8.10.3 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 4-byte 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 8.4.14 for setting heap sizes and Section 8.4.29 for setting stack sizes.

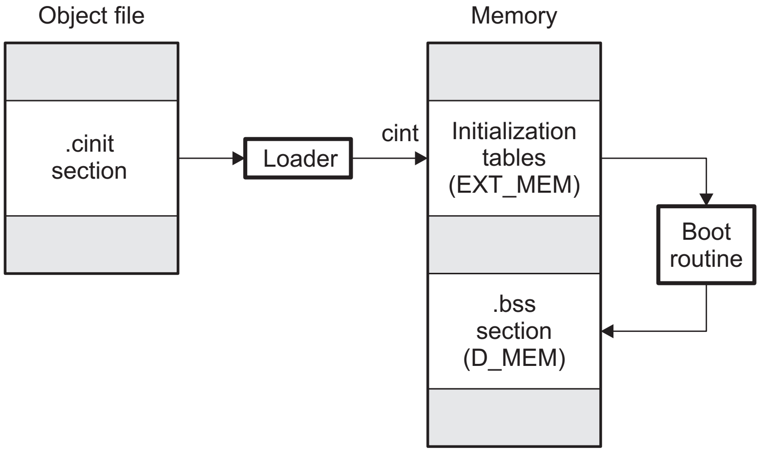
8.10.4 Autoinitializing Variables at Run Time (--rom_model)

Autoinitializing variables at run time is the default method of autoinitialization. To use this method, invoke the linker with the --rom_model option.

Using this method, the .cinit section is loaded into memory along with all the other initialized sections. The linker defines a special symbol called cinit 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 specified variables in the .bss section. This allows initialization data to be stored in slow external memory and copied to fast external memory each time the program starts.

Figure 8-7 illustrates autoinitialization at run time. Use this method in any system where your application runs from code burned into slow external memory.

Figure 8-7. Autoinitialization at Run Time



8.10.5 Initializing Variables at Load Time (--ram_model)

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.

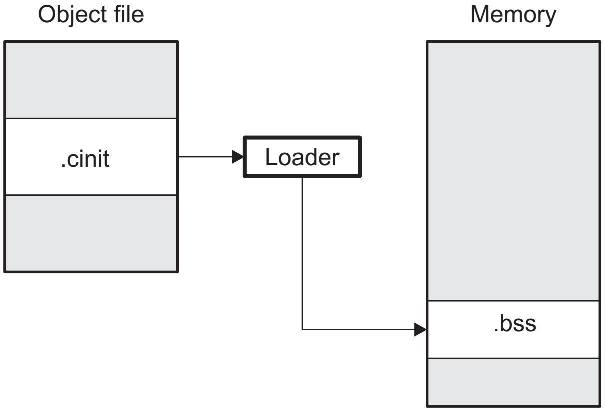
When you use the --ram_model linker option, the linker sets the STYP_COPY bit in the .cinit section's header. This tells the loader not to load the .cinit section into memory. (The .cinit section occupies no space in the memory map.) The linker also sets the cinit symbol to -1 (normally, cinit points to the beginning of the initialization tables). This indicates to the boot routine that the initialization tables are not present in memory; accordingly, no run-time initialization is performed at boot time.

A loader must be able to perform the following tasks to use initialization at load time:

- Detect the presence of the .cinit section in the object file.
- Determine that STYP_COPY is set in the .cinit section header, so that it knows not to copy the .cinit section into memory.
- Understand the format of the initialization tables.

Figure 8-8 illustrates the initialization of variables at load time.

Figure 8-8. Initialization at Load Time



8.10.6 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.obj; referencing _c_int00 ensures that boot.obj is automatically linked in from the appropriate run-time-support library.
- The .cinit output section is padded with a termination record to designate to the boot routine (autoinitialize at run time) or the loader (initialize at load time) when to stop reading the initialization tables.
- When you initialize at load time (--ram_model option):
  - The linker sets cinit to -1. This indicates that the initialization tables are not in memory, so no initialization is performed at run time.
  - The STYP_COPY flag (0010h) is set in the .cinit section header. STYP_COPY is the special attribute that tells the loader to perform initialization directly and not to load the .cinit section into memory. The linker does not allocate space in memory for the .cinit section.
- When you autoinitialize at run time (--rom_model option), the linker defines cinit as the starting address of the .cinit section. The C boot routine uses this symbol as the starting point for autoinitialization.

8.11 Linker Example

This example links three object files named demo.obj, ctrl.obj, and tables.obj and creates a program called demo.out.

Assume that target memory has the following program memory configuration:

Address Range	Contents
0x00000000 to 0x00001000	SLOW_MEM
0x00001000 to 0x00002000	FAST_MEM
0x08000000 to 0x08000400	EEPROM

The output sections are constructed in the following manner:

- Executable code, contained in the .text sections of demo.obj, fft.obj, and tables.obj, is linked into program memory ROM.
- Variables, contained in the var_defs section of demo.obj, are linked into data memory in block FAST_MEM_2.
- Tables of coefficients in the .data sections of demo.obj, tables.obj, and fft.obj are linked into FAST_MEM_1. A hole is created with a length of 100 and a fill value of 0x07A1C.
- The xy section form demo.obj, which contains buffers and variables, is linked by default into page 1 of the block STACK, since it is not explicitly linked.
- Executable code, contained in the .text sections of demo.obj, ctrl.obj, and tables.obj, must be linked into FAST_MEM.
- A set of interrupt vectors, contained in the .intvecs section of tables.obj, must be linked at address 0x00000000.
- A table of coefficients, contained in the .data section of tables.obj, must be linked into EEPROM. The remainder of block EEPROM must be initialized to the value 0xFF00FF00.
- A set of variables, contained in the .bss section of ctrl.obj, must be linked into SLOW_MEM and preinitialized to 0x00000100.
- The .bss sections of demo.obj and tables.obj must be linked into SLOW_MEM.

Example 8-25 shows the link command file for this example. Example 8-26 shows the map file.

Example 8-25. Linker Command File, demo.cmd

```
/**********************************************************************/
/***                     Specify Linker Options                     ***/
/**********************************************************************/
--entry_point SETUP           /* Define the program entry point       */
--output_file=demo.out        /* Name the output file                 */
--map_file=demo.map           /* Create an output map file            */
/**********************************************************************/
/***                     Specify the Input Files                    ***/
/**********************************************************************/
demo.obj
ctrl.obj
tables.obj
/**********************************************************************/
/***                Specify the Memory Configurations               ***/
/**********************************************************************/
MEMORY
{
   FAST_MEM : org = 0x00000000   len = 0x00001000
   SLOW_MEM : org = 0x00001000   len = 0x00001000
   EEPROM   : org = 0x08000000   len = 0x00000400
}
/**********************************************************************/
/*                   Specify the Output Sections                    ***/
/**********************************************************************/
SECTIONS
{
   .text    : {} > FAST_MEM  /* Link all .text sections into ROM      */
   .intvecs : {} > 0x0       /* Link interrupt vectors at 0x0         */
   .data    :                /* Link .data sections                   */
   {
      tables.obj(.data)
      . = 0x400;             /* Create hole at end of block           */
   } = 0xFF00FF00 > EEPROM   /* Fill and link into EEPROM             */
   ctrl_vars:                /* Create new ctrl variables section     */
   {
      ctrl.obj(.bss)
   } = 0x00000100 > SLOW_MEM /* Fill with 0x100 and link into RAM     */
   .bss     : {} > SLOW_MEM  /* Link remaining .bss sections into RAM */
}
/**********************************************************************/
/***                      End of Command File                       ***/
/**********************************************************************/
```

Invoke the linker by entering the following command:

cl6x --run_linker demo.cmd

This creates the map file shown in Example 8-26 and an output file called demo.out that can be run on a TMS320C6000.

Example 8-26. Output Map File, demo.map

```
OUTPUT FILE NAME:   <demo.out>
ENTRY POINT SYMBOL: 0

MEMORY CONFIGURATION

           name     origin    length      used    attributes    fill

         --------  --------  ---------  --------  ----------  --------
         FAST_MEM  00000000  000001000  00000078     RWIX
         SLOW_MEM  00001000  000001000  00000502     RWIX
         EEPROM    08000000  000000400  00000400     RWIX

SECTION ALLOCATION MAP

 output                                  attributes/
section   page    origin      length       input sections
--------  ----  ----------  ----------   ----------------
.text      0      00000000    00000064
                  00000000    00000030     demo.obj (.text)
                  00000030    00000000     tables.obj (.text)
                  00000030    00000010     --HOLE-- [fill = 00000000]
                  00000040    00000024     ctrl.obj (.text)
.intvecs   0      00000000    00000014
                  00000000    00000014     tables.obj (.intvecs)
.data      0      08000000    00000400
                  08000000    00000004     tables.obj (.data)
                  08000004    000003fc     --HOLE-- [fill = ff00ff00]
                  08000400    00000000     ctrl.obj (.data)
                  08000400    00000000     demo.obj (.data)
ctrl_vars   0     00001000    00000500
                  00001000    00000500     ctrl.obj (.bss) [fill = 00000100]
.bss       0      00001500    00000002     UNINITIALIZED
                  00001500    00000002     demo.obj (.bss)
                  00001502    00000000     tables.obj (.bss)

GLOBAL SYMBOLS

address  name                             address  name
-------- ----                             -------- ----
00001500 $bss                             00000000 .text
00001500 .bss                             00000000 _x42
08000000 .data                            00000018 _SETUP
00000000 .text                            00000040 _fill_tab
00000018 _SETUP                           00000064 etext
00000040 _fill_tab                        00001500 $bss
00000000 _x42                             00001500 .bss
08000400 edata                            00001502 end
00001502 end                              08000000 gvar
00000064 etext                            08000000 .data
08000000 gvar                             08000400 edata
[11 symbols]
```

8.12 Dynamic Linking with the C6000 Code Generation Tools

The C6000 v7.2 Code Generation Tools (CGT) support dynamic linking provided you build with EABI. If you are not already familiar with the limitations of EABI support in the C6000 compiler, please see http://processors.wiki.ti.com/index.php/EABI_Support_in_C6000_Compiler and *The C6000 Embedded Application Binary Interface Application Report* (SPRAB89).

8.12.1 Static vs Dynamic Linking

Static linking is the traditional process of combining relocatable object files and static libraries into a static link unit: either an ELF executable file (.exe) or an ELF shared object (.so). The term *object* is used to refer generically to either.

8.12.1.1 Code Size Reduction

A program consists of exactly one executable file (also commonly known as a client application) and any additional shared objects (such as libraries) that it depends on to satisfy any undefined references. If multiple executables depend on the same library, they can share a single copy of its code (hence the “shared” in “shared object”), thereby significantly reducing the memory requirements of the system.

A dynamic shared object (DSO), as the name implies, can be shared among several applications that may be running one-at-a-time in a single threaded environment, or at the same time in a multi-threaded environment. Rather than making a separate copy of the DSO code in memory for each application that needs to use it, a single version of the code can reside in one location (like ROM) where references to its functions can be resolved as the executables and other DSOs that use it are loaded and dynamically linked.

8.12.1.2 Binding Time

In a conventionally linked static executable, symbols are bound to addresses and library code is bound to the executable at link-time, so the library that the executable is bound to at link-time is the one that it will always use, regardless of changes or defect fixes that are made to the library.

In a static shared library, symbols are still bound to addresses at link-time, but the library code is not bound to the executable that uses the library until run-time.

With a dynamic shared library, decisions about binding library symbols to addresses and resolving symbol references between a dynamic shared library and the other objects that use it (or are used by it) are delayed until actual load-time. This allows you to load a shared library when its services are needed, and unload it when its services are not needed. Thus, making more effective use of limited target memory space.

8.12.1.3 Modular Development

Dynamically linking encourages modular development. The interface for a dynamic shared object is explicitly defined via the importing and exporting of global symbols. A cleanly defined interface for a dynamic shared object will tend to improve the cohesion of the code that implements the services provided by a given dynamic object.

8.12.1.4 Recommended Reading

For a more detailed discussion of the benefits and disadvantages of using dynamic executables and dynamic shared objects, please refer to available literature on the subject, including John R. Levine's excellent book *Linkers & Loaders* (ISBN-13: 978-1-55860-496-4).

8.12.2 Embedded Application Binary Interface (EABI) Required

All software components in a system that uses the Dynamic Linking Model must use the EABI Run-time model. The EABI Run-Time Model can be specified using the --abi=eabi option.

The compiler generates object files in ELF object file format when EABI is specified. The C6000 CGT makes use of the industry-standard dynamic linking mechanisms that are detailed in the *ELF Specification (Tool Interface Standard)*.

Specifically, for OMAP developers that are using devices with ROMed code, you must be sure that the ROMed code has been built using the EABI model. Similarly, if your application uses BIOS, you need to ensure that the BIOS version that you are using has been built using the EABI model. Finally, for developers that are relying on Code Composer Studio (CCS) to run and/or debug their application, you must use CCS version 4 or later (CCS ELF support begins in CCS version 4).

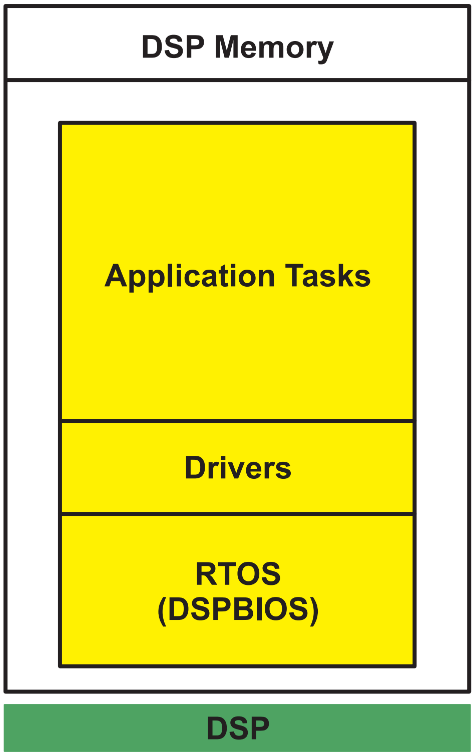
8.12.3 Bare-Metal Dynamic Linking Model

The bare-metal dynamic linking model is intended to support an application environment in which a Real Time Operating System (RTOS) is loaded and running on a DSP processor.

8.12.3.1 Consider a Static DSP Application

First, consider an example of a basic DSP run-time model. If the RTOS and the applications that use it are built as a single static executable, the resulting system will look something like this:

Figure 8-9. A Basic DSP Run-Time Model



In this scenario, the DSP application is a single static executable file that contains: the RTOS, any required driver functions, and all tasks that the application needs to carry out. All of the addresses in the static executable are bound at link-time, they cannot be relocated at load-time. Execution of the DSP application will proceed from the application's entry point.

8.12.3.2 Make it Dynamic

In a dynamic linking system you can build dynamic modules that are loaded and relocated by a dynamic loader at run time. The dynamic loader can also perform dynamic symbol resolution: resolving symbol references from dynamic modules with the symbol definitions from other dynamic modules. The dynamic linking model supports the creation of such dynamic modules. In particular, it supports creating dynamic executables and dynamic libraries.

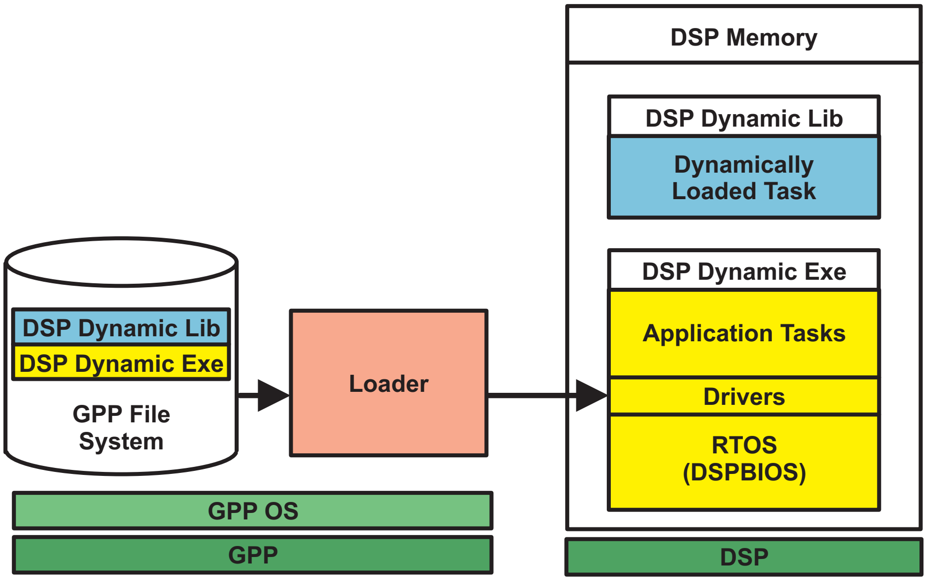
A dynamic executable:

- Will have a dynamic segment
- Can export/import symbols
- Is optionally relocatable (can contain dynamic relocations)
- Must have an entry point
- Can be created using -c/-cr compiler options
- Must use far DP or absolute addressing to access imported data, but can use near DP addressing to access its own data

A dynamic library:

- Will have a dynamic segment
- Can export/import symbols
- Is relocatable
- Does not require an entry point
- Cannot be created using -c/-cr compiler option
- Must use far DP or absolute addressing to access its own data as well as data that it imports from other modules

Figure 8-10. Dynamic Linking Model

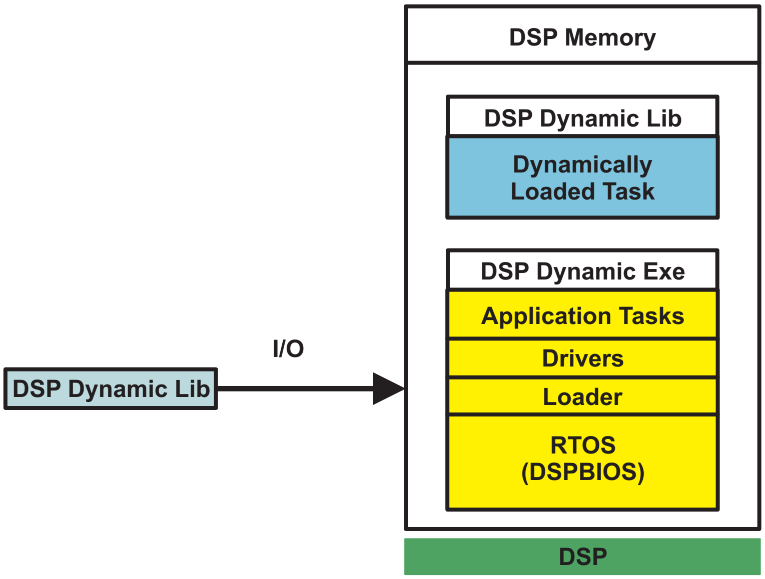


If we convert the earlier RTOS example into a dynamic system, the RTOS part of the system is still built like an executable and is assumed to be loaded by traditional means (bootstrap loader) and set running on the DSP by a host application.

Application tasks can be built as dynamic libraries that can then be loaded by the dynamic loader and linked against the RTOS that is already loaded and running on the DSP. In this scenario, the RTOS is a dynamic executable and is also sometimes referred to as the *base image*. The dynamic library is dynamically linked against the RTOS base image at load time.

In Figure 8-10, the dynamic loader is running on a General Purpose Processor (GPP) and is able to interact with the user to load and unload dynamic library components onto the DSP as needed. Another scenario is to load the dynamic loader as part of the RTOS base image executable:

Figure 8-11. Base Image Executable



An example of this scenario is the reference implementation of the C6000 dynamic loader. It is written to be built and run as a dynamic executable base image itself. It contains an interactive user interface which allows the user to identify their own base image, load and link dynamic libraries against that base image, and then execute a function that is defined in the dynamic library. For more details about the reference implementation of the dynamic loader, please see the Dynamic Loader wiki article.

8.12.3.3 Symbol Resolution

A dynamic library in a dynamic DSP application can utilize services that are provided by the RTOS. These functions in the RTOS that are callable from a dynamic library must be *exported* when the RTOS is built. Similarly, a dynamic library must *import* any function or data object symbols that are part of the RTOS when the dynamic library is built.

Exported symbols in a dynamic object, dynA, are available for use by any other dynamic object that links with dynA. When a dynamic object *imports* a symbol, it is asserting that when the object is loaded, the definition of that symbol must be contained in a dynamic object that is already loaded or one that is required to be loaded. The symbol importing and exporting mechanisms lie at the core of how dynamic objects are designed to interact with each other. This subject is explored in more detail in Section 8.12.5.1.

8.12.4 Building a Dynamic Executable

A dynamic executable is essentially a statically linked executable file that contains extra information in the form of a dynamic segment that can be used when a dynamic library is loaded and needs symbols that are defined in the dynamic executable.

In the sample system described here, the reference implementation of the dynamic loader (dl6x.6x) is built as a base image. This base image also contains the basic I/O functions and some run-time-support (RTS) functions. The base image should export these I/O and RTS functions. These symbols will then become available to a dynamic library when it is dynamically loaded and linked against the dynamic executable.

8.12.4.1 Exporting Symbols

To accomplish exporting of symbols, there are two methods available:

- **Recommended:** Declare exported symbols explicitly in the source of the dynamic executable using __declspec(dllexport).

  For example, if you want to export exp_func from the dynamic executable, you can declare it in your source as follows:

  ```
  __declspec(dllexport) int exp_func();
  ```

- Use the --export option at link time. You can specify one or more symbols to be exported with --export=*symbol* on the linker command line or in a linker command file. For example, you could export exp_func() at link time with:

  ```
  cl6x --abi=elfabi ... -z --dynamic=exe --export=exp_func ...
  ```

  In general, to build a dynamic executable, you must specify --dynamic=exe or --dynamic on the linker command line or in a linker command file. Consider the build of the dl6x.6x file described in the Dynamic Loader wiki article at http://processors.wiki.ti.com/index.php/C6000_EABI:Dynamic_Loader as an example of how to build a dynamic executable or base image:

  ```
  cl6x --abi=elfabi ... -z *.obj ... --dynamic --export=printf ...
  ```

  In this example, the --dynamic option indicates that the result of the link is going to be a dynamic executable. The --export=printf indicates that the printf() run-time-support function is exported by the dynamic executable and, if imported by a dynamic library, can be called at run time by the functions defined in the dynamic library.

8.12.5 Building a Dynamic Library

A dynamic library is a shared object that contains dynamic information in the form of a dynamic segment. It is relocatable and can import symbols from other ELF dynamic objects that it links against and it can also export symbols that it defines itself.

8.12.5.1 Importing/Exporting Symbols

Importing and exporting of symbols can be accomplished in two ways, similarly to how it can be done in dynamic executables:

- **Recommended:** Declare exported and/or imported symbols explicitly in the source code of the dynamic library using __declspec(dllexport) for exported symbols and __declspec(dllimport) for imported symbols.

  For example, if you want to export a function, red_fish(), and import another function, blue_fish(), you could specify this in a source file as follows:

  ```
  __declspec(dllexport) long red_fish();
  __declspec(dllimport) int blue_fish();
  ```

- You can also specify symbols to be imported or exported on the linker command line (or in a linker command file) using --import=*symbol* or "--export=*symbol*.

  So at link time, you might say:

  ```
  cl6x --abi=elfabi ... -z --dynamic=lib --export=red_fish --import=blue_fish
       blue.dll -o red.dll
  ```

  This informs the linker that the definition of red_fish() will be in the red.dll dynamic library and that we can find and use the definition of blue_fish() in blue.dll.

In general, to build a dynamic library, you must specify --dynamic=*lib* on the linker command line or in a linker command file. In addition, if any symbols are imported from other dynamic objects, then those dynamic objects must be specified on the linker command line when the dynamic library is built. This is sometimes referred to as static binding.

8.12.5.2 A Simple Example - hello.dll

This section describes a simple walk-through of the process used to build, load, and run a function that is defined in a dynamic library.

- First compile this simple "Hello World" source:

```
hello.c:

#include <stdio.h>
__declspec(dllexport) int start();
int start()
{
   printf("Hello World\n");
   return 0;
}
```

- Then build a dynamic library called hello.dll:

```
cl6x -mv6400+ --abi=elfabi hello.c -z --import=printf --dynamic=lib -o hello.dll
     dl6x.6x -e start
```

- Now, load the dynamic loader using a loader that supports C6000 ELF executable object files. Then start the dynamic loader running. When using the reference implementation of the dynamic loader (RIDL), you will see the RIDL prompt come up and then you need to issue the following commands:

```
RIDL> base_image dl6x.6x
RIDL> load hello.dll
RIDL> execute
```

  You should see the "Hello World" message displayed and then control will return to the RIDL prompt. To terminate the dynamic loader you can enter the exit command from the RIDL prompt.

  For more details, see the Dynamic Loader wiki site (http://processors.wiki.ti.com/index.php/C6000_Dynamic_Loader))

8.12.5.3 Summary of Compiler and Linker Options

This is a brief summary of the compiler and linker options that are related to support for the Dynamic Linking Model in the C6000 CGT. For more details, see the C6000 EABI wiki article (http://processors.wiki.ti.com/index.php/EABI_Support_in_C6000_Compiler).

Table 8-12. Compiler Options For Dynamic Linking

Option	Description
--abi=eabi	Specifies that EABI run-time model is to be used.
--dsbt	Generates addressing via Dynamic Segment Base Table
--export_all_cpp_vtbl	Exports C++ virtual tables by default
--import_undef[=off|on]	Specifies that all global symbol references that are not defined in a module are imported. Default is on.
--import_helper_functions	Specifies that all compiler generated calls to run-time-support functions are treated as calls to imported functions. See Section 8.12.6.
--inline_plt[=off|on]	Inlines the import function call stub. Default is on.
--linux	Generates code for Linux.
--pic[=off|on]	Generates position independent addressing for a shared object. Default is near.
--visibility={hidden|default|protected}	Specifies a default visibility to be assumed for global symbols. See Section 8.12.6.
–wchar_t	Generates 32-bit wchar_t type when --abi=eabi is specified. By default the compiler generates 16-bit wchar_t.

Table 8-13. Linker Options For Dynamic Linking

Option	Description
--dsbt_index=*int*	Requests a specific Data Segment Base Table (DSBT) index to be associated with the current output file. If the DSBT model is being used, and you do not request a specific DSBT index for the output file, then a DSBT index is assigned to the module at load time.
--dsbt_size=*int*	Specifies the size of the Data Segment Base Table (DSBT) for the current output file, in words. If the DSBT model is being used, this option can be used to override the default DSBT size (8 words).
--dynamic[=exe]	Specifies that the result of a link will be a dynamic executable. See Section 8.12.4.1.
--dynamic=*lib*	Specifies that the result of a link will be a dynamic library. See Section 8.12.5.1.
--export=*symbol*	Specifies that *symbol* is exported by the ELF object that is generated for this link.
--fini=*symbol*	Specifies the *symbol* name of the termination code for the output file currently being linked.
--import=*symbol*	Specifies that *symbol* is imported by the ELF object that is generated for this link.
--init=*symbol*	Specifies the *symbol* name of the initialization code for the output file currently being linked.
--rpath=*dir*	Adds a directory to the beginning of the dynamic library search path.
--runpath=*dir*	Adds a directory to the end of the dynamic library search path.
--shared	Generates a dynamically shared object.
--soname=*string*	Specifies shared object name to be used to identify this ELF object to the any downstream ELF object consumers.
--sysv	Generates SysV ELF output file.

8.12.6 Symbol Import/Export

In a dynamic linking system you can build dynamic modules that are loaded and relocated by a dynamic loader at run time. The dynamic loader can also perform dynamic symbol resolution: resolve references from dynamic modules with the definitions from other dynamic objects.

Only symbols explicitly imported or exported have dynamic linkage and participate in dynamic linking. Normal global symbols don't participate in dynamic symbol resolution. A symbol is exported if it is visible from a module during dynamic symbol resolution. A dynamic object is a dynamic library or a dynamic executable. Such a dynamic object imports a symbol when its symbol references are resolved by definitions from another dynamic object. The dynamic object that has the definition and makes it visible is said to export the symbol.

8.12.6.1 ELF Symbols

ELF symbols have two attributes that contribute to static and dynamic symbol binding:

- Symbol Binding - symbol’s scope with respect to other files
- Symbol Visibility - symbol’s scope with respect to other run-time components (dynamic executable or dynamic libraries)

A more detailed discussion of the symbol binding and visibility characteristics can be found in the *ELF Specification (Tool Interface Standard)*.

8.12.6.1.1 Symbol Binding Attribute Values

- **STB_LOCAL**
  - Indicates that a symbol is not visible outside the module where it is defined.
  - Any local references to the symbol will be resolved by the definition in the current module.
- **STB_GLOBAL**
  - Indicates that a symbol is visible to all files being combined during the link step
  - Any references to a global symbol that are left unresolved will result in a link-time error
- **STB_WEAK**
  - Indicates that a symbol is visible to all files being combined during a link step.
  - Global symbol definition takes precedence over corresponding weak symbol def.

8.12.6.1.2 ELF Symbol Visibility

GLOBAL/WEAK symbols can have any of the following visibility attributes:

- **STV_DEFAULT**
  - Symbol definition is visible outside the defining component.
  - Symbol definition can be preempted.
  - Symbol references can be resolved by definition outside the referenced component.
- **STV_PROTECTED**
  - Symbol definition is visible outside the defining component.
  - Symbol definition cannot be preempted.
  - Symbol reference must be resolved by a definition in the same component.
- **STV_HIDDEN**
  - Symbol definition is not visible outside its own component.
  - Symbol reference must be resolved by a definition in the same component.

8.12.6.2 Controlling Import/Export of Symbols

Symbols can be imported/exported by using:

- Source Code Annotations
- ELF Linkage Macros
- Compiler Options
- Linker Options

8.12.6.2.1 Source Code Annotations (Recommended)

A global symbol can be imported or exported by adding a __declspec() symbol annotation to the source file.

- Export Using __declspec(dllexport)

  ```
  __declspec(dllexport) int foo() { }
  ```

  __declspec(dllexport) can be applied to both symbol declarations and symbol definitions.
- Import Using __declspec(dllimport)

  ```
  __declspec(dllimport) int bar();
  ```

  __declspec(dllimport) can be applied to a symbol declaration.

  The compiler generates a warning if __declspec(dllimport) is applied to a symbol definition.
- Typically an API is exported by a module and is imported by another module. __declspec() can be added to the API header file
- The linker uses the most restrictive visibility for symbols. For example, consider if the following were true:
  - foo() is declared with __declspec(dllimport) in a.c
  - foo() is declared plain (no __declspec()) in b.c
  - a.c and b.c are compiled into ab.dll

  Then, the symbol, foo, is **not** imported in ab.dll and the linker reports an error indicating that the reference to foo() is unresolved.
- Some of the benefits of using the __declspec() approach include:
  - It enables the compiler to generate more optimal code.
  - The optimizer does not optimize out exported symbols.
  - The source code becomes a self-documenting in specifying the API for a given module, making it easier to read and maintain.
  - It can be used in the Dynamic Linking Model

8.12.6.2.2 Import/Export Using ELF Linkage Macros (elf_linkage.h)

The C6000 compiler provides a header file, elf_linkage.h, in the include sub-directory of the installed toolset. The elf_linkage.h file defines several macros that can be used to control symbol visibility:

- **TI_IMPORT** *symbol declaration*

  This macro imports the declared symbol. The TI_IMPORT macro cannot be applied to symbol definitions.

  ```
  TI_IMPORT int foo(void);
  extern TI_IMPORT long global_variable;
  ```

- **TI_EXPORT** *symbol definition***|***symbol declaration*

  This macro exports the symbol that is being declared or defined. The source module that makes use of this macro must contain a definition of the symbol.

  ```
  TI_EXPORT int foo(void);
  TI_EXPORT long global_variable;
  ```

- **TI_PATCHABLE** *symbol definition*

  This macro makes the definition of the symbol visible outside of the source module that uses it. Other modules can import the defined symbol. Also, a reference to the symbol can be patched (or re-directed) to a different definition of the symbol if needed. The compiler will generate an indirect call to a function that has been marked as patchable. This technique is also sometimes called symbol preemption.

  ```
  TI_PATCHABLE int foo(void);
  TI_PATCHABLE long global_variable;
  ```

- **TI_DEFAULT** *symbol definition***|***symbol declaration*

  This macro specifies that the symbol in question can be either imported or exported. The definition of the symbol is visible outside the module. Other modules can import the symbol definition. Any references to the symbol can also be patched.

- **TI_PROTECTED** *symbol definition***|***symbol declaration*

  This macro specifies that the symbol in question is visible outside of the module. Other modules can import the symbol definition. However, a reference to the symbol can never be patched (symbol is non-preemptable).

- **TI_HIDDEN** *symbol definition***|***symbol declaration*

  The definition of the symbol is not visible outside the module that defines it.

8.12.6.2.3 Import/Export Using Compiler Options

The following compiler options can be used to control the symbol visibility of global symbols. The symbols using source code annotations to control the visibility are not affected by these compiler options.

- **--visibility=***default visibility*

  The --visibility option specifies the default visibility for global symbols. This option does not affect the visibility of symbols that use the __declspec() or TI_xxx macros to specify a visibility in the source code. The *default visibility* is one of the following:

  – hidden - Global symbols are not imported or exported. This is the default compiler behavior.

  – default - All global symbols are imported, exported, and patchable.

  – protected - All global symbols are exported.

- **--import_undef**

  The --import_undef option makes all of the global symbol references imported. This option can be combined with the --visibility option. For example, the following option combination makes all definitions exported and all references imported:

  ```
  --import_undef --visibility=protected
  ```

  The --import_undef option takes precedence over the --visibility option.

- **--import_helper_functions**

  The compiler generates calls to functions that are defined in the run-time-support library. For example, to perform unsigned long division in user code, the compiler generates a call to __c6xabi_divul. Since there is no declaration and you do not call these functions directly, the __declspec() annotation cannot be used. This prevents you from importing such functions from the run-time-support library that is built as a dynamic library. To address this issue, the compiler supports the --import_helper_functions option. When specified on the compiler command line, for each run-time-support function that is called by the compiler, that function symbol will be imported.

8.12.6.2.4 Import/Export Using Linker Options

To import or export a symbol when the source code cannot be updated with a __declspec() annotation, the following linker options can be used:

- **--import=***symbol*

  This option adds *symbol* to the dynamic symbol table as an imported reference. At link-time, the static linker searches through any object libraries that are included in the link to make sure that a definition of symbol is available.

  If a definition of symbol is included in the current link, then the --import option is ignored with a warning.

- **--export=***symbol*

  This option adds *symbol* to the dynamic symbol table as an exported definition. At link-time, if the are any objects that contain an unresolved external reference to symbol when the object that exports symbol is encountered, then the object that contains the exported definition is included in the link.

  If the --export=*symbol* option is used on the compile of an object that does not have a definition of symbol in it, then the compiler generates an error.

The --import and --export Options

NOTE: The --import and --export options cannot be used when building a Linux executable or DSO.

Absolute Lister Description

The TMS320C6000 absolute lister is a debugging tool that accepts linked object files as input and creates .abs files as output. These .abs files can be assembled to produce a listing that shows the absolute addresses of object code. Manually, this could be a tedious process requiring many operations; however, the absolute lister utility performs these operations automatically.

NOTE: **Absolute Listing Is Not Supported for C6400+, C6740, and C6600**

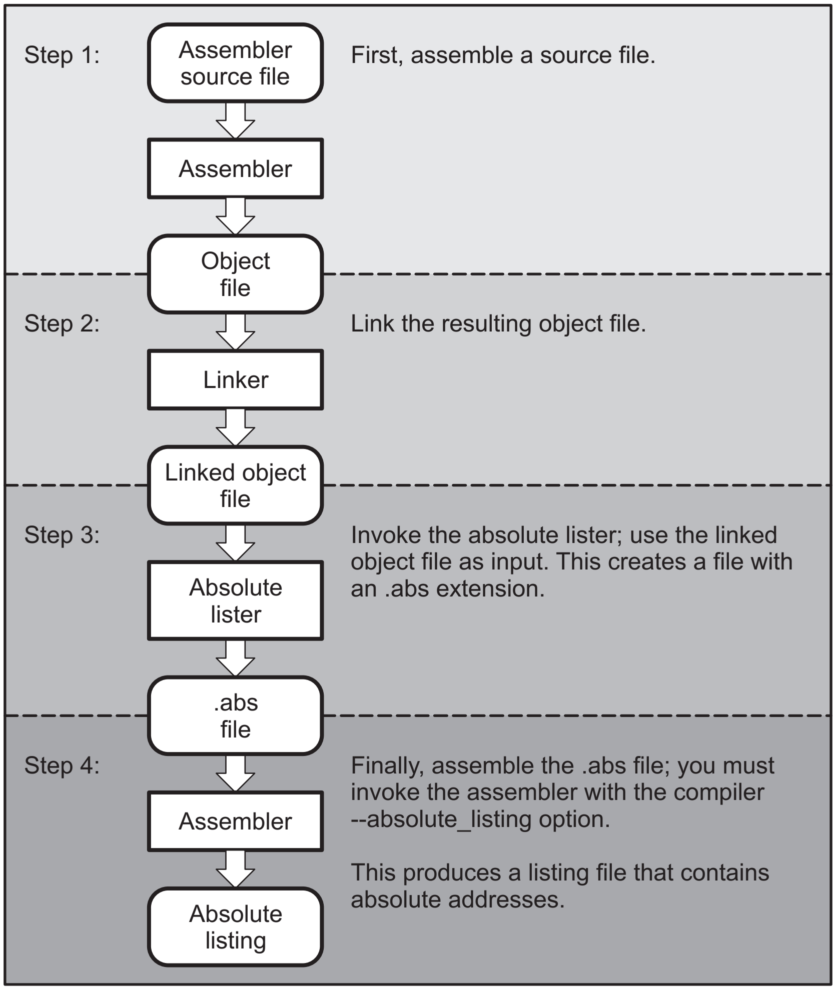
The absolute listing capability is not supported for C6400+, C6740, and C6600. You can use the disassembler (dis6x) or the --map_file linker option instead.

Topic **Page**

9.1 Producing an Absolute Listing

Figure 9-1 illustrates the steps required to produce an absolute listing.

Figure 9-1. Absolute Lister Development Flow


Step 1:
Assembler source file
First, assemble a source file.
Assembler
Object file
Step 2:
Link the resulting object file.
Linker
Linked object file
Step 3:
Invoke the absolute lister; use the linked object file as input. This creates a file with an .abs extension.
Absolute lister
.abs file
Step 4:
Finally, assemble the .abs file; you must invoke the assembler with the compiler --absolute_listing option.
Assembler
This produces a listing file that contains absolute addresses.
Absolute listing

9.2 Invoking the Absolute Lister

The syntax for invoking the absolute lister is:

abs6x [-*options*] *input file*

abs6x is the command that invokes the absolute lister.

options identifies the absolute lister 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 (-). The absolute lister options are as follows:

-e enables you to change the default naming conventions for filename extensions on assembly files, C source files, and C header files. The valid options are:

- ea [.]*asmext* for assembly files (default is .asm)
- ec [.]*cext* for C source files (default is .c)
- eh [.]*hext* for C header files (default is .h)
- ep [.]*pext* for CPP source files (default is cpp)

The . in the extensions and the space between the option and the extension are optional.

-q (quiet) suppresses the banner and all progress information.

input file names the linked object file. If you do not supply an extension, the absolute lister assumes that the input file has the default extension .out. If you do not supply an input filename when you invoke the absolute lister, the absolute lister prompts you for one.

The absolute lister produces an output file for each file that was linked. These files are named with the input filenames and an extension of .abs. Header files, however, do not generate a corresponding .abs file.

Assemble these files with the --absolute_listing assembler option as follows to create the absolute listing:

cl6x --absolute_listing *filename* **.abs**

The -e options affect both the interpretation of filenames on the command line and the names of the output files. They should always precede any filename on the command line.

The -e options are useful when the linked object file was created from C files compiled with the debugging option (--symdebug:dwarf compiler option). When the debugging option is set, the resulting linked object file contains the name of the source files used to build it. In this case, the absolute lister does not generate a corresponding .abs file for the C header files. Also, the .abs file corresponding to a C source file uses the assembly file generated from the C source file rather than the C source file itself.

For example, suppose the C source file hello.csr is compiled with the debugging option set; the debugging option generates the assembly file hello.s. The hello.csr file includes hello.hsr. Assuming the executable file created is called hello.out, the following command generates the proper .abs file:

```
abs6x -ea s -ec csr -eh hsr hello.out
```

An .abs file is not created for hello.hsr (the header file), and hello.abs includes the assembly file hello.s, not the C source file hello.csr.

9.3 Absolute Lister Example

This example uses three source files. The files module1.asm and module2.asm both include the file globals.def.

module1.asm

```
        .text
        .align  4
        .bss    array, 100
        .bss    dflag, 4
        .copy   globals.def

        MVKL    offset, A0
        MVKH    offset, A0
        LDW     *+b14(dflag), A2
        nop     4
```

module2.asm

```
        .bss    offset,2
        .copy   globals.def

        mvkl    offset,a0
        mvkh    offset,a0
        mvkl    array,a3
        mvkh    array,a3
```

globals.def

```
        .global dflag
        .global array
        .global offset
```

The following steps create absolute listings for the files **module1.asm** and **module2.asm**:

Step 1: First, assemble **module1.asm** and **module2.asm**:

```
cl6x module1
cl6x module2
```

This creates two object files called module1.obj and module2.obj.

Step 2: Next, link module1.obj and module2.obj using the following linker command file, called bttest.cmd:

```
--output_file=bttest.out
--map_file=bttest.map
module1.obj
module2.obj
MEMORY
{
        PMEM:   origin=00000000h      length=00010000h
        DMEM:   origin=80000000h      length=00010000h
}
SECTIONS
{
        .data: >DMEM
        .text: >PMEM
        .bss:  >DMEM
}
```

Invoke the linker:

```
cl6x --run_linker bttest.cmd
```

This command creates an executable object file called bttest.out; use this file as input for the absolute lister.

Step 3: Now, invoke the absolute lister:

```
abs6x bttest.out
```

This command creates two files called module1.abs and module2.abs:

module1.abs:

```
          .nolist
array     .setsym     080000000h
dflag     .setsym     080000064h
offset    .setsym     080000068h
.data     .setsym     080000000h
___data__  .setsym     080000000h
edata     .setsym     080000000h
___edata__  .setsym     080000000h
.text     .setsym     000000000h
___text__  .setsym     000000000h
etext     .setsym     000000040h
___etext__  .setsym     000000040h
.bss      .setsym     080000000h
___bss__  .setsym     080000000h
end       .setsym     08000006ah
___end__  .setsym     08000006ah
$bss      .setsym     080000000h
          .setsect    ".text",000000020h
          .setsect    ".data",080000000h
          .setsect    ".bss",080000000h
          .list
          .text
          .copy       "module1.asm"
```

module2.abs:

```
          .nolist
array     .setsym     080000000h
dflag     .setsym     080000064h
offset    .setsym     080000068h
.data     .setsym     080000000h
___data__  .setsym     080000000h
edata     .setsym     080000000h
___edata__  .setsym     080000000h
.text     .setsym     000000000h
___text__  .setsym     000000000h
etext     .setsym     000000040h
___etext__  .setsym     000000040h
.bss      .setsym     080000000h
___bss__  .setsym     080000000h
end       .setsym     08000006ah
___end__  .setsym     08000006ah
$bss      .setsym     080000000h
          .setsect    ".text",000000000h
          .setsect    ".data",080000000h
          .setsect    ".bss",080000068h
          .list
          .text
          .copy       "module2.asm"
```

These files contain the following information that the assembler needs for Step 4:

- They contain .setsym directives, which equate values to global symbols. Both files contain global equates for the symbol *dflag*. The symbol dflag was defined in the file globals.def, which was included in module1.asm and module2.asm.
- They contain .setsect directives, which define the absolute addresses for sections.
- They contain .copy directives, which defines the assembly language source file to include.

The .setsym and .setsect directives are useful only for creating absolute listings, not normal assembly.

Step 4: Finally, assemble the .abs files created by the absolute lister (remember that you must use the --absolute_listing option when you invoke the assembler):

```
cl6x --absolute_listing module1.abs
cl6x --absolute_listing module2.abs
```

This command sequence creates two listing files called module1.lst and module2.lst; no object code is produced. These listing files are similar to normal listing files; however, the addresses shown are absolute addresses.

The absolute listing files created are module1.lst (see Example 9-1) and module2.lst (see Example 9-2).

Example 9-1. module1.lst

```
module1.abs                                                          PAGE    1
      22 00000020                     .text
      23                              .copy       "module1.asm"
 A     1 00000020                   .text
 A     2                            .align  4
 A     3 80000000                   .bss    array, 100
 A     4 80000064                   .bss    dflag, 4
 A     5                            .copy   globals.def
 B     1                            .global dflag
 B     2                            .global array
 B     3                            .global offset
 A     6
 A     7 00000020 00003428!         MVKL            offset, A0
 A     8 00000024 00400068!         MVKH            offset, A0
 A     9 00000028 0100196C-         LDW             *+b14(dflag), A2
 A    10 0000002c 00006000          nop             4
 No Errors, No Warnings
```

Example 9-2. module2.lst

```
module2.abs                                                          PAGE    1
      22 00000000                     .text
      23                              .copy       "module2.asm"
 A     1 80000068                   .bss offset,2
 A     2                            .copy globals.def
 B     1                            .global dflag
 B     2                            .global array
 B     3                            .global offset
 A     3
 A     4 00000000 00003428-         mvkl    offset,a0
 A     5 00000004 00400068-         mvkh    offset,a0
 A     6 00000008 01800028!         mvkl    array,a3
 A     7 0000000c 01C00068!         mvkh    array,a3
 No Errors, No Warnings
```

Cross-Reference Lister Description

The TMS320C6000 cross-reference lister is a debugging tool. This utility accepts linked object files as input and produces a cross-reference listing as output. This listing shows symbols, their definitions, and their references in the linked source files.

Cross-Reference Listing Not Supported for C6400+, C6740, and C6600

NOTE: The cross-reference listing capability is not supported for C6400+, C6740, and C6600. You can use the disassembler, the -m linker option or the object file utility (ofd6x) to obtain similar information.

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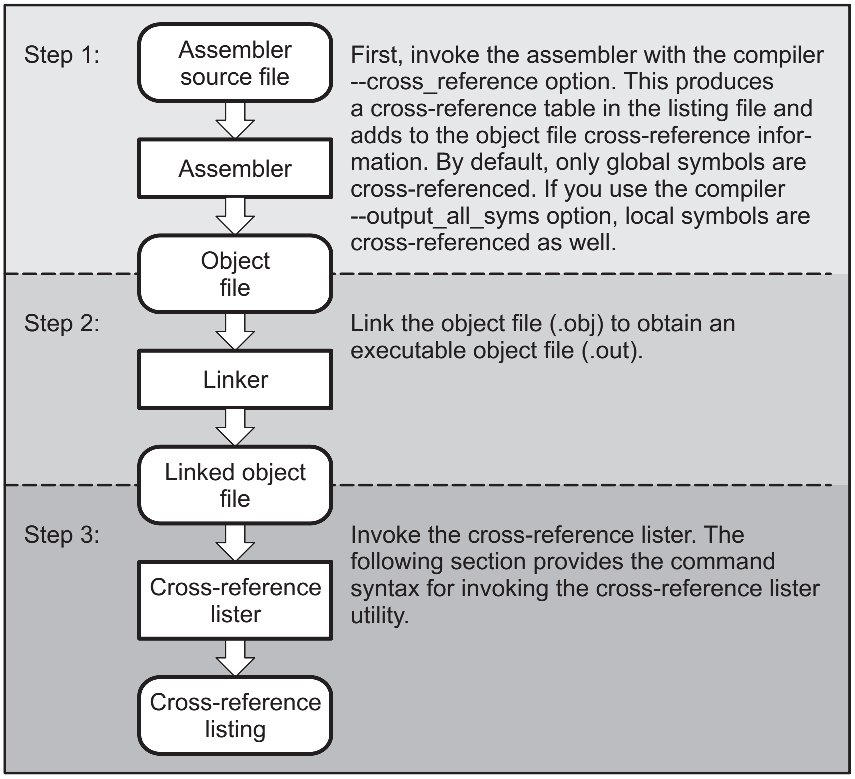
10.1 Producing a Cross-Reference Listing

Figure 10-1 illustrates the steps required to produce a cross-reference listing.

Figure 10-1. The Cross-Reference Lister Development Flow


Step 1:
Assembler source file
Assembler
Object file
First, invoke the assembler with the compiler --cross_reference option. This produces a cross-reference table in the listing file and adds to the object file cross-reference information. By default, only global symbols are cross-referenced. If you use the compiler --output_all_syms option, local symbols are cross-referenced as well.
Step 2:
Linker
Linked object file
Link the object file (.obj) to obtain an executable object file (.out).
Step 3:
Cross-reference lister
Cross-reference listing
Invoke the cross-reference lister. The following section provides the command syntax for invoking the cross-reference lister utility.

10.2 Invoking the Cross-Reference Lister

To use the cross-reference utility, the file must be assembled with the correct options and then linked into an executable file. Assemble the assembly language files with the --cross_reference option. This option creates a cross-reference listing and adds cross-reference information to the object file. By default, the assembler cross-references only global symbols, but if the assembler is invoked with the --output_all_syms option, local symbols are also added. Link the object files to obtain an executable file.

To invoke the cross-reference lister, enter the following:

xref6x [*options*] [*input filename* [*output filename*]]

xref6x is the command that invokes the cross-reference utility.

options identifies the cross-reference lister options you want to use. Options are not case sensitive and can appear anywhere on the command line following the command.

- **-l** (lowercase L) specifies the number of lines per page for the output file. The format of the -l option is -l*num*, where num is a decimal constant. For example, -l30 sets the number of lines per page in the output file to 30. The space between the option and the decimal constant is optional. The default is 60 lines per page.
- **-q** suppresses the banner and all progress information (run quiet).

input filename is a linked object file. If you omit the input filename, the utility prompts for a filename.

output filename is the name of the cross-reference listing file. If you omit the output filename, the default filename is the input filename with an .xrf extension.

10.3 Cross-Reference Listing Example

Example 10-1 is an example of cross-reference listing.

Example 10-1. Cross-Reference Listing

```
================================================================================
Symbol: _SETUP
Filename         RTYP    AsmVal     LnkVal      DefLn   RefLn    RefLn    RefLn
________         ____   ________   ________    ______  _______  _______  _______
demo.asm         EDEF  '00000018   00000018       18      13       20
================================================================================
Symbol: _fill_tab
Filename         RTYP    AsmVal     LnkVal      DefLn   RefLn    RefLn    RefLn
________         ____   ________   ________    ______  _______  _______  _______
ctrl.asm         EDEF  '00000000   00000040       10       5
================================================================================
Symbol: _x42
Filename         RTYP    AsmVal     LnkVal      DefLn   RefLn    RefLn    RefLn
________         ____   ________   ________    ______  _______  _______  _______
demo.asm         EDEF  '00000000   00000000        7       4       18
================================================================================
Symbol: gvar
Filename         RTYP    AsmVal     LnkVal      DefLn   RefLn    RefLn    RefLn
________         ____   ________   ________    ______  _______  _______  _______
tables.asm       EDEF  "00000000   08000000       11      10
================================================================================
```

The terms defined below appear in the preceding cross-reference listing:

Symbol Name of the symbol listed

Filename Name of the file where the symbol appears

RTYP The symbol's reference type in this file. The possible reference types are:

- **STAT** The symbol is defined in this file and is not declared as global.
- **EDEF** The symbol is defined in this file and is declared as global.
- **EREF** The symbol is not defined in this file but is referenced as global.
- **UNDF** The symbol is not defined in this file and is not declared as global.

AsmVal This hexadecimal number is the value assigned to the symbol at assembly time. A value may also be preceded by a character that describes the symbol's attributes. Table 10-1 lists these characters and names.

LnkVal This hexadecimal number is the value assigned to the symbol after linking.

DefLn The statement number where the symbol is defined.

RefLn The line number where the symbol is referenced. If the line number is followed by an asterisk (*), then that reference can modify the contents of the object. A blank in this column indicates that the symbol was never used.

Table 10-1. Symbol Attributes in Cross-Reference Listing

Character	Meaning
'	Symbol defined in a .text section
"	Symbol defined in a .data section
+	Symbol defined in a .sect section
-	Symbol defined in a .bss or .usect section

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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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11.1 Invoking the Object File Display Utility

The object file display utility, *ofd6x*, 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:

ofd6x [*options*] *input filename* [*input filename*]

ofd6x is the command that invokes the object file display utility.

input filename names the object file (.obj), executable file (.out), or archive library (.lib) source file. The filename must contain an extension.

options 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.

- **--dwarf_display**=*attributes* controls the DWARF display filter settings by specifying a comma-delimited list of *attributes*. 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 ofd6x --dwarf_display=help.

- **-g** appends DWARF debug information to program output.
- **-h** displays help
- **-o**=*filename* sends program output to *filename* rather than to the screen.
- **--obj_display** *attributes* controls the object file display filter settings by specifying a comma-delimited list of *attributes*. 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", ofd6x 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 ofd6x --obj_display=help.

- **-v** prints verbose text output.
- **-x** 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.

11.2 Invoking the Disassembler

The disassembler, *dis6x*, 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:

```
dis6x [options] input filename[.] [output filename]
```

dis6x 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:

-a	disables the printing of branch destination addresses along with labels.
-b	displays data as bytes instead of words.
-c	dumps the object file information.
-d	disables display of data sections.
-h	shows the current help screen.
-i	disassembles .data sections as instructions.
-l	disassembles data sections as text.
-n	suppresses FP header information for C64x+ Compact FPs.
-o##	disassembles single word ## or 0x## then exits.
-q	(quiet mode) suppresses the banner and all progress information.
-qq	(super quiet mode) suppresses all headers.
-s	suppresses printing of address and data words.
-t	suppresses the display of text sections in the listing.
-v	displays family of the target.

input filename[.*ext*] is the name of the input file. If the optional extension is not specified, the file is searched for in this order:

1. *infile*
2. *infile*.out, an executable file
3. *infile*.obj, 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.

11.3 Invoking the Name Utility

The name utility, *nm6x*, 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:

```
nm6x [-options] [input filenames]
```

nm6x is the command that invokes the name utility.

input filename is an object file (.obj), executable file (.out), or archive library (.lib).

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:

- **-a** prints all symbols.
- **-c** also prints C_NULL symbols for a COFF object module.
- **-d** also prints debug symbols for a COFF object module.
- **-f** prepends file name to each symbol.
- **-g** prints only global symbols.
- **-h** shows the current help screen.
- **-l** produces a detailed listing of the symbol information.
- **-n** sorts symbols numerically rather than alphabetically.
- **-o** *file* outputs to the given file.
- **-p** causes the name utility to not sort any symbols.
- **-q** (quiet mode) suppresses the banner and all progress information.
- **-r** sorts symbols in reverse order.
- **-t** also prints tag information symbols for a COFF object module.
- **-u** only prints undefined symbols.

11.4 Invoking the Strip Utility

The strip utility, *strip6x*, removes symbol table and debugging information from object and executable files.

To invoke the strip utility, enter the following:

```
strip6x [-p] input filename [input filename]
```

strip6x is the command that invokes the strip utility.

input filename is an object file (.obj) or an executable file (.out).

options 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:

- **-o** *filename* writes the stripped output to filename.
- **-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.

When the strip utility is invoked without the -o option, the input object files are replaced with the stripped version.

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Hex Conversion Utility Description

The TMS320C6000 assembler and linker create object files which are in binary formats that encourage modular programming and provide powerful and flexible methods for managing code segments and target system memory.

Most EPROM programmers do not accept object files as input. The hex conversion utility converts an object file into one of several standard ASCII hexadecimal formats, suitable for loading into an EPROM programmer. The utility is also useful in other applications requiring hexadecimal conversion of an object file (for example, when using debuggers and loaders).

The hex conversion utility can produce these output file formats:

- ASCII-Hex, supporting 32-bit addresses
- Extended Tektronix (Tektronix)
- Intel MCS-86 (Intel)
- Motorola Exorciser (Motorola-S), supporting 16-bit addresses
- Texas Instruments SDSMAC (TI-Tagged), supporting 16-bit addresses
- Texas Instruments TI-TXT format, supporting 16-bit addresses

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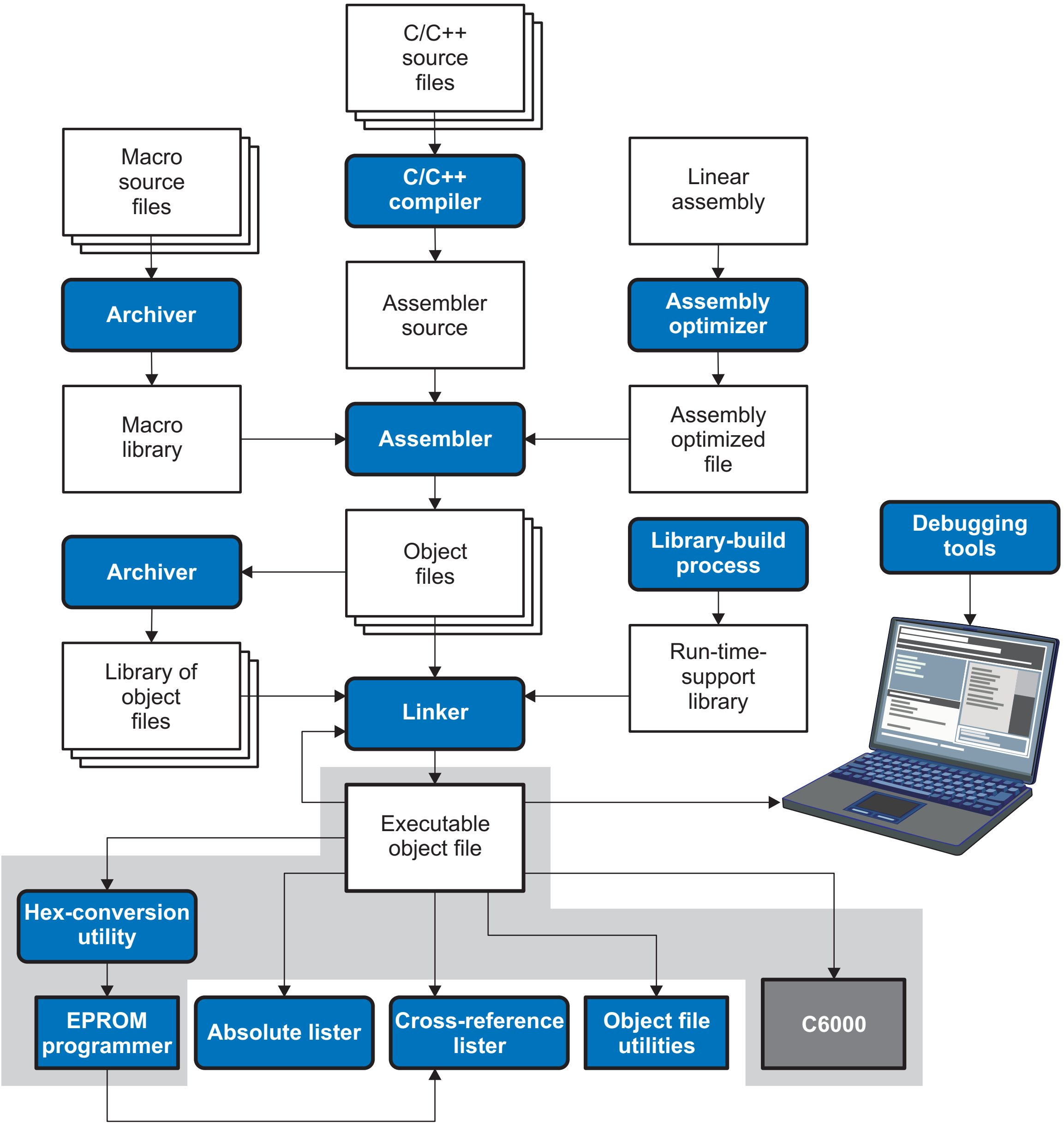
12.1 The Hex Conversion Utility's Role in the Software Development Flow

Figure 12-1 highlights the role of the hex conversion utility in the software development process.

Figure 12-1. The Hex Conversion Utility in the TMS320C6000 Software Development Flow



12.2 Invoking the Hex Conversion Utility

There are two basic methods for invoking the hex conversion utility:

- **Specify the options and filenames on the command line.** The following example converts the file firmware.out into TI-Tagged format, producing two output files, firm.lsb and firm.msb.

  ```
  hex6x -t firmware -o firm.lsb -o firm.msb
  ```

  ```
  hex6x --ti_tagged firmware --outfile=firm.lsb --outfile=firm.msb
  ```

- **Specify the options and filenames in a command file.** You can create a file that stores command line options and filenames for invoking the hex conversion utility. The following example invokes the utility using a command file called hexutil.cmd:

  ```
  hex6x hexutil.cmd
  ```

In addition to regular command line information, you can use the hex conversion utility ROMS and SECTIONS directives in a command file.

12.2.1 Invoking the Hex Conversion Utility From the Command Line

To invoke the hex conversion utility, enter:

hex6x [*options*] *filename*

hex6x is the command that invokes the hex conversion utility.

options supplies additional information that controls the hex conversion process. You can use options on the command line or in a command file. Table 12-1 lists the basic options.

- All options are preceded by a hyphen and are not case sensitive.
- Several options have an additional parameter that must be separated from the option by at least one space.
- Options with multi-character names must be spelled exactly as shown in this document; no abbreviations are allowed.
- Options are not affected by the order in which they are used. The exception to this rule is the --quiet option, which must be used before any other options.

filename names an object file or a command file (for more information, see Section 12.2.2).

Table 12-1. Basic Hex Conversion Utility Options

Option	Alias	Description	See
		General Options	
--byte	-byte	Number output locations by bytes rather than by target addressing	--
--entry_point=*addr*	-e	Specify the entry point address or global symbol at which to begin execution after boot loading	Section 12.10.3.3
--exclude={*fname*(*sname*) | *sname*}	-exclude	If the filename (*fname*) is omitted, all sections matching *sname* will be excluded.	Section 12.7
--fill=*value*	-fill	Fill holes with *value*	Section 12.9.2
--help	-options, -h	Display the syntax for invoking the utility and list available options. If the option is followed by another option or phrase, detailed information about that option or phrase is displayed. For example, to see information about options associated with generating a boot table, use --help boot.	Section 12.2.2
--image	-image	Select image mode	Section 12.9.1
--linkerfill	-linkerfill	Include linker fill sections in images	--
--map=*filename*	-map	Generate a map file	Section 12.4.2
--memwidth=*value*	-memwidth	Define the system memory word width (default 32 bits)	Section 12.3.2
--olength=*value*	-olength	Specify maximum number of data items per line of output	--

Table 12-1. Basic Hex Conversion Utility Options (continued)

Option	Alias	Description	See
--order={L|M}	-order	Specify data ordering (endianness)	Section 12.3.4
--outfile=*filename*	-o	Specify an output filename	Section 12.8
--quiet	-q	Run quietly (when used, it must appear *before* other options)	Section 12.2.2
--romwidth=*value*	-romwidth	Specify the ROM device width (default depends on format used)	Section 12.3.3
--zero	-zero, -z	Reset the address origin to 0 in image mode	Section 12.9.3
Diagnostic Options			
--diag_error=*id*		Categorizes the diagnostic identified by *id* as an error	Section 12.12
--diag_remark=*id*		Categorizes the diagnostic identified by *id* as a remark	Section 12.12
--diag_suppress=*id*		Suppresses the diagnostic identified by *id*	Section 12.12
--diag_warning=*id*		Categorizes the diagnostic identified by *id* as a warning	Section 12.12
--display_error_number		Displays a diagnostic's identifiers along with its text	Section 12.12
--issue_remarks		Issues remarks (nonserious warnings)	Section 12.12
--no_warnings		Suppresses warning diagnostics (errors are still issued)	Section 12.12
--set_error_limit=*count*		Sets the error limit to *count*. The linker abandons linking after this number of errors. (The default is 100.)	Section 12.12
Boot Table Options			
--boot	-boot	Convert all initialized sections into bootable form (use instead of a SECTIONS directive)	Section 12.10.3.1
--bootorg=*addr*	-bootorg	Specify origin address of the boot loader table	Section 12.10.3.1
--bootsection=*section*	-bootsection	Specify which section contains the boot routine and where it should be placed	Section 12.10.3.1
Output Options			
--ascii	-a	Select ASCII-Hex	Section 12.13.1
--intel	-i	Select Intel	Section 12.13.2
--motorola=1	-m1	Select Motorola-S1	Section 12.13.3
--motorola=2	-m2	Select Motorola-S2	Section 12.13.3
--motorola=3	-m3	Select Motorola-S3 (default -m option)	Section 12.13.3
--tektronix	-x	Select Tektronix (default format when no output option is specified)	Section 12.13.4
--ti_tagged	-t	Select TI-Tagged	Section 12.13.5
--ti_txt		Select TI-Txt	Section 12.13.6
Load Image Options			
--load_image		Select load image	Section 12.6
--section_name_prefix=*string*		Specify the section name prefix for load image object files	Section 12.6

12.2.2 Invoking the Hex Conversion Utility With a Command File

A command file is useful if you plan to invoke the utility more than once with the same input files and options. It is also useful if you want to use the ROMS and SECTIONS hex conversion utility directives to customize the conversion process.

Command files are ASCII files that contain one or more of the following:

- **Options and filenames.** These are specified in a command file in exactly the same manner as on the command line.
- **ROMS directive.** The ROMS directive defines the physical memory configuration of your system as a list of address-range parameters. (See Section 12.4.)
- **SECTIONS directive.** The hex conversion utility SECTIONS directive specifies which sections from the object file are selected. (See Section 12.5.)
- **Comments.** You can add comments to your command file by using the /* and */ delimiters. For example:

```
/*   This is a comment.   */
```

To invoke the utility and use the options you defined in a command file, enter:

hex6x *command_filename*

You can also specify other options and files on the command line. For example, you could invoke the utility by using both a command file and command line options:

```
hex6x firmware.cmd --map=firmware.mxp
```

The order in which these options and filenames appear is not important. The utility reads all input from the command line and all information from the command file before starting the conversion process. However, if you are using the -q option, *it must appear as the first option on the command line or in a command file.*

The **--help** option displays the syntax for invoking the compiler and lists available options. If the --help option is followed by another option or phrase, detailed information about the option or phrase is displayed. For example, to see information about options associated with generating a boot table use --help boot.

The **--quiet** option suppresses the hex conversion utility's normal banner and progress information.

- Assume that a command file named firmware.cmd contains these lines:

```
firmware.out         /* input file  */
--ti_tagged          /* TI-Tagged   */
--outfile=firm.lsb   /* output file */
--outfile=firm.msb   /* output file */
```

You can invoke the hex conversion utility by entering:

```
hex6x firmware.cmd
```

- This example shows how to convert a file called appl.out into eight hex files in Intel format. Each output file is one byte wide and 4K bytes long.

```
appl.out          /* input file   */
--intel           /* Intel format */
--map=appl.mxp    /* map file     */

ROMS
{
   ROW1: origin=0x00000000 len=0x4000 romwidth=8
         files={ appl.u0 appl.u1 app1.u2 appl.u3 }
   ROW2: origin=0x00004000 len=0x4000 romwidth=8
         files={ app1.u4 appl.u5 appl.u6 appl.u7 }
}

SECTIONS
{   .text, .data, .cinit, .sect1, .vectors, .const:
}
```

12.3 Understanding Memory Widths

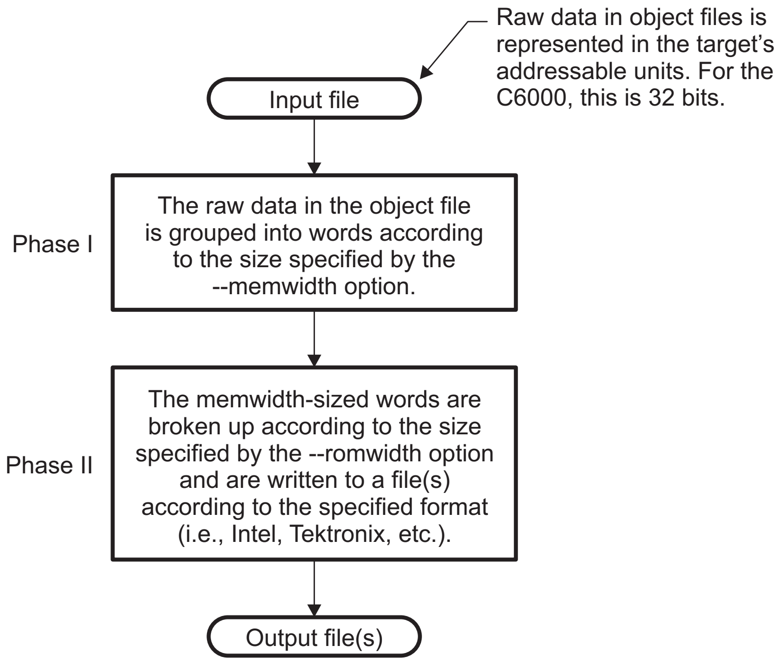
The hex conversion utility makes your memory architecture more flexible by allowing you to specify memory and ROM widths. To use the hex conversion utility, you must understand how the utility treats word widths. Three widths are important in the conversion process:

- Target width
- Memory width
- ROM width

The terms target word, memory word, and ROM word refer to a word of such a width.

Figure 12-2 illustrates the separate and distinct phases of the hex conversion utility's process flow.

Figure 12-2. Hex Conversion Utility Process Flow


Raw data in object files is represented in the target's addressable units. For the C6000, this is 32 bits.
Input file
Phase I
The raw data in the object file is grouped into words according to the size specified by the --memwidth option.
Phase II
The memwidth-sized words are broken up according to the size specified by the --romwidth option and are written to a file(s) according to the specified format (i.e., Intel, Tektronix, etc.).
Output file(s)

12.3.1 Target Width

Target width is the unit size (in bits) of the target processor's word. The unit size corresponds to the data bus size on the target processor. The width is fixed for each target and cannot be changed. The TMS320C6000 targets have a width of 32 bits.

12.3.2 Specifying the Memory Width

Memory width is the physical width (in bits) of the memory system. Usually, the memory system is physically the same width as the target processor width: a 32-bit processor has a 32-bit memory architecture. However, some applications require target words to be broken into multiple, consecutive, and narrower memory words.

By default, the hex conversion utility sets memory width to the target width (in this case, 32 bits).

You can change the memory width (except for TI-TXT format) by:

- Using the **--memwidth** option. This changes the memory width value for the entire file.
- Setting the **memwidth** parameter of the ROMS directive. This changes the memory width value for the address range specified in the ROMS directive and overrides the --memwidth option for that range. See Section 12.4.

For both methods, use a value that is a power of 2 greater than or equal to 8.

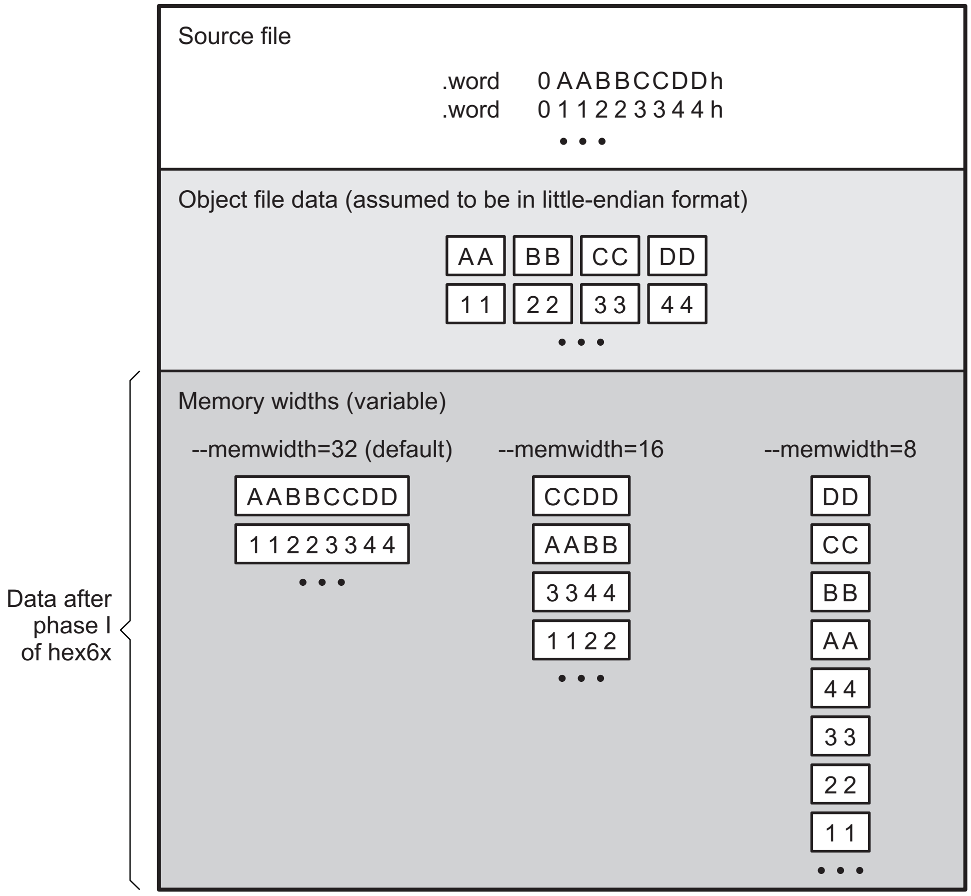
You should change the memory width default value of 32 only when you need to break single target words into consecutive, narrower memory words.

TI-TXT Format is 8 Bits Wide

NOTE: You cannot change the memory width of the TI-TXT format. The TI-TXT hex format supports an 8-bit memory width only.

Figure 12-3 demonstrates how the memory width is related to object file data.

Figure 12-3. Object File Data and Memory Widths



12.3.3 Partitioning Data Into Output Files

ROM width specifies the physical width (in bits) of each ROM device and corresponding output file (usually one byte or eight bits). The ROM width determines how the hex conversion utility partitions the data into output files. After the object file data is mapped to the memory words, the memory words are broken into one or more output files. The number of output files is determined by the following formulas:

- If memory width ≥ ROM width:

  number of files = memory width ÷ ROM width
- If memory width < ROM width:

  number of files = 1

For example, for a memory width of 32, you could specify a ROM width value of 32 and get a single output file containing 32-bit words. Or you can use a ROM width value of 16 to get two files, each containing 16 bits of each word.

The default ROM width that the hex conversion utility uses depends on the output format:

- All hex formats except TI-Tagged are configured as lists of 8-bit bytes; the default ROM width for these formats is 8 bits.
- TI-Tagged is a 16-bit format; the default ROM width for TI-Tagged is 16 bits.

The TI-Tagged Format is 16 Bits Wide

NOTE: You cannot change the ROM width of the TI-Tagged format. The TI-Tagged format supports a 16-bit ROM width only.

TI-TXT Format is 8 Bits Wide

NOTE: You cannot change the ROM width of the TI-TXT format. The TI-TXT hex format supports only an 8-bit ROM width.

You can change ROM width (except for TI-Tagged and TI-TXT formats) by:

- Using the **--romwidth** option. This option changes the ROM width value for the entire object file.
- Setting the **romwidth** parameter of the ROMS directive. This parameter changes the ROM width value for a specific ROM address range and overrides the --romwidth option for that range. See Section 12.4.

For both methods, use a value that is a power of 2 greater than or equal to 8.

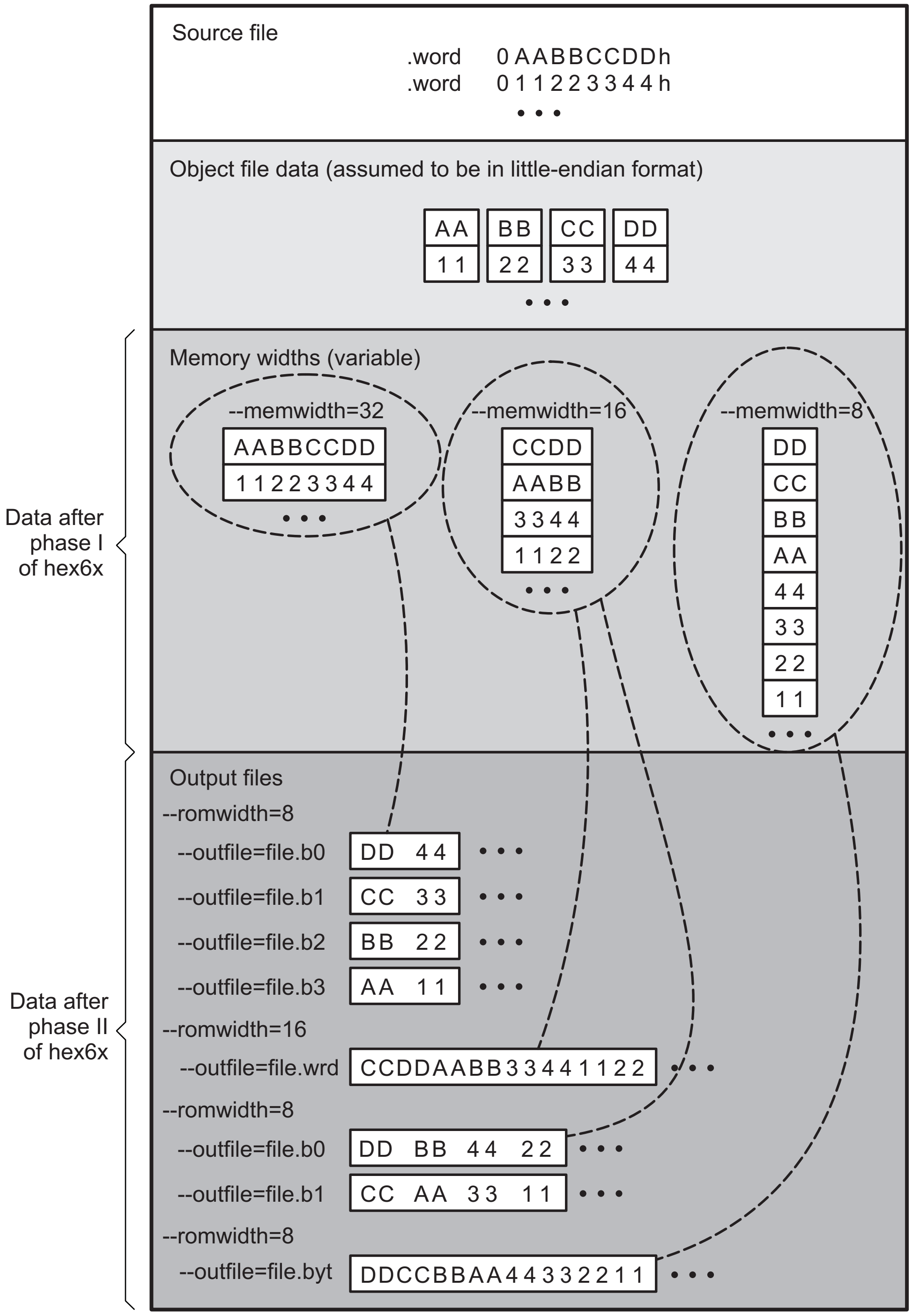
If you select a ROM width that is wider than the natural size of the output format (16 bits for TI-Tagged or 8 bits for all others), the utility simply writes multibyte fields into the file.

Figure 12-4 illustrates how the object file data, memory, and ROM widths are related to one another.

Memory width and ROM width are used only for grouping the object file data; they do not represent values. Thus, the byte ordering of the object file data is maintained throughout the conversion process. To refer to the partitions within a memory word, the bits of the memory word are always numbered from right to left as follows:

```
          --memwidth=32
 _________________________________
| A A B B C C D D 1 1 2 2 3 3 4 4 |
 ---------------------------------
 31                              0
```

Figure 12-4. Data, Memory, and ROM Widths


Source file
.word 0AABBCCDDh
.word 011223344h
• • •
Object file data (assumed to be in little-endian format)
AA BB CC DD
11 22 33 44
• • •
Memory widths (variable)
--memwidth=32
AABBCCDD
11223344
• • •
--memwidth=16
CCDD
AABB
3344
1122
• • •
--memwidth=8
DD
CC
BB
AA
44
33
22
11
• • •
Data after phase I of hex6x
Output files
--romwidth=8
--outfile=file.b0 DD 44 • • •
--outfile=file.b1 CC 33 • • •
--outfile=file.b2 BB 22 • • •
--outfile=file.b3 AA 11 • • •
--romwidth=16
--outfile=file.wrd CCDDAABB33441122 • • •
--romwidth=8
--outfile=file.b0 DD BB 44 22 • • •
--outfile=file.b1 CC AA 33 11 • • •
--romwidth=8
--outfile=file.byt DDCCBBAA44332211 • • •
Data after phase II of hex6x

12.3.4 Specifying Word Order for Output Words

There are two ways to split a wide word into consecutive memory locations in the same hex conversion utility output file:

- **--order=M** specifies **big-endian** ordering, in which the most significant part of the wide word occupies the first of the consecutive locations.
- **--order=L** specifies **little-endian** ordering, in which the least significant part of the wide word occupies the first of the consecutive locations.

By default, the utility uses little-endian format. Unless your boot loader program expects big-endian format, avoid using --order=M.

NOTE: **When the -order Option Applies**

- This option applies only when you use a memory width with a value of 32 (--memwidth32). Otherwise, the hex utility does not have access to the entire 32-bit word and cannot perform the byte swapping necessary to change the endianness; --order is ignored.
- This option does not affect the way memory words are split into output files. Think of the files as a set: the set contains a least significant file and a most significant file, but there is no ordering over the set. When you list filenames for a set of files, you always list the least significant first, regardless of the --order option.

12.4 The ROMS Directive

The ROMS directive specifies the physical memory configuration of your system as a list of address-range parameters.

Each address range produces one set of files containing the hex conversion utility output data that corresponds to that address range. Each file can be used to program one single ROM device.

The ROMS directive is similar to the MEMORY directive of the TMS320C6000 linker: both define the memory map of the target address space. Each line entry in the ROMS directive defines a specific address range. The general syntax is:

ROMS
{

romname **:** [**origin**=*value*,] [**length**=*value*,] [**romwidth**=*value*,]
[**memwidth**=*value*,] [**fill**=*value*]
[**files**=**{** *filename* $_1$, *filename* $_2$, ...**}**]

romname **:** [**origin**=*value*,] [**length**=*value*,] [**romwidth**=*value*,]
[**memwidth**=*value*,] [**fill**=*value*]
[**files**=**{** *filename* $_1$, *filename* $_2$, ...**}**]

...

}

ROMS begins the directive definition.

romname identifies a memory range. The name of the memory range can be one to eight characters in length. The name has no significance to the program; it simply identifies the range, except when the output is for a load image in which case it denotes the section name. (Duplicate memory range names are allowed.)

origin specifies the starting address of a memory range. It can be entered as origin, org, or o. The associated value must be a decimal, octal, or hexadecimal constant. If you omit the origin value, the origin defaults to 0. The following table summarizes the notation you can use to specify a decimal, octal, or hexadecimal constant:

Constant	Notation	Example
Hexadecimal	0x prefix or h suffix	0x77 or 077h
Octal	0 prefix	077
Decimal	No prefix or suffix	77

length specifies the length of a memory range as the physical length of the ROM device. It can be entered as length, len, or l. The value must be a decimal, octal, or hexadecimal constant. If you omit the length value, it defaults to the length of the entire address space.

romwidth specifies the physical ROM width of the range in bits (see Section 12.3.3). Any value you specify here overrides the --romwidth option. The value must be a decimal, octal, or hexadecimal constant that is a power of 2 greater than or equal to 8.

memwidth specifies the memory width of the range in bits (see Section 12.3.2). Any value you specify here overrides the --memwidth option. The value must be a decimal, octal, or hexadecimal constant that is a power of 2 greater than or equal to 8. *When using the memwidth parameter, you must also specify the paddr parameter for each section in the SECTIONS directive.* (See Section 12.5.)

fill specifies a fill value to use for the range. In image mode, the hex conversion utility uses this value to fill any holes between sections in a range. A hole is an area between the input sections that comprises an output section that contains no actual code or data. The fill value must be a decimal, octal, or hexadecimal constant with a width equal to the target width. Any value you specify here overrides the --fill option. When using fill, you must also use the --image command line option. (See Section 12.9.2.)

files identifies the names of the output files that correspond to this range. Enclose the list of names in curly braces and order them from *least significant* to *most significant* output file, where the bits of the memory word are numbered from right to left. The number of file names must equal the number of output files that the range generates. To calculate the number of output files, see Section 12.3.3. The utility warns you if you list too many or too few filenames.

Unless you are using the --image option, all of the parameters that define a range are optional; the commas and equal signs are also optional. A range with no origin or length defines the entire address space. In image mode, an origin and length are required for all ranges.

Ranges must not overlap and must be listed in order of ascending address.

12.4.1 When to Use the ROMS Directive

If you do not use a ROMS directive, the utility defines a single default range that includes the entire address space. This is equivalent to a ROMS directive with a single range without origin or length.

Use the ROMS directive when you want to:

- **Program large amounts of data into fixed-size ROMs**. When you specify memory ranges corresponding to the length of your ROMs, the utility automatically breaks the output into blocks that fit into the ROMs.
- **Restrict output to certain segments**. You can also use the ROMS directive to restrict the conversion to a certain segment or segments of the target address space. The utility does not convert the data that falls outside of the ranges defined by the ROMS directive. Sections can span range boundaries; the utility splits them at the boundary into multiple ranges. If a section falls completely outside any of the ranges you define, the utility does not convert that section and issues no messages or warnings. Thus, you can exclude sections without listing them by name with the SECTIONS directive. However, if a section falls partially in a range and partially in unconfigured memory, the utility issues a warning and converts only the part within the range.

- **Use image mode.** When you use the --image option, you must use a ROMS directive. Each range is filled completely so that each output file in a range contains data for the whole range. Holes before, between, or after sections are filled with the fill value from the ROMS directive, with the value specified with the --fill option, or with the default value of 0.

12.4.2 An Example of the ROMS Directive

The ROMS directive in Example 12-1 shows how 16K bytes of 16-bit memory could be partitioned for two 8K-byte 8-bit EPROMs. Figure 12-5 illustrates the input and output files.

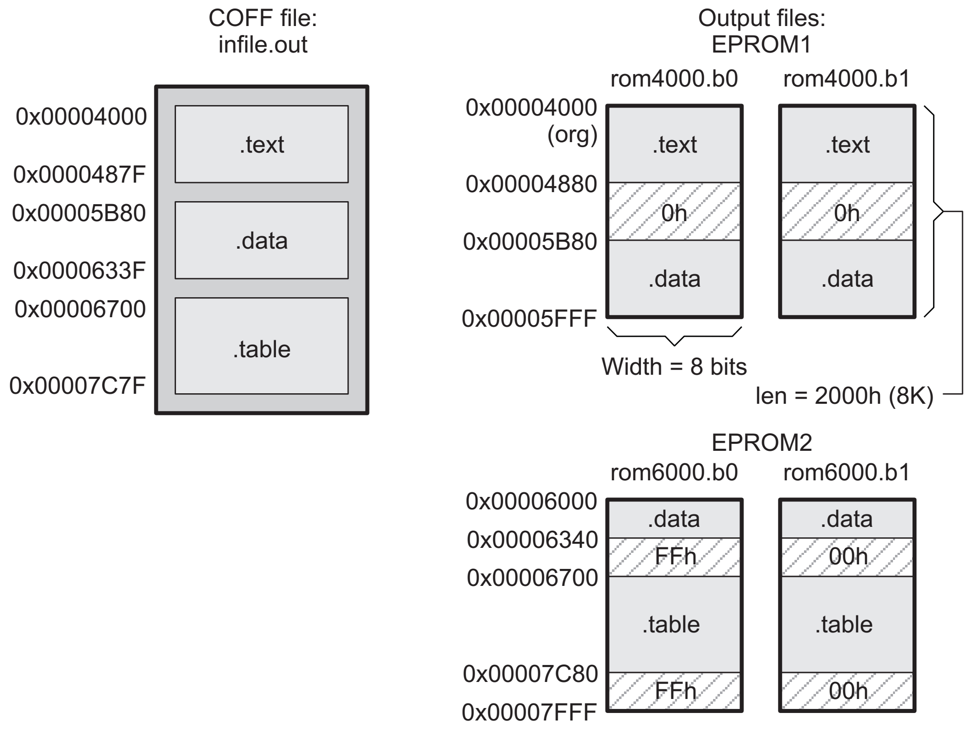
Example 12-1. A ROMS Directive Example

```
infile.out
--image
--memwidth 16

ROMS
{
   EPROM1: org = 0x00004000, len = 0x2000, romwidth = 8
           files = { rom4000.b0, rom4000.b1}

   EPROM2: org = 0x00006000, len = 0x2000, romwidth = 8,
           fill = 0xFF00FF00,
           files = { rom6000.b0, rom6000.b1}
}
```

Figure 12-5. The infile.out File Partitioned Into Four Output Files



The map file (specified with the --map option) is advantageous when you use the ROMS directive with multiple ranges. The map file shows each range, its parameters, names of associated output files, and a list of contents (section names and fill values) broken down by address. Example 12-2 is a segment of the map file resulting from the example in Example 12-1.

Example 12-2. Map File Output From Example 12-1 Showing Memory Ranges

```
-----------------------------------------------------
00004000..00005fff Page=0 Width=8 "EPROM1"
-----------------------------------------------------
   OUTPUT FILES:   rom4000.b0   [b0..b7]
                   rom4000.b1   [b8..b15]
   CONTENTS: 00004000..0000487f .text
             00004880..00005b7f FILL = 00000000
             00005b80..00005fff .data
-----------------------------------------------------
00006000..00007fff Page=0 Width=8 "EPROM2"
-----------------------------------------------------
   OUTPUT FILES:   rom6000.b0   [b0..b7]
                   rom6000.b1   [b8..b15]
   CONTENTS: 00006000..0000633f .data
             00006340..000066ff FILL = ff00ff00
             00006700..00007c7f .table
             00007c80..00007fff FILL = ff00ff00
```

EPROM1 defines the address range from 0x00004000 through 0x00005FFF with the following sections:

This section ...	Has this range ...
.text	0x00004000 through 0x0000487F
.data	0x00005B80 through 0x00005FFF

The rest of the range is filled with 0h (the default fill value), converted into two output files:

- rom4000.b0 contains bits 0 through 7
- rom4000.b1 contains bits 8 through 15

EPROM2 defines the address range from 0x00006000 through 0x00007FFF with the following sections:

This section ...	Has this range ...
.data	0x00006000 through 0x0000633F
.table	0x00006700 through 0x00007C7F

The rest of the range is filled with 0xFF00FF00 (from the specified fill value). The data from this range is converted into two output files:

- rom6000.b0 contains bits 0 through 7
- rom6000.b1 contains bits 8 through 15

12.5 The SECTIONS Directive

You can convert specific sections of the object file by name with the hex conversion utility SECTIONS directive. You can also specify those sections that you want to locate in ROM at a different address than the *load* address specified in the linker command file. If you:

- Use a SECTIONS directive, the utility converts only the sections that you list in the directive and ignores all other sections in the object file.
- Do not use a SECTIONS directive, the utility converts all initialized sections that fall within the configured memory.

Uninitialized sections are *never* converted, whether or not you specify them in a SECTIONS directive.

Sections Generated by the C/C++ Compiler

NOTE: The TMS320C6000 C/C++ compiler automatically generates these sections:

- **Initialized sections:** .text, .const, .cinit, and .switch
- **Uninitialized sections:** .bss, .stack, and .sysmem

Use the SECTIONS directive in a command file. (See Section 12.2.2.) The general syntax for the SECTIONS directive is:

SECTIONS
{
    oname(*sname*)[**:**] [**paddr**=*value*]
    oname(*sname*)[**:**] [**paddr**= **boot**]
    oname(*sname*)[**:**] [**boot**]
    ...
}

SECTIONS begins the directive definition.

oname identifies the object filename the section is located within. The filename is optional when only a single input file is given, but required otherwise.

sname identifies a section in the input file. If you specify a section that does not exist, the utility issues a warning and ignores the name.

paddr=*value* specifies the physical ROM address at which this section should be located. This value overrides the section load address given by the linker. This value must be a decimal, octal, or hexadecimal constant. It can also be the word **boot** (to indicate a boot table section for use with a boot loader). *If your file contains multiple sections, and if one section uses a paddr parameter, then all sections must use a paddr parameter.*

boot configures a section for loading by a boot loader. This is equivalent to using **paddr=boot**. Boot sections have a physical address determined by the location of the boot table. The origin of the boot table is specified with the --bootorg option.

For more similarity with the linker's SECTIONS directive, you can use colons after the section names (in place of the equal sign on the boot keyboard). For example, the following statements are equivalent:

```
SECTIONS { .text: .data: boot }
```

```
SECTIONS { .text: .data = boot }
```

In the example below, the object file contains six initialized sections: .text, .data, .const, .vectors, .coeff, and .tables. Suppose you want only .text and .data to be converted. Use a SECTIONS directive to specify this:

```
SECTIONS { .text: .data: }
```

To configure both of these sections for boot loading, add the boot keyword:

```
SECTIONS { .text = boot .data = boot }
```

Using the --boot Option and the SECTIONS Directive

NOTE: When you use the SECTIONS directive with the boot table (--boot) option, the --boot option is ignored. You must explicitly specify any boot sections in the SECTIONS directive. For more information about --boot and other command line options associated with boot tables, see Section 12.2 and Section 12.10.

12.6 The Load Image Format (--load_image Option)

A load image is an object file which contains the load addresses and initialized sections of one or more executable files. The load image object file can be used for ROM masking or can be relinked in a subsequent link step.

12.6.1 Load Image Section Formation

The load image sections are formed by collecting the initialized sections from the input executables. There are two ways the load image sections are formed:

- **Using the ROMS Directive**. Each memory range that is given in the ROMS directive denotes a load image section. The romname is the section name. The origin and length parameters are required. The memwidth, romwidth, and files parameters are invalid and are ignored.

  When using the ROMS directive and the load_image option, the --image option is required.
- **Default Load Image Section Formation**. If no ROMS directive is given, the load image sections are formed by combining contiguous initialized sections in the input executables. Sections with gaps smaller than the target word size are considered contiguous.

  The default section names are image_1, image_2, ... If another prefix is desired, the --section_name_prefix=*prefix* option can be used.

12.6.2 Load Image Characteristics

All load image sections are initialized data sections. In the absence of a ROMS directive, the load/run address of the load image section is the load address of the first input section in the load image section. If the SECTIONS directive was used and a different load address was given using the paddr parameter, this address will be used.

The load image format always creates a single load image object file. The format of the load image object file is determined based on the input files. The file is not marked executable and does not contain an entry point. The default load image object file name is ti_load_image.obj. This can be changed using the --outfile option. Only one --outfile option is valid when creating a load image, all other occurrences are ignored.

Concerning Load Image Format

NOTE: These options are invalid when creating a load image:

- --memwidth
- --romwidth
- --order
- --zero
- --byte

If a boot table is being created, either using the SECTIONS directive or the --boot option, the ROMS directive must be used.

12.7 Excluding a Specified Section

The --exclude *section_name* option can be used to inform the hex utility to ignore the specified section. If a SECTIONS directive is used, it overrides the --exclude option.

For example, if a SECTIONS directive containing the section name *mysect* is used and an --exclude *mysect* is specified, the SECTIONS directive takes precedence and *mysect* is not excluded.

The --exclude option has a limited wildcard capability. The * character can be placed at the beginning or end of the name specifier to indicate a suffix or prefix, respectively. For example, --exclude sect* disqualifies all sections that begin with the characters sect.

If you specify the --exclude option on the command line with the * wildcard, use quotes around the section name and wildcard. For example, --exclude"sect*". Using quotes prevents the * from being interpreted by the hex conversion utility. If --exclude is in a command file, do not use quotes.

If multiple object files are given, the object file in which the section to be excluded can be given in the form oname(sname). If the object filename is not provided, all sections matching the section name are excluded. Wildcards cannot be used for the filename, but can appear within the parentheses.

12.8 Assigning Output Filenames

When the hex conversion utility translates your object file into a data format, it partitions the data into one or more output files. When multiple files are formed by splitting memory words into ROM words, *filenames are always assigned in order from least to most significant*, where bits in the memory words are numbered from right to left. This is true, regardless of target or endian ordering.

The hex conversion utility follows this sequence when assigning output filenames:

1. **It looks for the ROMS directive.** If a file is associated with a range in the ROMS directive and you have included a list of files (files = {. . .}) on that range, the utility takes the filename from the list.

   For example, assume that the target data is 32-bit words being converted to four files, each eight bits wide. To name the output files using the ROMS directive, you could specify:

   ```
   ROMS
   {
      RANGE1: romwidth=8, files={ xyz.b0 xyz.b1 xyz.b2 xyz.b3 }
   }
   ```

   The utility creates the output files by writing the least significant bits to xyz.b0 and the most significant bits to xyz.b3.

2. **It looks for the --outfile options.** You can specify names for the output files by using the --outfile option. If no filenames are listed in the ROMS directive and you use --outfile options, the utility takes the filename from the list of --outfile options. The following line has the same effect as the example above using the ROMS directive:

   ```
   --outfile=xyz.b0 --outfile=xyz.b1 --outfile=xyz.b2 --outfile=xyz.b3
   ```

   If both the ROMS directive and --outfile options are used together, the ROMS directive overrides the --outfile options.

3. **It assigns a default filename.** If you specify no filenames or fewer names than output files, the utility assigns a default filename. A default filename consists of the base name from the input file plus a 2- to 3-character extension. The extension has three parts:

   (a) A format character, based on the output format (see Section 12.13):

a	for ASCII-Hex
i	for Intel
m	for Motorola-S
t	for TI-Tagged
x	for Tektronix

   (b) The range number in the ROMS directive. Ranges are numbered starting with 0. If there is no ROMS directive, or only one range, the utility omits this character.

   (c) The file number in the set of files for the range, starting with 0 for the least significant file.

   For example, assume a.out is for a 32-bit target processor and you are creating Intel format output. With no output filenames specified, the utility produces four output files named a.i0, a.i1, a.i2, a.i3.

   If you include the following ROMS directive when you invoke the hex conversion utility, you would have eight output files:

```
ROMS
{
   range1: o = 0x00001000 l = 0x1000
   range2: o = 0x00002000 l = 0x1000
}
```

These output files ...	Contain data in these locations ...
a.i00, a.i01, a.i02, a.i03	0x00001000 through 0x00001FFF
a.i10, a.i11, a.i12, a.i13	0x00002000 through 0x00002FFF

12.9 Image Mode and the --fill Option

This section points out the advantages of operating in image mode and describes how to produce output files with a precise, continuous image of a target memory range.

12.9.1 Generating a Memory Image

With the --image option, the utility generates a memory image by completely filling all of the mapped ranges specified in the ROMS directive.

An object file consists of blocks of memory (sections) with assigned memory locations. Typically, all sections are not adjacent: there are holes between sections in the address space for which there is no data. When such a file is converted *without* the use of image mode, the hex conversion utility bridges these holes by using the address records in the output file to skip ahead to the start of the next section. In other words, there may be discontinuities in the output file addresses. Some EPROM programmers do not support address discontinuities.

In image mode, there are no discontinuities. Each output file contains a continuous stream of data that corresponds exactly to an address range in target memory. Any holes before, between, or after sections are filled with a fill value that you supply.

An output file converted by using image mode still has address records, because many of the hexadecimal formats require an address on each line. However, in image mode, these addresses are always contiguous.

Defining the Ranges of Target Memory

NOTE: If you use image mode, you must also use a ROMS directive. In image mode, each output file corresponds directly to a range of target memory. You must define the ranges. If you do not supply the ranges of target memory, the utility tries to build a memory image of the entire target processor address space. This is potentially a huge amount of output data. To prevent this situation, the utility requires you to explicitly restrict the address space with the ROMS directive.

12.9.2 Specifying a Fill Value

The --fill option specifies a value for filling the holes between sections. The fill value must be specified as an integer constant following the --fill option. The width of the constant is assumed to be that of a word on the target processor. For example, specifying --fill=0x0FFF. The constant value is not sign extended.

The hex conversion utility uses a default fill value of 0 if you do not specify a value with the fill option. *The --fill option is valid only when you use --image*; otherwise, it is ignored.

12.9.3 Steps to Follow in Using Image Mode

Step 1: Define the ranges of target memory with a ROMS directive. See Section 12.4.

Step 2: Invoke the hex conversion utility with the --image option. You can optionally use the --zero option to reset the address origin to 0 for each output file. If you do not specify a fill value with the ROMS directive and you want a value other than the default of 0, use the --fill option.

12.10 Building a Table for an On-Chip Boot Loader

On the C621x, C671x, and C64x devices**,** a ROM boot process is supported where the EDMA copies 1K bytes from the beginning of CE1 (EMIFB CE1 on C64x) to address 0, using default ROM timings. After the transfer, the CPU begins executing from address 0. In this mode a second level boot load typically occurs, due to the limited amount of memory copied at boot.

The hex conversion utility supports the second level boot loader by automatically building the boot table.

See Section 3.1.2 for a general discussion of bootstrap loading.

12.10.1 Description of the Boot Table

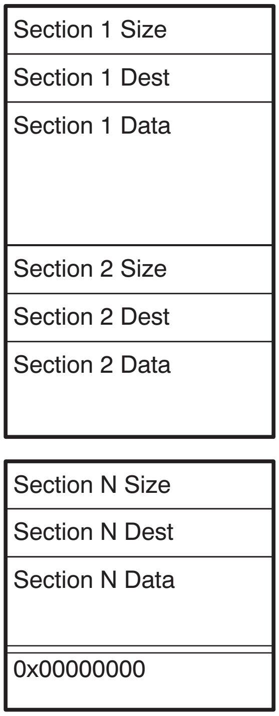
The input for a boot loader is the boot table. The boot table contains records that instruct the boot loader to copy blocks of data contained in the table to specified destination addresses. The hex conversion utility automatically builds the boot table for the boot loader. Using the utility, you specify the sections you want the boot loader to initialize through the boot table, the table location, and the name of the section containing the boot loader and where it should be located. The hex conversion utility builds a complete image of the table and converts it into hexadecimal in the output files. Then, you can burn the table into ROM.

12.10.2 The Boot Table Format

The boot table format is simple. There is a header record containing a 4-byte field that indicates where the boot loader should branch after it has completed copying data. After the header, each section that is to be included in the boot table will have the following:

1. 4-byte field containing the size of the section
2. 4-byte field containing the destination address for the copy
3. The actual data to be copied

Multiple sections can be entered; a termination block containing a 4-byte field of zeros follows the last section.



Section 1 Size
Section 1 Dest
Section 1 Data
Section 2 Size
Section 2 Dest
Section 2 Data

Section N Size
Section N Dest
Section N Data
0x00000000

12.10.3 How to Build the Boot Table

Table 12-2 summarizes the hex conversion utility options available for the boot loader.

Table 12-2. Boot-Loader Options

Option	Description
--boot	Convert all sections into bootable form (use instead of a SECTIONS directive).
--bootorg=*value*	Specify the source address of the boot loader table.
--bootsection=*section value*	Specify the *section* name containing the boot loader routine. The *value* argument tells the hex utility where to place the boot loader routine.
--entry_point=*value*	Specify the entry point at which to begin execution after boot loading. The *value* can be an address or a global symbol.

12.10.3.1 Building the Boot Table

To build the boot table, follow these steps:

Step 1: **Link the file.** Each block of the boot table data corresponds to an initialized section in the object file. Uninitialized sections are not converted by the hex conversion utility (see Section 12.5). You must link into your application a boot loader routine that will read the boot table and perform the copy operations. It should be linked to its eventual run-time address.

When you select a section for placement in a boot-loader table, the hex conversion utility places the section's *load address* in the destination address field for the block in the boot table. The section content is then treated as raw data for that block. *The hex conversion utility does not use the section run address.* When linking, you need not worry about the ROM address or the construction of the boot table; the hex conversion utility handles this.

Step 2: **Identify the bootable sections.** You can use the --boot option to tell the hex conversion utility to configure all sections for boot loading. Or, you can use a SECTIONS directive to select specific sections to be configured (see Section 12.5). If you use a SECTIONS directive, the --boot option is ignored.

Step 3: **Set the ROM address of the boot table.** Use the --bootorg option to set the source address of the complete table. For example, if you are using the C6711 and booting from memory location 0x90000400, specify --bootorg=0x90000400. The address field for the boot table in the hex conversion utility output file will then start at 0x90000400.

If you do not use the --bootorg option at all, the utility places the table at the origin of the first memory range in a ROMS directive. If you do not use a ROMS directive, the table will start at the first section load address.

Step 4: **Set boot-loader-specific options.** Set entry point. If --entry_point is not used to set the entry point, then it will default to the entry point indicated in the object file.

Step 5: **Describe the boot routine.** If the boot option is used, then you should use the --bootsection option to indicate to the hex utility which section contains the boot routine. This option will prevent the boot routine from being in the boot table. The --bootsection option also indicates to the hex utility where the routine should be placed in ROM. For the C621x, C671x, and C64x devices, this address would typically be the beginning of CE1 (EMIFB CE1 on C64x). This option is ignored if --boot is not used.

When the SECTIONS directive is used to explicitly identify which sections should exits in the boot table, use the PADDR section option to indicate where the boot routine section will exist.

Step 6: **Describe your system memory configuration.** See Section 12.3 and Section 12.4.

12.10.3.2 Leaving Room for the Boot Table

The complete boot table is similar to a single section containing all of the header records and data for the boot loader. The address of this section is the boot table origin. As part of the normal conversion process, the hex conversion utility converts the boot table to hexadecimal format and maps it into the output files like any other section.

Be sure to leave room in your system memory for the boot table, especially when you are using the ROMS directive. The boot table cannot overlap other nonboot sections or unconfigured memory. Usually, this is not a problem; typically, a portion of memory in your system is reserved for the boot table. Simply configure this memory as one or more ranges in the ROMS directive, and use the --bootorg option to specify the starting address.

12.10.3.3 Setting the Entry Point for the Boot Table

After the boot routine finishes copying data, it branches to the entry point defined the object file. By using the --entry_point option with the hex conversion utility, you can set the entry point to a different address.

For example, if you want your program to start running at address 0x0123 after loading, specify --entry_point=0x0123 on the command line or in a command file. You can determine the --entry_point address by looking at the map file that the linker generates.

Valid Entry Points

NOTE: The value can be a constant, or it can be a symbol that is externally defined (for example, with a .global) in the assembly source.

12.10.4 Using the C6000 Boot Loader

This subsection explains how to use the hex conversion utility with the boot loader for C6000 devices through sample hex utility command files. Example 12-3 uses the SECTIONS directive to specify exactly which sections will be placed in the boot table.

Example 12-3. Sample Command File for Booting From a C6000 EPROM

```
abc.out                               /* input file                */
--ascii                               /* ascii format              */
--image                               /* create complete ROM image */
--zero                                /* reset address origin to 0 */
--memwidth 8                          /* 8-bit memory              */
--map=abchex.map                      /* create a hex map file     */
--bootorg=0x90000400                  /* external memory boot      */

ROMS
{
   FLASH: org=0x90000000, len=0x20000, romwidth=8, files={abc.hex}
}

SECTIONS
{
      .boot_load:   PADDR=0x90000000
      .text:        BOOT
      .cinit:       BOOT
      .const:       BOOT
}
```

Example 12-4 does not explicitly name the boot sections with the SECTIONS directive. Instead, it uses the --boot option to indicate that all initialized sections should be placed in the boot table. It also uses the --bootsection option to distinguish the section containing the boot routine.

Example 12-4. Alternative Sample Command File for Booting From a C6000 EPROM

```
abc.out                             /* input file                */
--ascii                             /* ascii format              */
--image                             /* create complete Rom image */
--zero                              /* reset address origin to 0 */
--memwidth=8                        /* 8-bit memory              */
--map=abchex.map                    /* create a hex map file     */
--boot                              /* create boot table         */
--bootorg=0x90000400                /* external memory boot      */
--bootsection=.boot_load 0x90000000  /* give boot section & addr  */

ROMS
{
  FLASH: org=0x90000000, len=0x20000, romwidth=8, files={abc.hex}
}
```

12.11 Controlling the ROM Device Address

The hex conversion utility output address field corresponds to the ROM device address. The EPROM programmer burns the data into the location specified by the hex conversion utility output file address field. The hex conversion utility offers some mechanisms to control the starting address in ROM of each section. However, many EPROM programmers offer direct control of the location in ROM in which the data is burned.

Depending on whether or not you are using the boot loader, the hex conversion utility output file controlling mechanisms are different.

Non-boot loader mode. The address field of the hex conversion utility output file is controlled by the following mechanisms listed from low to high priority:

1. **The linker command file.** By default, the address field of the hex conversion utility output file is the load address (as given in the linker command file).
2. **The paddr parameter of the SECTIONS directive.** When the paddr parameter is specified for a section, the hex conversion utility bypasses the section load address and places the section in the address specified by paddr.
3. **The --zero option.** When you use the --zero option, the utility resets the address origin to 0 for each output file. Since each file starts at 0 and counts upward, any address records represent offsets from the beginning of the file (the address within the ROM) rather than actual target addresses of the data.

   You must use the --zero option in conjunction with the --image option to force the starting address in each output file to be zero. If you specify the --zero option without the --image option, the utility issues a warning and ignores the --zero option.

Boot-Loader Mode. When the boot loader is used, the hex conversion utility places the different sections that are in the boot table into consecutive memory locations. Each section becomes a boot table block whose destination address is equal to the linker-assigned section load address.

In a boot table, the address field of the hex conversion utility output file is not related to the section load addresses assigned by the linker. The address fields of the boot table are simply offsets to the beginning of the table. The section load addresses assigned by the linker will be encoded into the boot table along with the size of the section and the data contained within the section. These addresses will be used to store the data into memory during the boot load process.

The beginning of the boot table defaults to the linked load address of the first bootable section in the input file, unless you use one of the following mechanisms, listed here from low to high priority. Higher priority mechanisms override the values set by low priority options in an overlapping range.

1. **The ROM origin specified in the ROMS directive.** The hex conversion utility places the boot table at the origin of the first memory range in a ROMS directive.
2. **The --bootorg option.** The hex conversion utility places the boot table at the address specified by the --bootorg option if you select boot loading from memory.

12.12 Control Hex Conversion Utility Diagnostics

The hex conversion utility uses certain C/C++ compiler options to control hex-converter-generated diagnostics.

--diag_error=*id* Categorizes the diagnostic identified by *id* as an error. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_error=*id* to recategorize the diagnostic as an error. You can only alter the severity of discretionary diagnostics.

--diag_remark=*id* Categorizes the diagnostic identified by *id* as a remark. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_remark=*id* to recategorize the diagnostic as a remark. You can only alter the severity of discretionary diagnostics.

--diag_suppress=*id* Suppresses the diagnostic identified by *id*. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_suppress=*id* to suppress the diagnostic. You can only suppress discretionary diagnostics.

--diag_warning=*id* Categorizes the diagnostic identified by *id* as a warning. To determine the numeric identifier of a diagnostic message, use the --display_error_number option first in a separate link. Then use --diag_warning=*id* to recategorize the diagnostic as a warning. You can only alter the severity of discretionary diagnostics.

--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 (--diag_suppress, --diag_error, --diag_remark, and --diag_warning). 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 -D; otherwise, no suffix is present. See the *TMS320C6000 Optimizing Compiler User's Guide* for more information on understanding diagnostic messages.

--issue_remarks Issues remarks (nonserious warnings), which are suppressed by default.

--no_warnings Suppresses warning diagnostics (errors are still issued).

--set_error_limit=*count* Sets the error limit to *count*, which can be any decimal value. The linker abandons linking after this number of errors. (The default is 100.)

--verbose_diagnostics Provides verbose diagnostics that display the original source with line-wrap and indicate the position of the error in the source line

12.13 Description of the Object Formats

The hex conversion utility has options that identify each format. Table 12-3 specifies the format options. They are described in the following sections.

- You need to use only one of these options on the command line. If you use more than one option, the last one you list overrides the others.
- The default format is Tektronix (--tektronix option).

Table 12-3. Options for Specifying Hex Conversion Formats

Option	Alias	Format	Address Bits	Default Width
--ascii	-a	ASCII-Hex	16	8
--intel	-i	Intel	32	8
--motorola=1	-m1	Motorola-S1	16	8
--motorola=2	-m2	Motorola-S2	24	8
--motorola=3	-m3	Motorola-S3	32	8
--ti-tagged	-t	TI-Tagged	16	16
--ti_txt		TI_TXT	8	8
--tektronix	-x	Tektronix	32	8

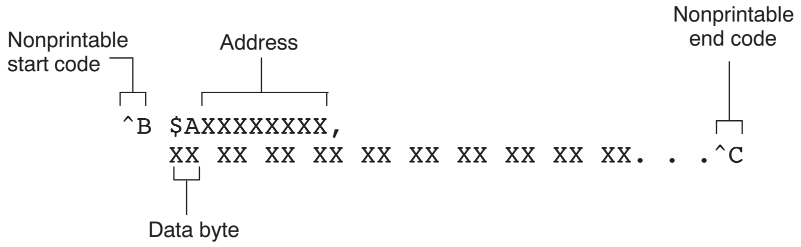
Address bits determine how many bits of the address information the format supports. Formats with 16-bit addresses support addresses up to 64K only. The utility truncates target addresses to fit in the number of available bits.

The **default width** determines the default output width of the format. You can change the default width by using the --romwidth option or by using the romwidth parameter in the ROMS directive. You cannot change the default width of the TI-Tagged format, which supports a 16-bit width only.

12.13.1 ASCII-Hex Object Format (--ascii Option)

The ASCII-Hex object format supports 32-bit addresses. The format consists of a byte stream with bytes separated by spaces. Figure 12-6 illustrates the ASCII-Hex format.

Figure 12-6. ASCII-Hex Object Format



```
^B $AXXXXXXXX,
   XX XX XX XX XX XX XX XX XX XX. . .^C
```

The file begins with an ASCII STX character (ctrl-B, 02h) and ends with an ASCII ETX character (ctrl-C, 03h). Address records are indicated with $AXXXXXXX, in which XXXXXXXX is a 8-digit (16-bit) hexadecimal address. The address records are present only in the following situations:

- When discontinuities occur
- When the byte stream does not begin at address 0

You can avoid all discontinuities and any address records by using the --image and --zero options. This creates output that is simply a list of byte values.

12.13.2 Intel MCS-86 Object Format (--intel Option)

The Intel object format supports 16-bit addresses and 32-bit extended addresses. Intel format consists of a 9-character (4-field) prefix (which defines the start of record, byte count, load address, and record type), the data, and a 2-character checksum suffix.

The 9-character prefix represents three record types:

Record Type	Description
00	Data record
01	End-of-file record
04	Extended linear address record

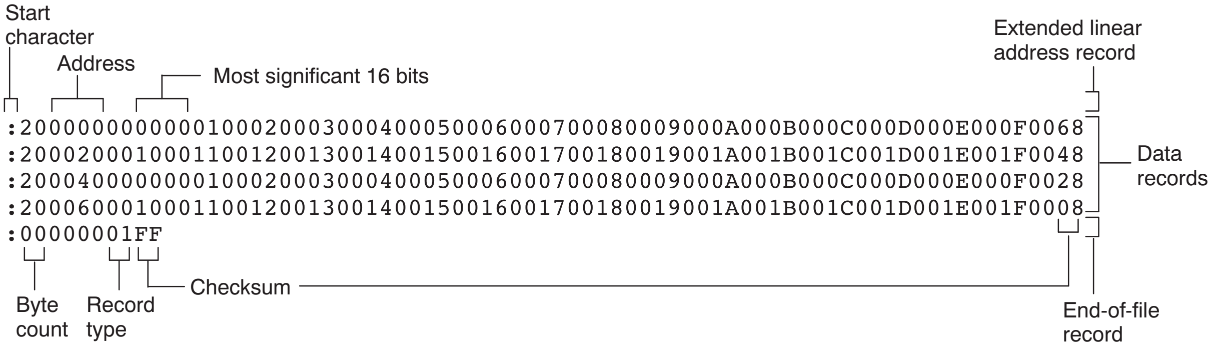
Record type00, the data record, begins with a colon (:) and is followed by the byte count, the address of the first data byte, the record type (00), and the checksum. The address is the least significant 16 bits of a 32-bit address; this value is concatenated with the value from the most recent 04 (extended linear address) record to create a full 32-bit address. The checksum is the 2s complement (in binary form) of the preceding bytes in the record, including byte count, address, and data bytes.

Record type 01, the end-of-file record, also begins with a colon (:), followed by the byte count, the address, the record type (01), and the checksum.

Record type 04, the extended linear address record, specifies the upper 16 address bits. It begins with a colon (:), followed by the byte count, a dummy address of 0h, the record type (04), the most significant 16 bits of the address, and the checksum. The subsequent address fields in the data records contain the least significant bytes of the address.

Figure 12-7 illustrates the Intel hexadecimal object format.

Figure 12-7. Intel Hexadecimal Object Format



```
:2000000000000100020003000400050006000700080009000A000B000C000D000E000F0068
:2000200010001100120013001400150016001700180019001A001B001C001D001E001F0048
:2000400000000100020003000400050006000700080009000A000B000C000D000E000F0028
:2000600010001100120013001400150016001700180019001A001B001C001D001E001F0008
:00000001FF
```

12.13.3 Motorola Exorciser Object Format (--motorola Option)

The Motorola S1, S2, and S3 formats support 16-bit, 24-bit, and 32-bit addresses, respectively. The formats consist of a start-of-file (header) record, data records, and an end-of-file (termination) record. Each record consists of five fields: record type, byte count, address, data, and checksum. The three record types are:

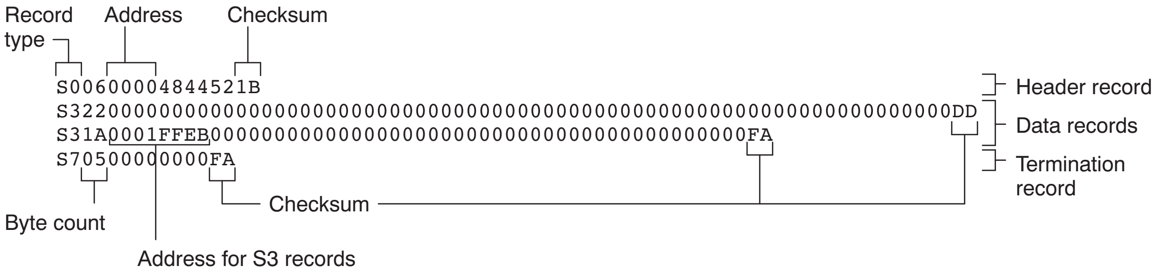
Record Type	Description
S0	Header record
S1	Code/data record for 16-bit addresses (S1 format)
S2	Code/data record for 24-bit addresses (S2 format)
S3	Code/data record for 32-bit addresses (S3 format)
S7	Termination record for 32-bit addresses (S3 format)
S8	Termination record for 24-bit addresses (S2 format)
S9	Termination record for 16-bit addresses (S1 format)

The byte count is the character pair count in the record, excluding the type and byte count itself.

The checksum is the least significant byte of the 1s complement of the sum of the values represented by the pairs of characters making up the byte count, address, and the code/data fields.

Figure 12-8 illustrates the Motorola-S object format.

Figure 12-8. Motorola-S Format



```
S00600004844521B
S322000000000000000000000000000000000000000000000000000000000000000000DD
S31A0001FFEB000000000000000000000000000000000000000000FA
S70500000000FA
```

12.13.4 Extended Tektronix Object Format (--tektronix Option)

The Tektronix object format supports 32-bit addresses and has two types of records:

Data records	contains the header field, the load address, and the object code.
Termination records	signifies the end of a module.

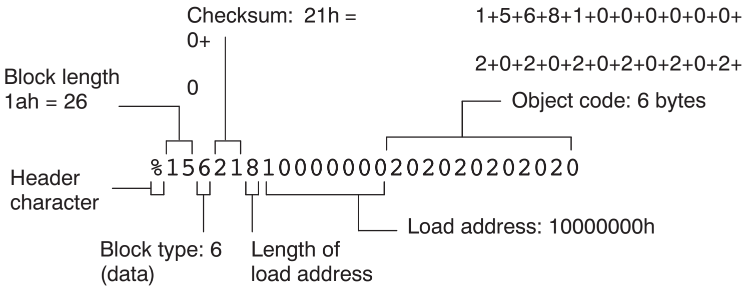
The header field in the data record contains the following information:

Item	Number of ASCII Characters	Description
%	1	Data type is Tektronix format
Block length	2	Number of characters in the record, minus the %
Block type	1	6 = data record 8 = termination record
Checksum	2	A 2-digit hex sum modulo 256 of all values in the record except the % and the checksum itself.

The load address in the data record specifies where the object code will be located. The first digit specifies the address length; this is always 8. The remaining characters of the data record contain the object code, two characters per byte.

Figure 12-9 illustrates the Tektronix object format.

Figure 12-9. Extended Tektronix Object Format



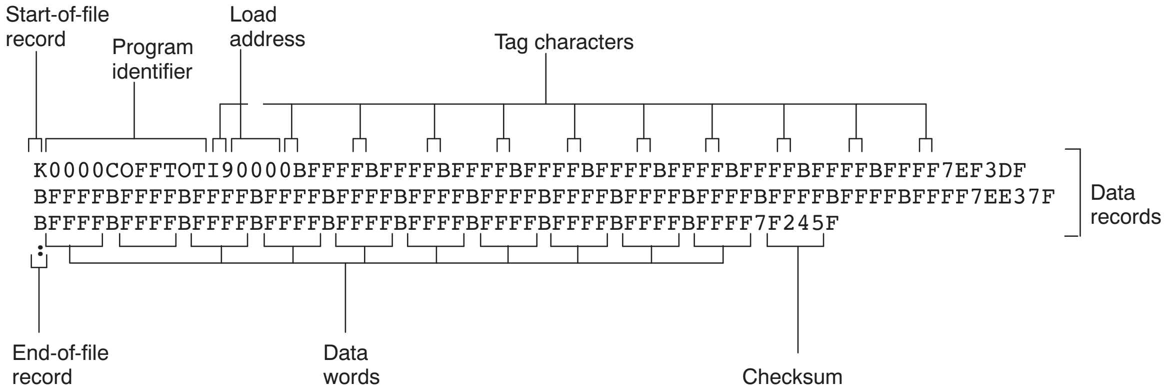
12.13.5 Texas Instruments SDSMAC (TI-Tagged) Object Format (--ti_tagged Option)

The Texas Instruments SDSMAC (TI-Tagged) object format supports 16-bit addresses, including start-of-file record, data records, and end-of-file record. Each data records consists of a series of small fields and is signified by a tag character:

Tag Character	Description
K	Followed by the program identifier
7	Followed by a checksum
8	Followed by a dummy checksum (ignored)
9	Followed by a 16-bit load address
B	Followed by a data word (four characters)
F	Identifies the end of a data record
*	Followed by a data byte (two characters)

Figure 12-10 illustrates the tag characters and fields in TI-Tagged object format.

Figure 12-10. TI-Tagged Object Format



```
K0000COFFTOTI90000BFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFF7EF3DF
BFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFF7EE37F
BFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFFBFFFF7F245F
:
```

If any data fields appear before the first address, the first field is assigned address 0000h. Address fields may be expressed but not required for any data byte. The checksum field, preceded by the tag character 7, is the 2s complement of the sum of the 8-bit ASCII values of characters, beginning with the first tag character and ending with the checksum tag character (7 or 8). The end-of-file record is a colon (:).

12.13.6 TI-TXT Hex Format (--ti_txt Option)

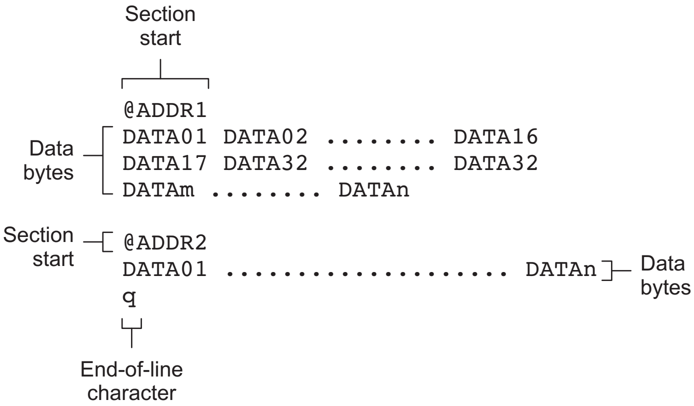
The TI-TXT hex format supports 16-bit hexadecimal data. It consists of section start addresses, data byte, and an end-of-file character. These restrictions apply:

- The number of sections is unlimited.
- Each hexadecimal start address must be even.
- Each line must have 16 data bytes, except the last line of a section.
- Data bytes are separated by a single space.
- The end-of-file termination tag q is mandatory.

The data record contains the following information:

Item	Description
@ADDR	Hexadecimal start address of a section
DATAn	Hexadecimal data byte
q	End-of-file termination character

Figure 12-11. TI-TXT Object Format



```
@ADDR1
DATA01 DATA02 ........ DATA16
DATA17 DATA32 ........ DATA32
DATAm ........ DATAn
@ADDR2
DATA01 .................... DATAn
q
```

Example 12-5. TI-TXT Object Format

```
@F000
31 40 00 03 B2 40 80 5A 20 01 D2 D3 22 00 D2 E3
21 00 3F 40 E8 FD 1F 83 FE 23 F9 3F
@FFFE
00 F0
Q
```

Sharing C/C++ Header Files With Assembly Source

You can use the .cdecls assembler directive to share C headers containing declarations and prototypes between C and assembly code. Any legal C/C++ can be used in a .cdecls block and the C/C++ declarations will cause suitable assembly to be generated automatically, allowing you to reference the C/C++ constructs in assembly code.

Topic **Page**

13.1 Overview of the .cdecls Directive

The .cdecls directive allows programmers in mixed assembly and C/C++ environments to share C headers containing declarations and prototypes between the C and assembly code. Any legal C/C++ can be used in a .cdecls block and the C/C++ declarations will cause suitable assembly to be generated automatically. This allows the programmer to reference the C/C++ constructs in assembly code — calling functions, allocating space, and accessing structure members — using the equivalent assembly mechanisms. While function and variable definitions are ignored, most common C/C++ elements are converted to assembly: enumerations, (non function-like) macros, function and variable prototypes, structures, and unions.

See the .cdecls directive description for details on the syntax of the .cdecls assembler directive.

The .cdecls directive can appear anywhere in an assembly source file, and can occur multiple times within a file. However, the C/C++ environment created by one .cdecls is **not** inherited by a later .cdecls; the C/C++ environment starts over for each .cdecls instance.

For example, the following code causes the warning to be issued:

```
.cdecls C,NOLIST
%{
    #define ASMTEST 1
%}

.cdecls C,NOLIST
%{
    #ifndef ASMTEST
        #warn "ASMTEST not defined!"  /* will be issued */
    #endif
%}
```

Therefore, a typical use of the .cdecls block is expected to be a single usage near the beginning of the assembly source file, in which all necessary C/C++ header files are included.

Use the compiler --include_path=*path* options to specify additional include file paths needed for the header files used in assembly, as you would when compiling C files.

Any C/C++ errors or warnings generated by the code of the .cdecls are emitted as they normally would for the C/C++ source code. C/C++ errors cause the directive to fail, and any resulting converted assembly is not included.

C/C++ constructs that cannot be converted, such as function-like macros or variable definitions, cause a comment to be output to the converted assembly file. For example:

```
; ASM HEADER WARNING - variable definition 'ABCD' ignored
```

The prefix ASM HEADER WARNING appears at the beginning of each message. To see the warnings, either the WARN parameter needs to be specified so the messages are displayed on STDERR, or else the LIST parameter needs to be specified so the warnings appear in the listing file, if any.

Finally, note that the converted assembly code does not appear in the same order as the original C/C++ source code and C/C++ constructs may be simplified to a normalized form during the conversion process, but this should not affect their final usage.

13.2 Notes on C/C++ Conversions

The following sections describe C and C++ conversion elements that you need to be aware of when sharing header files with assembly source.

13.2.1 Comments

Comments are consumed entirely at the C level, and do not appear in the resulting converted assembly file.

13.2.2 Conditional Compilation (#if/#else/#ifdef/etc.)

Conditional compilation is handled entirely at the C level during the conversion step. Define any necessary macros either on the command line (using the compiler --define=*name*=*value* option) or within a .cdecls block using #define. The #if, #ifdef, etc. C/C++ directives are **not** converted to assembly .if, .else, .elseif, and .endif directives.

13.2.3 Pragmas

Pragmas found in the C/C++ source code cause a warning to be generated as they are not converted. They have no other effect on the resulting assembly file. See the .cdecls topic for the WARN and NOWARN parameter discussion for where these warnings are created.

13.2.4 The #error and #warning Directives

These preprocessor directives are handled completely by the compiler during the parsing step of conversion. If one of these directives is encountered, the appropriate error or warning message is emitted. These directives are not converted to .emsg or .wmsg in the assembly output.

13.2.5 Predefined symbol _ _ASM_HEADER_ _

The C/C++ macro _ _ASM_HEADER_ _ is defined in the compiler while processing code within .cdecls. This allows you to make changes in your code, such as not compiling definitions, during the .cdecls processing.

Be Careful With the _ _ASM_HEADER_ _ Macro

NOTE: You must be very careful not to use this macro to introduce any changes in the code that could result in inconsistencies between the code processed while compiling the C/C++ source and while converting to assembly.

13.2.6 Usage Within C/C++ asm( ) Statements

The .cdecls directive is not allowed within C/C++ asm( ) statements and will cause an error to be generated.

13.2.7 The #include Directive

The C/C++ #include preprocessor directive is handled transparently by the compiler during the conversion step. Such #includes can be nested as deeply as desired as in C/C++ source. The assembly directives .include and .copy are not used or needed within a .cdecls. Use the command line --include_path option to specify additional paths to be searched for included files, as you would for C compilation.

13.2.8 Conversion of #define Macros

Only object-like macros are converted to assembly. Function-like macros have no assembly representation and so cannot be converted. Pre-defined and built-in C/C++ macros are not converted to assembly (i.e., __FILE__, __TIME__, __TI_COMPILER_VERSION__, etc.). For example, this code is converted to assembly because it is an object-like macro:

```
#define NAME Charley
```

This code is not converted to assembly because it is a function-like macro:

```
#define MAX(x,y) (x>y ? x : y)
```

Some macros, while they are converted, have no functional use in the containing assembly file. For example, the following results in the assembly substitution symbol FOREVER being set to the value while(1), although this has no useful use in assembly because while(1) is not legal assembly code.

```
#define FOREVER while(1)
```

Macro values are **not** interpreted as they are converted. For example, the following results in the assembler substitution symbol OFFSET being set to the literal string value 5+12 and **not** the value 17. This happens because the semantics of the C/C++ language require that macros are evaluated in context and not when they are parsed.

```
#define OFFSET 5+12
```

Because macros in C/C++ are evaluated in their usage context, C/C++ printf escape sequences such as \n are not converted to a single character in the converted assembly macro. See Section 13.2.11 for suggestions on how to use C/C++ macro strings.

Macros are converted using the .define directive (see Section 13.4.2), which functions similarly to the .asg assembler directive. The exception is that .define disallows redefinitions of register symbols and mnemonics to prevent the conversion from corrupting the basic assembly environment. To remove a macro from the assembly scope, .undef can be used following the .cdecls that defines it (see Section 13.4.3).

The macro functionality of # (stringize operator) is only useful within functional macros. Since functional macros are not supported by this process, # is not supported either. The concatenation operator ## is only useful in a functional context, but can be used degenerately to concatenate two strings and so it is supported in that context.

13.2.9 The #undef Directive

Symbols undefined using the #undef directive before the end of the .cdecls are not converted to assembly.

13.2.10 Enumerations

Enumeration members are converted to .enum elements in assembly. For example:

```
enum state { ACTIVE=0x10, SLEEPING=0x01, INTERRUPT=0x100, POWEROFF, LAST};
```

is converted to the following assembly code:

```
state      .enum
ACTIVE     .emember 16
SLEEPING   .emember 1
NTERRUPT   .emember 256
POWEROFF   .emember 257
LAST       .emember 258
           .endenum
```

The members are used via the pseudo-scoping created by the .enum directive.

The usage is similar to that for accessing structure members, enum_name.member.

This pseudo-scoping is used to prevent enumeration member names from corrupting other symbols within the assembly environment.

13.2.11 C Strings

Because C string escapes such as \n and \t are not converted to hex characters 0x0A and 0x09 until their use in a string constant in a C/C++ program, C macros whose values are strings cannot be represented as expected in assembly substitution symbols. For example:

```
#define MSG "\tHI\n"
```

becomes, in assembly:

```
.define """\tHI\n""",MSG ; 6 quoted characters! not 5!
```

When used in a C string context, you expect this statement to be converted to 5 characters (tab, H, I, newline, NULL), but the .string assembler directive does not know how to perform the C escape conversions.

You can use the .cstring directive to cause the escape sequences and NULL termination to be properly handled as they would in C/C++. Using the above symbol MSG with a .cstring directive results in 5 characters of memory being allocated, the same characters as would result if used in a C/C++ strong context. (See Section 13.4.7 for the .cstring directive syntax.)

13.2.12 C/C++ Built-In Functions

The C/C++ built-in functions, such as sizeof( ), are not translated to their assembly counterparts, if any, if they are used in macros. Also, their C expression values are not inserted into the resulting assembly macro because macros are evaluated in context and there is no active context when converting the macros to assembly.

Suitable functions such as $sizeof( ) are available in assembly expressions. However, as the basic types such as int/char/float have no type representation in assembly, there is no way to ask for $sizeof(int), for example, in assembly.

13.2.13 Structures and Unions

C/C++ structures and unions are converted to assembly .struct and .union elements. Padding and ending alignments are added as necessary to make the resulting assembly structure have the same size and member offsets as the C/C++ source. The primary purpose is to allow access to members of C/C++ structures, as well as to facilitate debugging of the assembly code. For nested structures, the assembly .tag feature is used to refer to other structures/unions.

The alignment is also passed from the C/C++ source so that the assembly symbol is marked with the same alignment as the C/C++ symbol. (See Section 13.2.3 for information about pragmas, which may attempt to modify structures.) Because the alignment of structures is stored in the assembly symbol, built-in assembly functions like $sizeof( ) and $alignof( ) can be used on the resulting structure name symbol.

When using unnamed structures (or unions) in typedefs, such as:

```
typedef struct { int a_member; } mystrname;
```

This is really a shorthand way of writing:

```
struct temporary_name { int a_member; };
typedef temporary_name mystrname;
```

The conversion processes the above statements in the same manner: generating a temporary name for the structure and then using .define to output a typedef from the temporary name to the user name. You should use your *mystrname* in assembly the same as you would in C/C++, but do not be confused by the assembly structure definition in the list, which contains the temporary name. You can avoid the temporary name by specifying a name for the structure, as in:

```
typedef struct a_st_name { ... } mystrname;
```

If a shorthand method is used in C to declare a variable with a particular structure, for example:

```
extern struct a_name { int a_member; } a_variable;
```

Then after the structure is converted to assembly, a .tag directive is generated to declare the structure of the external variable, such as:

```
_a_variable .tag a_st_name
```

This allows you to refer to _a_variable.a_member in your assembly code.

13.2.14 Function/Variable Prototypes

Non-static function and variable prototypes (not definitions) will result in a .global directive being generated for each symbol found.

See Section 13.3.1 for C++ name mangling issues.

Function and variable definitions will result in a warning message being generated (see the WARN/NOWARN parameter discussion for where these warnings are created) for each, and they will not be represented in the converted assembly.

The assembly symbol representing the variable declarations will not contain type information about those symbols. Only a .global will be issued for them. Therefore, it is your responsibility to ensure the symbol is used appropriately.

See Section 13.2.13 for information on variables names which are of a structure/union type.

13.2.15 C Constant Suffixes

The C constant suffixes u, l, and f are passed to the assembly unchanged. The assembler will ignore these suffixes if used in assembly expressions.

13.2.16 Basic C/C++ Types

Only complex types (structures and unions) in the C/C++ source code are converted to assembly. Basic types such as int, char, or float are not converted or represented in assembly beyond any existing .int, .char, .float, etc. directives that previously existed in assembly.

Typedefs of basic types are therefore also not represented in the converted assembly.

13.3 Notes on C++ Specific Conversions

The following sections describe C++ specific conversion elements that you need to be aware of when sharing header files with assembly source.

13.3.1 Name Mangling

Symbol names may be mangled in C++ source files. When mangling occurs, the converted assembly will use the mangled names to avoid symbol name clashes. You can use the demangler (dem6x) to demangle names and identify the correct symbols to use in assembly.

To defeat name mangling in C++ for symbols where polymorphism (calling a function of the same name with different kinds of arguments) is not required, use the following syntax:

```
extern "C" void somefunc(int arg);
```

The above format is the short method for declaring a single function. To use this method for multiple functions, you can also use the following syntax:

```
extern "C"
  {
      void somefunc(int arg);
      int  anotherfunc(int arg);
      ...
   }
```

13.3.2 Derived Classes

Derived classes are only partially supported when converting to assembly because of issues related to C++ scoping which does not exist in assembly. The greatest difference is that base class members do not automatically become full (top-level) members of the derived class. For example:

```
----------------------------------------------------------
        class base
        {
           public:
                int b1;
        };

        class derived : public base
        {
            public:
               int d1;
        }
```

In C++ code, the class derived would contain both integers b1 and d1. In the converted assembly structure "derived", the members of the base class must be accessed using the name of the base class, such as derived.__b_base.b1 rather than the expected derived.b1.

A non-virtual, non-empty base class will have __b_ prepended to its name within the derived class to signify it is a base class name. That is why the example above is derived.__b_base.b1 and not simply derived.base.b1.

13.3.3 Templates

No support exists for templates.

13.3.4 Virtual Functions

No support exists for virtual functions, as they have no assembly representation.

13.4 Special Assembler Support

13.4.1 Enumerations (.enum/.emember/.endenum)

The following directives support a pseudo-scoping for enumerations:

ENUM_NAME **.enum**
MEMBER1 **.emember** [*value*]
MEMBER2 **.emember** [*value*]
...
.endenum

The **.enum** directive begins the enumeration definition and **.endenum** terminates it.

The enumeration name (*ENUM_NAME*) cannot be used to allocate space; its size is reported as zero.

The format to use the value of a member is *ENUM_NAME.MEMBER*, similar to a structure member usage.

The **.emember** directive optionally accepts the value to set the member to, just as in C/C++. If not specified, the member takes a value one more than the previous member. As in C/C++, member names cannot be duplicated, although values can be. Unless specified with .emember, the first enumeration member will be given the value 0 (zero), as in C/C++.

The .endenum directive cannot be used with a label, as structure .endstruct directives can, because the .endenum directive has no value like the .endstruct does (containing the size of the structure).

Conditional compilation directives (.if/.else/.elseif/.endif) are the only other non-enumeration code allowed within the .enum/.endenum sequence.

13.4.2 The .define Directive

The .define directive functions in the same manner as the .asg directive, except that .define disallows creation of a substitution symbol that has the same name as a register symbol or mnemonic. It does not create a new symbol name space in the assembler, rather it uses the existing substitution symbol name space. The syntax for the directive is:

.define *substitution string* **,** *substitution symbol name*

The .define directive is used to prevent corruption of the assembly environment when converting C/C++ headers.

13.4.3 The .undefine/.unasg Directives

The .undef directive is used to remove the definition of a substitution symbol created using .define or .asg. This directive will remove the named symbol from the substitution symbol table from the point of the .undef to the end of the assembly file. The syntax for these directives is:

.undefine *substitution symbol name*

.unasg *substitution symbol name*

This can be used to remove from the assembly environment any C/C++ macros that may cause a problem.

Also see Section 13.4.2, which covers the .define directive.

13.4.4 The $defined( ) Built-In Function

The $defined directive returns true/1 or false/0 depending on whether the name exists in the current substitution symbol table or the standard symbol table. In essence $defined returns TRUE if the assembler has any user symbol in scope by that name. This differs from $isdefed in that $isdefed only tests for NON-substitution symbols. The syntax is:

$defined(*substitution symbol name* **)**

A statement such as ".if $defined(macroname)" is then similar to the C code "#ifdef macroname".

See Section 13.4.2 and Section 13.4.3 for the use of .define and .undef in assembly.

13.4.5 The $sizeof Built-In Function

The assembly built-in function $sizeof( ) can be used to query the size of a structure in assembly. It is an alias for the already existing $structsz( ). The syntax is:

$sizeof(*structure name* **)**

The $sizeof function can then be used similarly to the C built-in function sizeof( ).

The assembler's $sizeof( ) built-in function cannot be used to ask for the size of basic C/C++ types, such as $sizeof(int), because those basic type names are not represented in assembly. Only complex types are converted from C/C++ to assembly.

Also see Section 13.2.12, which notes that this conversion does not happen automatically if the C/C++ sizeof( ) built-in function is used within a macro.

13.4.6 Structure/Union Alignment and $alignof( )

The assembly .struct and .union directives take an optional second argument which can be used to specify a minimum alignment to be applied to the symbol name. This is used by the conversion process to pass the specific alignment from C/C++ to assembly.

The assembly built-in function $alignof( ) can be used to report the alignment of these structures. This can be used even on assembly structures, and the function will return the minimum alignment calculated by the assembler.

13.4.7 The .cstring Directive

You can use the .cstring directive to cause the escape sequences and NULL termination to be properly handled as they would in C/C++.

```
.cstring "String with C escapes.\nWill be NULL terminated.\012"
```

See Section 13.2.11 for more information on the .cstring directive.

Appendix A

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Symbolic Debugging Directives

The assembler supports several directives that the TMS320C6000 C/C++ compiler uses for symbolic debugging. These directives differ for the two debugging formats, DWARF and COFF.

These directives are not meant for use by assembly-language programmers. They require arguments that can be difficult to calculate manually, and their usage must conform to a predetermined agreement between the compiler, the assembler, and the debugger. This appendix documents these directives for informational purposes only.

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A.1 DWARF Debugging Format

A subset of the DWARF symbolic debugging directives are always listed in the assembly language file that the compiler creates for program analysis purposes. To list the complete set used for full symbolic debug, invoke the compiler with the --symdebug:dwarf option, as shown below:

```
cl6x --symdebug:dwarf --keep_asm input_file
```

The --keep_asm option instructs the compiler to retain the generated assembly file.

To disable the generation of all symbolic debug directives, invoke the compiler with the -symdebug:none option:

```
cl6x --symdebug:none --keep_asm input_file
```

The DWARF debugging format consists of the following directives:

- The **.dwtag** and **.dwendtag** directives define a Debug Information Entry (DIE) in the .debug_info section.
- The **.dwattr** directive adds an attribute to an existing DIE.
- The **.dwpsn** directive identifies the source position of a C/C++ statement.
- The **.dwcie** and **.dwendentry** directives define a Common Information Entry (CIE) in the .debug_frame section.
- The **.dwfde** and **.dwendentry** directives define a Frame Description Entry (FDE) in the .debug_frame section.
- The **.dwcfi** directive defines a call frame instruction for a CIE or FDE.

A.2 COFF Debugging Format

COFF symbolic debug is obsolete. These directives are supported for backwards-compatibility only. The decision to switch to DWARF as the symbolic debug format was made to overcome many limitations of COFF symbolic debug, including the absence of C++ support.

The COFF debugging format consists of the following directives:

- The **.sym** directive defines a global variable, a local variable, or a function. Several parameters allow you to associate various debugging information with the variable or function.
- The **.stag**, **.etag**, and **.utag** directives define structures, enumerations, and unions, respectively. The **.member** directive specifies a member of a structure, enumeration, or union. The **.eos** directive ends a structure, enumeration, or union definition.
- The **.func** and **.endfunc** directives specify the beginning and ending lines of a C/C++ function.
- The **.block** and **.endblock** directives specify the bounds of C/C++ blocks.
- The **.file** directive defines a symbol in the symbol table that identifies the current source filename.
- The **.line** directive identifies the line number of a C/C++ source statement.

A.3 Debug Directive Syntax

Table A-1 is an alphabetical listing of the symbolic debugging directives. For information on the C/C++ compiler, refer to the *TMS320C6000 Optimizing Compiler User's Guide.*

Table A-1. Symbolic Debugging Directives

Label	Directive	Arguments
	.block	[*beginning line number*]
	.dwattr	*DIE label* **,** *DIE attribute name* **(** *DIE attribute value* **)[,** *DIE attribute name* **(** *attribute value* **)** [, ...]
	.dwcfi	*call frame instruction opcode*[**,** *operand*[**,** *operand*]]
CIE label	**.dwcie**	*version* **,** *return address register*
	.dwendentry	
	.dwendtag	
	.dwfde	*CIE label*
	.dwpsn	**"** *filename* **",** *line number* **,** *column number*
DIE label	.**dwtag**	*DIE tag name* **,** *DIE attribute name* **(** *DIE attribute value* **)[,** *DIE attribute name* **(** *attribute value* **)** [, ...]
	.endblock	[*ending line number*]
	.endfunc	[*ending line number*[**,** *register mask*[**,** *frame size*]]]
	.eos	
	.**etag**	*name*[**,** *size*]
	.file	**"** *filename* **"**
	.func	[*beginning line number*]
	.**line**	*line number*[**,** *address*]
	.member	*name* **,** *value*[**,** *type* **,** *storage class* **,** *size* **,** *tag* **,** *dims*]
	.stag	*name*[**,** *size*]
	.sym	*name* **,** *value*[**,** *type* **,** *storage class* **,** *size* **,** *tag* **,** *dims*]
	.utag	*name*[**,** *size*]

XML Link Information File Description

The TMS320C6000 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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B.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 32-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 B.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).

B.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.

B.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 B-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>
```

B.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 B-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>
```

B.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 B-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>
```

B.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 B-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>
   ...
</logical_group_list>
```

B.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 B-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>
```

B.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 B-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>
```

B.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 B-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>
```

Glossary

ABI — Application binary interface.

absolute address — An address that is permanently assigned to a TMS320C6000 memory location.

absolute constant expression — An expression that does not refer to any external symbols or any registers or memory reference. The value of the expression must be knowable at assembly time.

absolute lister — A debugging tool that allows you to create assembler listings that contain absolute addresses.

address constant expression — A symbol with a value that is an address plus an addend that is an absolute constant expression with an integer value.

alignment — A process in which the linker places an output section at an address that falls on an *n*-byte boundary, where *n* is a power of 2. You can specify alignment with the SECTIONS linker directive.

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.

ASCII — American Standard Code for Information Interchange; a standard computer code for representing and exchanging alphanumeric information.

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.

assembly-time constant — A symbol that is assigned a constant value with the .set directive.

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*

binding — A process in which you specify a distinct address for an output section or a symbol.

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.

COFF — Common object file format; a system of object files configured according to a standard developed by AT&T. These files are relocatable in memory space.

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.

conditional processing — A method of processing one block of source code or an alternate block of source code, according to the evaluation of a specified expression.

configured memory — Memory that the linker has specified for allocation.

constant — A type whose value cannot change.

constant expression — An expression that does not in any way refer to a register or memory reference.

cross-reference lister — A utility that produces an output file that lists the symbols that were defined, what file they were defined in, what reference type they are, what line they were defined on, which lines referenced them, and their assembler and linker final values. The cross-reference lister uses linked object files as input.

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.

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).

DWARF — A standardized debugging data format that was originally designed along with ELF, although it is independent of the object file format.

EABI — An embedded application binary interface (ABI) that provides standards for file formats, data types, and more.

ELF — Executable and linking format; a system of object files configured according to the System V Application Binary Interface specification.

emulator — A hardware development system that duplicates the TMS320C6000 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. See also *pipelined-loop epilog*.

executable module — A linked object file that can be executed in 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.

field — For the TMS320C6000, a software-configurable data type whose length can be programmed to be any value in the range of 1-32 bits.

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.

GROUP — An option of the SECTIONS directive that forces specified output sections to be allocated contiguously (as a group).

hex conversion utility — A utility that converts object files into one of several standard ASCII hexadecimal formats, suitable for loading into an EPROM programmer.

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.

hole — An area between the input sections that compose an output section that contains no code.

identifier— Names used as labels, registers, and symbols.

immediate operand — An operand whose value must be a constant expression.

incremental linking — Linking files in several passes. Incremental linking is useful for large applications, because you can partition the application, link the parts separately, and then link all of the parts together.

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 module.

input section — A section from an object file that will be linked into an executable module.

ISO — International Organization for Standardization; a worldwide federation of national standards bodies, which establishes international standards voluntarily followed by industries.

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 object module that can be allocated into system memory and executed by the device.

listing file — An output file, created by the assembler, that lists source statements, their line numbers, and their effects on the section program counter (SPC).

literal constant — A value that represents itself. It may also be called a *literal* or an *immediate value*.

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 module into system memory.

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.

macro library — An archive library composed of macros. Each file in the library must contain one macro; its name must be the same as the macro name it defines, and it must have an extension of .asm.

map file — An output file, created by the linker, that shows the memory configuration, section composition, section allocation, symbol definitions and the addresses at which the symbols were defined for your program.

member — The elements or variables of a structure, union, archive, or enumeration.

memory map — A map of target system memory space that is partitioned into functional blocks.

memory reference operand — An operand that refers to a location in memory using a target-specific syntax.

mnemonic — An instruction name that the assembler translates into machine code.

model statement — Instructions or assembler directives in a macro definition that are assembled each time a macro is invoked.

named section — An initialized section that is defined with a .sect directive.

object file — An assembled or linked file that contains machine-language object code.

object library — An archive library made up of individual object files.

object module — A linked, executable object file that can be downloaded and executed on a target system.

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. See also *assembly optimizer*.

options — Command-line parameters that allow you to request additional or specific functions when you invoke a software tool.

output module — A linked, executable object file that is downloaded and executed on a target system.

output section — A final, allocated section in a linked, executable module.

partial linking — Linking files in several passes. Incremental linking is useful for large applications because you can partition the application, link the parts separately, and then link all of the parts together.

quiet run — An option that suppresses the normal banner and the progress information.

raw data — Executable code or initialized data in an output section.

register operand — A special pre-defined symbol that represents a CPU register.

relocatable constant expression— An expression that refers to at least one external symbol, register, or memory location. The value of the expression is not known until link time.

relocation — A process in which the linker adjusts all the references to a symbol when the symbol's address changes.

ROM width — The width (in bits) of each output file, or, more specifically, the width of a single data value in the hex conversion utility file. The ROM width determines how the utility partitions the data into output files. After the target words are mapped to memory words, the memory words are broken into one or more output files. The number of output files is determined by the ROM width.

run address — The address where a section runs.

run-time-support library — A library file, rts.src, that 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.

section program counter (SPC) — An element that keeps track of the current location within a section; each section has its own SPC.

sign extend — A process that fills the unused MSBs of a value with the value's sign bit.

simulator — A software development system that simulates TMS320C6000 operation.

source file — A file that contains C/C++ code or assembly language code that is compiled or assembled to form an object file.

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 name that represents an address or a value.

symbolic constant — A symbol with a value that is an absolute constant expression.

symbolic debugging — The ability of a software tool to retain symbolic information that can be used by a debugging tool such as a simulator or an emulator.

tag — An optional *type* name that can be assigned to a structure, union, or enumeration.

target memory — Physical memory in a system into which executable object code is loaded.

.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.

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. These sections are built with the .bss and .usect directives.

UNION — An option of the SECTIONS directive that causes the linker to allocate the same address to multiple sections.

union — A variable that can hold objects of different types and sizes.

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.

well-defined expression — A term or group of terms that contains only symbols or assembly-time constants that have been defined before they appear in the expression.

word — A 32-bit addressable location in target memory

Revision History

This table lists significant changes made since the previous version of this document was published.

Chapter	Location	Additions / Modifications / Deletions
Linker	Section 8.5.4.1	Removed invalid syntax for load and fill properties.

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