TMS320C6000 Assembly Language Tools User's Guide

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Preface

Read This First

About This Manual

The *TMS320C6000 Assembly Language Tools User's Guide* tells you how to use these assembly language tools:

- Assembler
- Archiver
- Linker
- Cross-reference lister
- Absolute lister
- Hex conversion utility

Before you use this book, you should install the assembly language tools.

How to Use This Manual

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

- **Introductory information**, consisting of Chapters 1 and 2, gives you an overview of the assembly language development tools. It also discusses common object file format (COFF), which helps you to use the TMS320C6000 tools more efficiently. Read Chapter 2, *Introduction to Common Object File Format*, before using the assembler and linker.

- **Assembler description**, consisting of Chapters 3 through 5, 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.

- **Additional assembly language tools**, consisting of Chapters 6 through 10, describes in detail each of the tools provided with the assembler to help you create executable object files. For example, Chapter 7 explains how to invoke the linker, how the linker operates, and how to use linker directives. Chapter 10 explains how to use the hex conversion utility.

- **Reference material**, consisting of Appendixes A through C, provides technical data about the internal format and structure of COFF object files. It discusses symbolic debugging directives that the TMS320C6000 C/C++ compiler uses. Finally, it includes hex conversion utility examples, assembler and linker error messages, and a glossary.

Notational Conventions

This document uses the following conventions:

- The TMS320C62x, ’C64x, and ’C67x core is referred to as TMS320C6000 or C6000.

- Program listings, program examples, and interactive displays are shown in a `special typeface`. Examples use a **`bold version`** of the special typeface for emphasis; 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 program listing:

```
1 00000000                      .data
2 00000000 0000002F   x         .byte   47
3 00000001 00000032   z         .byte   50
4 00000000                      .text
5 00000000 010401E0             ADD     A0,A1,A2
```

- 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. Syntax that is entered on a command line is centered. Syntax that is used in a text file is left justified. Here is an example of command-line syntax:

  lnk6x [*options*] *filename*$_1$ *. ... filename*$_n$

  The **lnk6x** command invokes the linker and has two parameters. The first parameter, *options*, is optional (see the next bullet for details). The second parameter, *filename*, is required and you can enter more than one.

- 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 a **bold** typeface, do not enter the brackets themselves. This is an example of a command that has an optional parameter:

  hex6x [*options*] *filename*

  The **hex6x** command has two parameters. The second parameter, *filename*, is required. The first parameter, *options*, is optional. Since options is plural, you can select several options.

- 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 shaded 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*]

  The *symbol* is required for the .usect directive and must begin in column 1. The *section name* must be enclosed in quotes and the parameter *size in bytes* must be separated from the *section name* by a comma. The *alignment* is optional and, if used, must be separated by a comma.

- Some directives can have a varying number of parameters. For example, the .byte directive can have up to 100 parameters. The syntax for this directive is:

  .byte $value_1$ [**,** ... **,** $value_n$]

  This syntax shows that .byte must have at least one value parameter, but you have the option of supplying additional value parameters, each separated from the previous one by a comma.

- In program listings and program examples, pipe symbols (||) indicate parallel instructions, and square brackets ([]) indicate conditional instructions. This is an example of parallel and conditional instructions:

```
 1                                        .global tab1, tab2
 2
 3 00000000 00000028!           MVK      tab1,A0
 4 00000004 00000068!           MVKH     tab1,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
```

  The instruction on line five executes in parallel with instruction on line six. The instruction on line eight is conditional: the branch to $1 only occurs if the contents of A1 are not equal to 0.

- Following are other symbols and abbreviations used throughout this document:

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

Related Documentation From Texas Instruments

The following books describe the TMS320C6000 devices and related support tools. To obtain a copy of any of these TI documents, call the Texas Instruments Literature Response Center at (800) 477–8924. When ordering, please identify the book by its title and literature number.

TMS320C6000 Optimizing Compiler User's Guide (literature number SPRU187) describes the 'C6000 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 'C6000 generation of devices. The assembly optimizer helps you optimize your assembly code.

Code Composer User's Guide (literature number SPRU296) explains how to use the Code Composer development environment to build and debug embedded real-time DSP applications.

TMS320C6000 Programmer's Guide (literature number SPRU198) describes ways to optimize C and assembly code for the TMS320C6000 DSPs and includes application program examples.

TMS320C6000 CPU and Instruction Set Reference Guide (literature number SPRU189) describes the 'C6000 CPU architecture, instruction set, pipeline, and interrupts for these digital signal processors.

TMS320C6000 Peripherals Reference Guide (literature number SPRU190) describes common peripherals available on the TMS320C6000 digital signal processors. This book includes information on the internal data and program memories, the external memory interface (EMIF), the host port interface (HPI), multichannel buffered serial ports (McBSPs), direct memory access (DMA), enhanced DMA (EDMA), expansion bus, clocking and phase-locked loop (PLL), and the power-down modes.

TMS320C6000 Technical Brief (literature number SPRU197) gives an introduction to the 'C6000 platform of digital signal processors, development tools, and third-party support.

Trademarks

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Chapter 1

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
- Absolute lister
- Cross-reference lister
- 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 books listed in *Related Documentation From Texas Instruments* on page vi.

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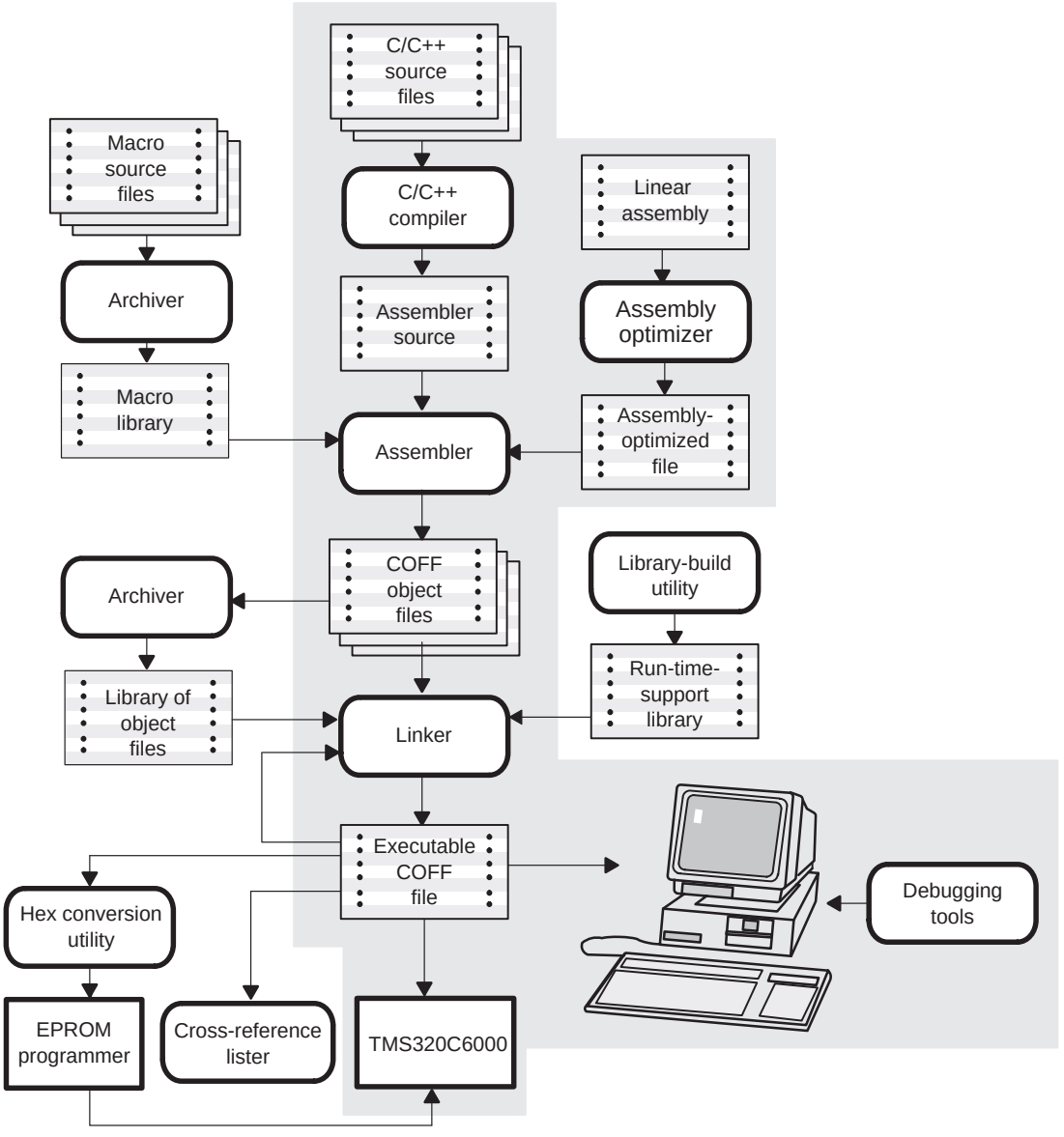
1.1 Software Development Tools Overview

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 **assembly optimizer** allows you to write linear assembly code without being concerned with the pipeline structure or with assigning registers. It 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 **C/C++ compiler** accepts C/C++ source code and produces TMS320C6000 assembly language source code. A **shell program**, an **optimizer**, and an **interlist utility** are included in the compiler package:

  - 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 **assembler** translates assembly language source files into machine language COFF object files. 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 3, *Assembler Description*, through Chapter 5, *Macro Language*, for more information. See the *TMS320C62x/64x/67x CPU and Instruction Set Reference Guide* for detailed information on the assembly language instruction set.

- The **linker** combines object files into a single executable COFF object module. As it creates the executable module, it performs relocation and resolves external references. The linker accepts relocatable COFF object files (created by the assembler) as input. It also accepts archiver library members and output modules created by a previous linker run. Linker 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 7, *Linker Description,* for more information.

- The **archiver** allows you to collect a group of files into a single archive file, called a library. 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. See Chapter 6, *Archiver Description,* for more information.

- 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 a COFF object file into TI-Tagged, ASCII-Hex, Intel, Motorola-S™, or Tektronix™ object format. The converted file can be downloaded to an EPROM programmer. See Chapter 10, *Hex Conversion Utility Description,* for more information.

- 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 9, *Cross-Reference Lister Description,* for more information.

- The main product of this development process is a module 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

  For information about these debugging tools, see the *TMS320C6000 C Source Debugger User's Guide.*

Chapter 2

Introduction to Common Object File Format

The assembler and linker create object files that can be executed by a TMS320C6000™ device. The format for these object files is called common object file format (COFF).

COFF makes modular programming easier because it encourages 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. See Appendix A, *Common Object File Format*, for details about COFF object file structure.

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2.1 Sections

The smallest unit of an object file is called a *section*. A section is a block of code or data that occupies contiguous space in the memory map with other sections. Each section of an object file is separate and distinct. COFF object files always contain three default sections:

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

In addition, the assembler and linker allow you to create, name, and link *named* sections that are used like the .data, .text, and .bss sections.

There are two basic types of sections:

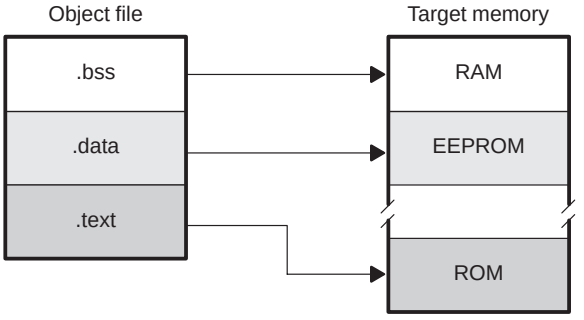
Initialized sections	contain data or code. The .text and .data sections are initialized; named sections created with the .sect assembler directive are also initialized.
Uninitialized sections	reserve space in the memory map for uninitialized data. The .bss section is uninitialized; named sections created 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 *allocation*. 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 into a portion of the memory map that contains ROM.

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



2.2 How the Assembler Handles Sections

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

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

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 2.2.4, *Subsections*, on page 2-7, for more information.

Note: Default Sections Directive

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

2.2.1 Uninitialized Sections

Uninitialized sections reserve space in TMS320C6000 memory; they are usually allocated into 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 .bss and .usect assembler directives.

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

Each time you invoke the .bss or .usect directive, the assembler reserves additional space in the .bss or the 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 assembler directive).

size in bytes is an absolute expression.

- The .bss directive reserves *size in bytes* bytes in the .bss section. You must specify a size; there is no default value.
- The .usect directive reserves *size in bytes* bytes in *section name*. 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. The value must be 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 which named section to reserve space in. For more information, see section 2.2.3, *Named Sections*.

The initialized section directives (.text, .data, and .sect) tell the assembler to stop assembling into the current section and begin assembling into the indicated section. The .bss and .usect directives, however, *do not* end the current section and begin a new one; they simply escape from the current section temporarily. The .bss and .usect directives can appear anywhere in an initialized section without affecting its contents. For an example, see section 2.2.6, *Using Sections Directives*, on page 2-8.

The assembler treats uninitialized subsections (created with the .usect directive) in the same manner as uninitialized sections. See section 2.2.4, *Subsections*, on page 2-7 for more information on creating subsections.

2.2.2 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 section-relative references.

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

.text

.data

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

When the assembler encounters one of these directives, it stops assembling into the current section (acting as an implied end of current section command). It then assembles subsequent code into the designated section until it encounters another .text, .data, or .sect directive.

Sections are built through an iterative process. For example, when the assembler first encounters a .data directive, the .data section is empty. The statements following this first .data directive are assembled into the .data section (until the assembler encounters a .text or .sect directive). If the assembler encounters subsequent .data directives, it adds the statements following these .data directives to the statements already in the .data section. This creates a single .data section that can be allocated continuously into memory.

Initialized subsections are created with the .sect directive. The assembler treats initialized subsections in the same manner as initialized sections. See section 2.2.4, on page 2-7 for more information on creating subsections.

2.2.3 Named Sections

Named sections are sections that *you* create. You can use them like the default .text, .data, and .bss sections, but they are assembled separately.

For example, repeated use of the .text directive builds up a single .text section in the object file. When linked, this .text section is allocated into memory as a single unit. Suppose there is a portion of executable code (perhaps an initialization routine) that you do not want allocated with .text. If you assemble this segment of code into a named section, it is assembled separately from .text, and you can 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.

Two directives let you create 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 named sections with relocatable addresses.

The syntaxes for these directives are:

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

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

The *section name* parameter is the name of the section. Section names are significant to 200 characters. You can create up to 32 767 separate named sections. For the .usect and .sect directives, a section name can refer to a subsection; see section 2.2.4 for details.

Each time you invoke one of these directives with a new name, you create a new named section. Each time you invoke one of these directives with a name that was already used, the assembler assembles 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.

2.2.4 Subsections

Subsections are smaller sections within larger sections. Like sections, subsections can be manipulated by the linker. Subsections give you tighter control of the memory map. You can create subsections 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. 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. See section 7.8.1, *SECTIONS Directive Syntax*, on page 7-28, for an example using subsections.

You can create two types of subsections:

- Initialized subsections are created using the .sect directive. See section 2.2.2, *Initialized Sections*, on page 2-6.
- Uninitialized subsections are created using the .usect directive. See section 2.2.1, *Uninitialized Sections*, on page 2-4.

Subsections are allocated in the same manner as sections. See section 7.8, *The SECTIONS Directive*, on page 7-28, for more information.

2.2.5 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 each section according to its final location in the memory map. For more information, see section 2.4, *Relocation*, on page 2-14.

2.2.6 Using Sections Directives

Example 2–1 shows how you can build COFF 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 Example 2–1 is a listing file. Example 2–1 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 3.10, *Source Listings*, on page 3-30 for more information on interpreting the fields in a source listing.

Example 2–1. Using Sections Directives

```
 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
```

Field 1 Field 2 Field 3 Field 4

As Figure 2–2 shows, the file in Example 2–1 creates five sections:

.text	contains 15 32-bit words of object code.
.data	contains six words of initialized data.
vectors	is a named section created with the .sect directive; it contains two words of object code.
.bss	reserves 44 bytes in memory.
newvars	is a 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 2–2. Object Code Generated by the File in Example 2–1

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’	
	No data—	.bss
9	44 bytes	
10	reserved	
	No data—	newvars
38	8 bytes	
39	reserved	

2.3 How the Linker Handles Sections

The linker has two main functions related to sections. First, the linker uses the sections in COFF object files as building blocks; it combines input sections (when more than one file is being linked) to create output sections in an executable COFF output module. Second, the linker chooses memory addresses for the output sections.

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 sections with greater precision. You can specify subsections 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.

It is not always necessary to use linker directives. If you do not use them, the linker uses the target processor's default allocation algorithm described in section 7.12, *Default Allocation Algorithm*. When you *do* use linker directives, you must specify them in a linker command file.

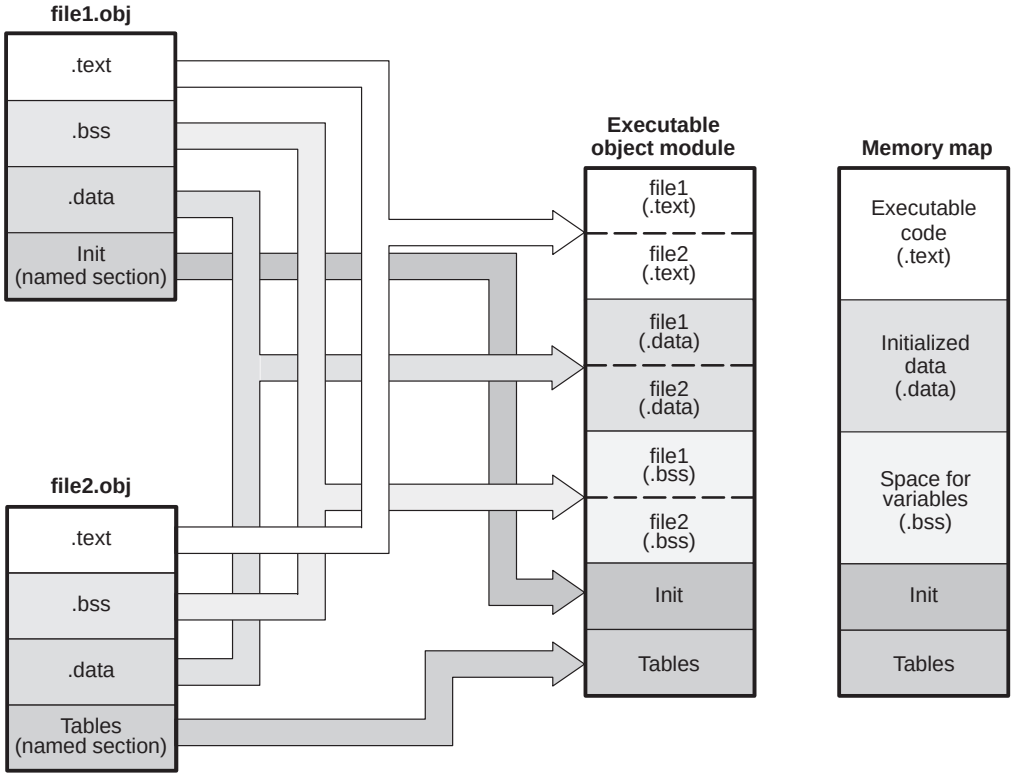
Refer to the following sections for more information about linker command files and linker directives:

Section **Page**

2.3.1 Default Memory Allocation

Figure 2–3 illustrates the process of linking two files together.

Figure 2–3. Combining Input Sections to Form an Executable Object Module



In Figure 2–3, 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 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 named sections at the end. The memory map shows how the sections are put into memory; by default, the linker begins at 0h and places the sections one after the other in the following order: .text, .const, .data, .bss, .cinit, and then any named sections in the order they are encountered in the input files.

The C/C++ compiler uses the .const section to store string constants, and variables or arrays that are defined as *far const*. The C/C++ compiler produces tables of data for autoinitializing global variables; these variables are stored in a named section called .cinit (see Figure 7–5 on page 7-69). For more information on the .const and .cinit sections, see the *TMS320C6000 Optimizing Compiler User's Guide.*

2.3.2 Placing Sections in the Memory Map

Figure 2–3 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 named section placed where the .data section would normally be allocated. Most memory maps contain various types of memory (RAM, ROM, EPROM, 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 7.7, *The MEMORY Directive*, on page 7-25, and section 7.8, *The SECTIONS Directive*, on page 7-28.

2.4 Relocation

The assembler treats each section as if it began at address 0. All relocatable symbols (labels) are relative to address 0 in their sections. Of course, all sections cannot actually begin at address 0 in memory, so the linker *relocates* 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 2–2 contains a code segment for a TMS320C6000 device that generates relocation entries.

Example 2–2. Code That Generates Relocation Entries

```
1                              .global X
2 00000000 00000012! Z:        B       X       ; Uses an external relocation
3 00000004 0180082A'           MVKL     Y,B3    ; Uses an internal relocation
4 00000008 0180006A'           MVKH    Y,B3    ; Uses an internal relocation
5 0000000c 00004000            NOP     3
6
7 00000010 0001E000  Y:        IDLE
8 00000014 00000212            B       Y
9 00000018 00008000            NOP     5
```

In Example 2–2, 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). 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
```

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. For example:

Example 2–3. 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 MVK instruction is patched to:

```
       00808028            MVK       100h,A1
```

Note: Expression Can Not Be Larger Than Space Reserved

If the value of an expression is larger, in bits, then the space reserved for it, you will receive an error message from the linker.

Each section in a COFF object file 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 –r option (see page 7-7).

2.5 Run-Time Relocation

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 an external-memory-based system. The code must be loaded into external memory, but it would run faster in internal memory.

The linker provides a simple 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.

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 an example that illustrates how to move a block of code at run-time, see Example 7–6 on page 7-43.

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 7.9, *Specifying a section's Run-Time Address*, on page 7-40.

2.6 Loading a Program

The linker produces executable COFF object modules. An executable object file has the same COFF format as object files that are used as linker input; the sections in an executable object file, however, are combined and relocated into target memory.

To run a program, the data in the executable object module must be transferred, or loaded, into target system memory. Several methods can be used for loading a program, depending on the execution environment. Three common situations are described below:

- Code Composer Studio can load an executable COFF file into a simulator or onto hardware. The CCS loader reads the executable file and copies the program into target memory.
- You can use the hex conversion utility (hex6x, which is shipped as part of the assembly language package) to convert the executable COFF object module into one of several object file formats. You can then use the converted file with an EPROM programmer to burn the program into an EPROM.
- A standalone simulator can be invoked by the load6x command and the name of the executable object file. The standalone simulator reads the executable file, copies the program into the simulator and executes it, displaying any C I/O.

2.7 Symbols in a COFF File

A COFF file contains a symbol table that stores information about symbols in the program. The linker uses this table when it performs relocation. Debugging tools can also use the symbol table to provide symbolic debugging.

2.7.1 External Symbols

External symbols are symbols that are defined in one module and referenced in another module. You can use the .def, .ref, or .global directive to identify symbols as external:

.def The symbol is defined in the current module and used in another module.

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

.global The symbol may be either of the above.

The following code segment illustrates these definitions.

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

q:  B       B3
    NOP     4
    MVK     1, 1
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 module and that other modules can reference x. The .ref definition of y says that it is an undefined symbol that is defined in another module. The .global definition of z says that it is defined in some module and available in this file. The .global definition of q says that it is defined in this module and that other modules 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 must 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.

2.7.2 The Symbol Table

The assembler always generates an entry in the symbol table when it encounters an external symbol (both definitions and references defined by one of the directives in section 2.7.1). The assembler also creates special symbols that point to the beginning of each section; the linker uses these symbols to relocate references to other symbols.

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 are not included in the symbol table unless they are declared with the .global directive. For symbolic debugging 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 –as option (see page 3-6).

Chapter 3

Assembler Description

The TMS320C6000™ assembler translates assembly language source files into machine language object files. These files are in common object file format (COFF), which is discussed in Chapter 2, *Introduction to Common Object File Format*, and Appendix A, *Common Object File Format*. Source files can contain the following assembly language elements:

Assembler directives	described in Chapter 4
Macro directives	described in Chapter 5
Assembly language instructions	described in the *TMS320C6000 CPU and Instruction Set Reference Guide*

Topic **Page**

3.1 Assembler Overview

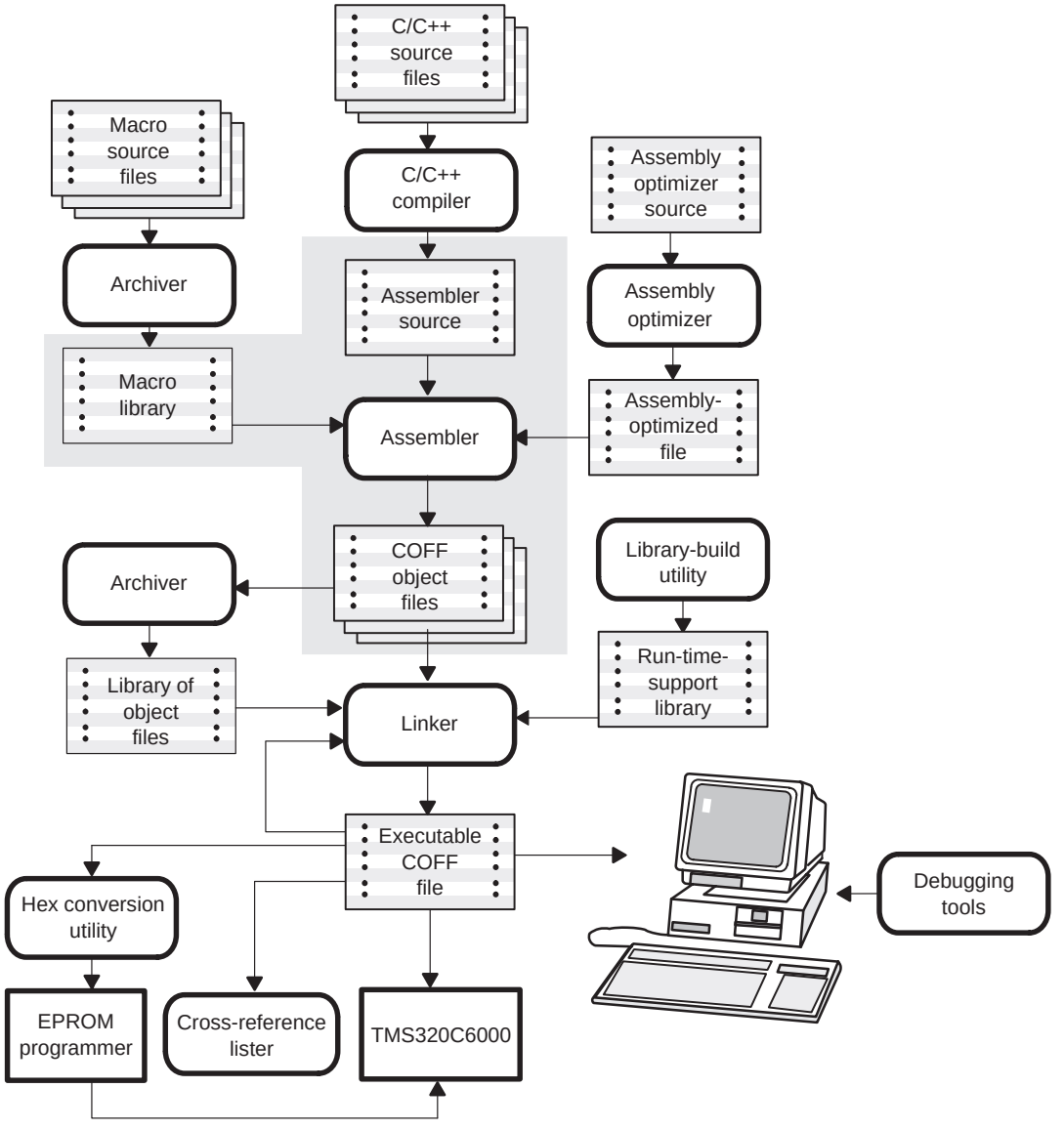
The 2-pass assembler does the following:

- ❑ 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 segment 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

3.2 The Assembler's Role in the Software Development Flow

Figure 3–1 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 3–1. The Assembler in the TMS320C6000 Software Development Flow



3.3 Invoking the Assembler

To invoke the assembler, enter the following:

cl6x [options] [assembly source filenames]

cl6x is the command that invokes the assembler.

assembly source filenames names the assembly language source file. The file name must contain a .asm extension.

object file names the C6000 object file that the assembler creates. If you do not supply an extension, the assembler uses *.obj* as a default. If you do not supply an object file, the assembler creates a file that uses the input filename with the *.obj* extension.

listing file names the optional listing file that the assembler can create.

- If you do not supply a *listing file*, the assembler does not create one unless you use the –l (lowercase L) option or the –x option. In this case, the assembler uses the input filename with a .lst extension and places the listing file in the input file directory.
- If you supply a *listing file* but do not supply an extension, the assembler uses *.lst* as the default extension.

options identify the assembler 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.

–@ –@ *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.

–aa creates an absolute listing. When you use –aa, the assembler does not produce an object file. The –aa option is used in conjunction with the absolute lister.

–apd same as -ppd and -ppi for compiler EXCEPT for assembly fiels only and produce files with a .ppa extension.

–api same as -ppd and -ppi for compiler EXCEPT for assembly fiels only and produce files with a .ppa extension.

–ac makes case insignificant in the assembly language files. For example, –ac will make 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.

–ad **–ad***name* [=*value*] sets the *name* symbol. This is equivalent to inserting *name* **.set** [*value*] at the beginning of the assembly file. If *value* is omitted, the symbol is set to 1. For more information, see section 3.8.4, *Defining Symbolic Constants (–d Option)*, on page 3-20.

–af suppresses the assembler's default behavior of adding the .asm extension to an input file with no specified extension.

–g enables assembler source debugging in the C source debugger. Line information is output to the COFF file for every line of source in the assembly language source file. You cannot use the –g option on assembly code that contains .line directives.

–ahc –ahc*filename* tells the assembler to copy the specified file for the assembly module. The file is inserted before source file statements. The copied file appears in the assembly listing files.

–ahi –ahi*filename* tells the assembler to include 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.

–i specifies a directory where the assembler can find files named by the .copy, .include, or .mlib directives. The format of the –i option is **–i***pathname*. You can specify up to 32 directories in this manner; each pathname must be preceded by the –i option. For more information, see section 3.4.1, *Using the –i Assembler Option*, on page 3-7.

–al (lowercase L) produces a listing file with the same name as the input file with a *.lst* extension.

–me produces object code in big-endian format.

–ml –ml*num* sets the processor symbols .SMALL_MODEL, .LARGE_MODEL, and .LARGE_MODEL_OPTION. If you are compiling C/C++ code separately, you can use this option to mimic the compiler's –ml*num* option. If you are compiling with C/C++ code, the –ml*num* information is passed to the assembler, and the model symbols are appropriately defined.

–mm suppresses MVK warnings. By default, the assembler issues warnings when an MVK constant expression that is part of a well-defined expression does not fit within 16-bits signed (–32768 to 32767). If the constant operand is a symbol or expression that cannot be evaluated by the assembler, the warning is issued by the linker when the corresponding object file is linked. The –mm option suppresses the assembler and linker behavior.

Alternately, use the MVKL instruction. It has the same properties as MVK, except one: the constant expression is not limited to 16-bits. MVKL sign-extends the constant when loading it into the register. Use MVKL only with MVKH, otherwise, use MVK.

–mv<silicon> Specifiy target silicon version

–q suppresses the banner and progress information (assembler runs in quiet mode).

–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 –as, symbols defined as labels or as assembly-time constants are also placed in the table.

–au **–au***name* undefines the predefined constant *name*, which overrides any –ad options for the specified constant.

–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 –ax option, the assembler creates a listing file automatically, naming it with the same name as the input file with a *.lst* extension.

3.4 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 4, *Assembler Directives*, 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. 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 –i assembler option

3) Any directories named with the C6X_A_DIR or A_DIR environment variable

Because of this search hierarchy, you can augment the assembler's directory search algorithm by using the –i assembler option (described in section 3.4.1) or the C6X_A_DIR or A_DIR environment variable (described in section 3.4.2).

3.4.1 Using the –i Assembler Option

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

cl6x –i*pathname source filename* [*other options*]

You can use up to 32 –i options per invocation; each –i 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 –i 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™: /320tools/files/copy.asm

Windows™: c:\320tools\files\copy.asm

Operating System	Enter
UNIX	**cl6x –i/320tools/files source.asm**
Windows	**cl6x –ic:\320tools\files source.asm**

If you invoke the assembler for your system as as shown above, the assembler first searches for copy.asm in the current directory because source.asm (the input file) is in the current directory. Then the assembler searches in the directory named with the –i option.

3.4.2 Using the C6X_A_DIR or A_DIR Environment Variable

An environment variable is a system symbol that you define and assign a string to. The assembler uses the A_DIR environment variable to name alternate directories that contain copy/include files or macro libraries. The command syntax for assigning the environment variable is as follows:

Operating System	Enter
UNIX	**setenv A_DIR "***pathname*$_1$*;pathname*$_2$*; . . .***"**
Windows	**set A_DIR=** *pathname*$_1$*;pathname*$_2$*; . . .*

The *pathnames* are directories that contain copy/include files or macro libraries. You can separate the pathnames with a semicolon or with blanks. 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 –i option, it searches the paths named by the environment variable.

For setup information for the C6X_A_DIR or A_DIR environment variable, refer to the DosRun.bat file provide with Code Composer Studio. If A_DIR is not set up, the assembler uses C_DIR to specify the include file search path. See the *TMS320C6000 Optimizing Compiler User's Guide* for details on C_DIR.

3.5 Source Statement Format

TMS320C6000 assembly language source programs consist of source statements that can contain assembler directives, assembly language instructions, macro directives, and comments. A source statement 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*]

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
```

The C6000 assembler reads up to 200 characters per line. Any characters beyond 200 are truncated. Keep the operational part of your source statements (that is, everything other than comments) less than 200 characters in length for correct assembly. Your comments can extend beyond the 200-character limit, but the truncated portion is not included in the listing file.

Follow these guidelines:

- All statements must begin with a label, a blank, an asterisk, or a semicolon.
- Labels are optional; if used, they must begin in column 1.
- One or more blanks must separate each field. Tab and space characters are blanks. You must separate the operand list from the preceding field with a blank.
- 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.
- A mnemonic cannot begin in column 1 or it will be interpreted as a label.

The following sections describe each of the fields.

3.5.1 Label Field

Labels are optional for all assembly language instructions and for most (but not all) assembler directives. When used, a label must begin in column 1 of a source statement. A label can contain up to 128 alphanumeric characters (A–Z, a–z, 0–9, _, and $). Labels are case sensitive (except when the –ac option is used), and the first character cannot be a number. 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 with an instruction that is in parallel with a previous instruction.

When you use a label, its value is the current value of the SPC. The label points to the statement it is associated with. For example, if you use the .word directive to initialize several words, a label points to the first word. In the following example, the label Start has the value 40h.

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

A label on a line by itself is a valid statement. The label assigns the current value of the section program counter to the label; this is equivalent to the following directive statement:

```
label .equ  $  ; $ provides the current value of the SPC
```

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
```

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

3.5.2 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 can begin with one of the following items:

- Pipe symbols (||) indicate instructions that are in parallel with a previous instruction. You can have up to eight instructions running in parallel. The following example demonstrates six instructions running in parallel:

```
        Inst1
||      Inst2
||      Inst3
||      Inst4
||      Inst5
||      Inst6
        Inst7
```

These five instructions run in parallel with the first instruction.

- 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. 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
```

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 directive (such as .macro, .var, .mexit)
- Macro call

3.5.3 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 and operand field.

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

3.5.4 Operand Field

The operand field follows the mnemonic field and contains one or more operands. The operand field is not required for all instructions or directives. An operand consists of the following items:

- ❑ Symbols (see section 3.8 on page 3-17)
- ❑ Constants (see section 3.6 on page 3-13)
- ❑ Expressions (combination of constants and symbols; see section 3.9 on page 3-25)

You must separate operands with commas.

3.5.5 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.

3.6 Constants

The assembler supports six types of constants:

- Binary integer
- Octal integer
- Decimal integer
- Hexadecimal integer
- Character
- Assembly-time

The assembler maintains each constant internally as a 32-bit quantity. Constants are not sign extended. For example, the constant 00FFh is equal to 00FF (base 16) or 255 (base 10); it *does not* equal –1. However, when used with the .byte directive, –1 *is* equivalent to 00FFh.

3.6.1 Binary Integers

A binary integer constant is a string of up to 32 binary digits (0s and 1s) followed by the suffix B (or b). 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 constants:

00000000B	Constant equal to 0_{10} or 0_{16}
0100000b	Constant equal to 32_{10} or 20_{16}
01b	Constant equal to 1_{10} or 1_{16}
11111000B	Constant equal to 248_{10} or $0F8_{16}$

3.6.2 Octal Integers

An octal integer constant is a string of up to 11 octal digits (0 through 7) followed by the suffix Q (or q). These are examples of valid octal constants:

10Q	Constant equal to 8_{10} or 8_{16}
010	Constant equal to 8_{10} or 8_{16} (C format)
100000Q	Constant equal to $32\ 768_{10}$ or 8000_{16}
226q	Constant equal to 150_{10} or 96_{16}

3.6.3 Decimal Integers

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

1000	Constant equal to 1000_{10} or $3E8_{16}$
–32768	Constant equal to $-32\ 768_{10}$ or 8000_{16}
25	Constant equal to 25_{10} or 19_{16}

3.6.4 Hexadecimal Integers

A hexadecimal integer constant is a string of up to eight hexadecimal digits followed by the suffix H (or h). Hexadecimal digits include the decimal values 0–9 and the letters A–F or a–f. *A hexadecimal constant must begin with a decimal value (0–9).* If fewer than eight hexadecimal digits are specified, the assembler right justifies the bits. These are examples of valid hexadecimal constants:

78h	Constant equal to 120_{10} or 0078_{16}
0x78	Constant equal to 120_{10} or 0078_{16} (C format)
0Fh	Constant equal to 15_{10} or $000F_{16}$
37ACh	Constant equal to $14\ 252_{10}$ or $37AC_{16}$

3.6.5 Character Constants

A character constant 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 constant. A character constant consisting only of two single quotes is valid and is assigned the value 0. These are examples of valid character constants:

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

Notice the difference between character *constants* and character *strings.* (section 3.7 discusses character strings). A character constant represents a single integer value; a string is a sequence of characters.

3.6.6 Assembly-Time Constants

If you use the .set directive (see page 4-63) to assign a value to a symbol, the symbol becomes a constant. To use this constant in expressions, the value that is assigned to it must be absolute. For example:

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

You can also use the .set directive to assign symbolic constants for register names. In this case, the symbol becomes a synonym for the register:

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

3.7 Character Strings

A character string is a string 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

3.8 Symbols

Symbols are used as labels, constants, and substitution symbols. A symbol name is a string of up to 200 alphanumeric characters (A–Z, a–z, 0–9, $, and _). The first character in a symbol cannot be a number, and symbols cannot contain embedded blanks. The symbols you define are case sensitive; for example, the assembler recognizes ABC, Abc, and abc as three unique symbols. You can override case sensitivity with the –ac assembler option (see page 3-5). A symbol is valid only during the assembly in which it is defined, unless you use the .global directive or the .def directive to declare it as an external symbol (see section 2.7.1 on page 2-18).

3.8.1 Labels

Symbols used as labels become symbolic addresses that are associated with locations in the program. Labels used locally within a file must be unique. Mnemonic opcodes and assembler directive names without the . prefix are valid label names.

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
```

3.8.2 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 3–1.
- *name*?, where *name* is any legal symbol name 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. You cannot declare this label as global. See Example 3–2.

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 3–1. 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 can be in effect at one time. 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.

Because local labels are intended to be used only locally, branches to local labels are not expanded in case the branch's offset is out of range.

Example 3–2. 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
```

3.8.3 Symbolic Constants

Symbols can be set to constant values. By using constants, you can equate meaningful names with constant values. The .set and .struct/.tag/.endstruct directives enable you to set constants to symbolic names. Symbolic constants *cannot* be redefined. The following example shows how these directives can be used:

```
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 several predefined symbolic constants; these are discussed in section 3.8.5.

3.8.4 Defining Symbolic Constants (–ad Option)

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

cl6x –ad*name*=[*value*]

The *name* is the name of the symbol you want to define. The *value* is the value you want to assign to the symbol. If the *value* is omitted, the symbol is set to 1.

Once you have defined the name with the –ad option, the symbol can be used in place of a constant value, a well-defined expression, or an otherwise undefined symbol used with assembly directives and instructions. For example, on the command line you enter:

```
cl6x –adSYM1=1 –adSYM2=2 –adSYM3=3 –adSYM4=4 value.asm
```

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

Example 3–3. 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
```

Within assembler source, you can test the symbol defined with the –ad option with the following 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.

3.8.5 Predefined Symbolic Constants

The assembler has several predefined symbols, including the following types:

- **$**, the dollar-sign character, represents the current value of the section program counter (SPC). $ is a relocatable symbol.
- **Register symbols**, including A0–A15 and B0–B15 for ’C6200 and ’C6700; and A16–31 and B16–31 for ’C6400.
- **CPU control registers**, including the following:

Register	Description
AMR	Addressing mode register
CSR	Control status register
FADCR (’C6700 only)	Floating-point adder configuration register
FAUCR (’C6700 only)	Floating-point auxiliary configuration register
FMCR (’C6700 only)	Floating-point multiplier configuration register
GFPGFR (’C6400 only)	Galois field polynomial generator function register
ICR	Interrupt clear register
IER	Interrupt enable register
IFR	Interrupt flag register
NRP	Nonmaskable interrupt return pointer
IRP	Interrupt return pointer
ISR	Interrupt set register
ISTP	Interrupt service table pointer
PCE1	Program counter

Control registers can be entered as all upper-case or all lower-case characters; for example, CSR can also be entered as csr.

- **Processor symbols**, including the following items:

Symbol name	Description
.TMS320C6000	Always set to 1
.TMS320C6200	Set to 1 for ’6200, otherwise 0
.TMS320C6400	Set to 1 for ’6400, otherwise 0
.TMS320C6700	Set to 1 for ’6700, otherwise 0
.LITTLE_ENDIAN	Set to 1 if little-endian mode is selected (the –me assembler option is not used); otherwise 0.
.BIG_ENDIAN	Set to 1 if big-endian mode is selected (the –me assembler option is used); otherwise 0.

- Memory Model Symbols

Symbol name	Description
.SMALL_MODEL	Set to 1 if a small memory model is used (does not use the –ml<num> option). Otherwise 0
.LARGE_MODEL	Set to 1 if a large memory model is used (does not use the –ml<num> option). Otherwise 0
.LARGE_MODEL_OPTION	Always defined. Set to the value used with the –ml option. The –ml option can be used when invoking the shell (the C/C++ compiler) or the assembler. See the *TMS320C600 Optimizing Compiler User’s Guide* for more information on the –ml option.

- Assembler Version Symbols

Symbol name	Description
.ASSEMBLER_VERSION	Always defined. Set to a number that consists of a major version number and a 2-digit minor version number. The number does not contain a decimal. For example, for version 5.00 of the assembler, .ASSEMBLER_VERSION is set to 500.

3.8.6 Substitution Symbols

Symbols can be assigned a string value (variable). This enables you to alias 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
```

For more information about macros, see Chapter 5, *Macro Language*.

3.9 Expressions

An expression is a constant, a symbol, or a series of constants and symbols separated by arithmetic operators. The 32-bit ranges of valid expression values are –2 147 483 648 to 2 147 483 647 for signed values, and 0 to 4 294 967 295 for unsigned values. 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 3–1, 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

3.9.1 Operators

Table 3–1 lists the operators that can be used in expressions, according to precedence group.

Table 3–1. Operators Used in Expressions (Precedence)

Group	Operator	Description
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

Note: Group 1 operators are evaluated right to left. All other operators are evaluated left to right.

3.9.2 Expression Overflow and Underflow

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

3.9.3 Well-Defined Expressions

Some assembler directives require well-defined expressions as operands. Well-defined expressions contain only symbols or assembly-time constants that are defined before they are encountered in the expression. The evaluation of a well-defined expression must be absolute.

This is an example of a well-defined expression:

```
1000h+X
```

where X was previously defined as an absolute symbol.

3.9.4 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 may be used only on operands of equivalent types; for example, absolute value compared to absolute value, but not absolute value compared to relocatable value.

3.9.5 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 an expression contains more than one relocatable symbol or cannot be evaluated at assembly time, 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 will receive an error message from the linker. For more information on relocation expressions, see section 2.4 on page 2-14.

3.9.5.1 Exceptions to Legal Expressions

- When using the register relative addressing mode, the expression in brackets or parenthesis must be a well-defined expression, as described in section 3.9.3. 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:

  relocatable symbol ± *absolute symbol* `B (extern_1-10)`

  or

  a well-defined expression `*+B14/B15[14]`

3.9.6 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.

  ```
  .word extern_1 * intern_2 – 13 ; Legal

  MVKL  (intern_1 – extern_1),A1 ; Legal
  ```

- **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
```

3.10 Source Listings

A source listing shows source statements and the object code they produce. To obtain a listing file, invoke the assembler with the –al (lowercase L) option (see page 3-5).

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. Example 3–4 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.

Example 3–4 shows an assembler listing with each of the four fields identified.

Example 3–4. Assembler Listing

Include file letter — Nesting level number — Line number

```
       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
```

Field 1 — Field 2 — Field 3 — Field 4

3.11 Cross-Reference Listings

A cross-reference listing shows symbols and their definitions. To obtain a cross-reference listing, invoke the assembler with the –ax option (see page 3-6) or use the .option directive with the X operand (see page 4-59). The assembler appends the cross-reference to the end of the source listing. Example 3–5 shows the four fields contained in the cross-reference listing.

Example 3–5. 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 3–2 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 3–2. 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 4

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 (sections 4.1 through 4.9) describes the directives according to function, and the second part (section 4.10) is an alphabetical reference.

Topic **Page**

4.1 Directives Summary

Table 4–1 summarizes the assembler directives.

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

- The assembler uses several directives for macros. Macro directives are discussed in Chapter 5, *Macro Language*; 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*; they are not discussed in this book.
- The C compiler uses directives for symbolic debugging. Unlike other directives, symbolic debugging directives are not used in most assembly language programs. Appendix B, *Symbolic Debugging Directives*, discusses these directives; they are not discussed in this chapter.

Note: Labels and Comments in Not Shown Syntaxes

Any source statement that contains a directive can also contain a label and a comment. Labels begin in the first column (they are the only elements, except comments, that can appear in the first column), and comments must be preceded by a semicolon or an asterisk if the comment is only element in the line. To improve readability, labels and comments are not shown as part of the directive syntax.

Table 4–1. Assembler Directives Summary

(a) Directives that define sections

Mnemonic and Syntax	Description	Page
.bss *symbol*, *size in bytes*[, *alignment*[, *bank offset*]]	Reserves *size* bytes in the .bss (uninitialized data) section	4-25
.clink [**"***section name***"**]	Enables conditional linking for the current or specified section.	4-27
.data	Assembles into the .data (initialized data) section	4-31
.sect "*section name***"**	Assembles into a named (initialized) section	4-62
.text	Assembles into the .text (executable code) section	4-75
symbol **.usect "***section name***",** *size in bytes*[, *alignment*[, *bank offset*]]	Reserves *size* bytes in a named (uninitialized) section	4-77

Table 4–1. Assembler Directives Summary (Continued)

(b) Directives that initialize constants (data and memory)

Mnemonic and Syntax	Description	Page
.byte *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more successive bytes in the current section	4-26
.char *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more successive bytes in the current section	4-26
.double *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 64-bit, IEEE double-precision, floating-point constants	4-32
.field *value* [**,** *size*]	Initializes a field of *size* bits (1–32) with *value*	4-38
.float *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 32-bit, IEEE single-precision, floating-point constants	4-41
.half *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 16-bit integers (halfword)	4-44
.uhalf *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 16-bit integers (halfword)	4-44
.int *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 32-bit integers	4-47
.uint *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 32-bit integers	4-47
.long *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 32-bit integers	4-47
.short *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 16-bit integers (halfword)	4-44
.ushort *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 16-bit integers (halfword)	4-44
.string {*expr*$_1$|**"***string*$_1$**"**} [**,** ... **,** {*expr*$_n$|**"***string*$_n$**"**}]	Initializes one or more text strings	4-67
.word *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 32-bit integers	4-47
.uword *value*$_1$ [**,** ... **,** *value*$_n$]	Initializes one or more 32-bit integers	4-47

(c) Directives that perform alignment and reserve space

Mnemonic and Syntax	Description	Page
.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	4-22
.bes *size*	Reserves *size* bytes in the current section; a label points to the end of the reserved space	4-64
.space *size*	Reserves *size* bytes in the current section; a label points to the beginning of the reserved space	4-64

Table 4–1. Assembler Directives Summary (Continued)

(d) Directives that format the output listing

Mnemonic and Syntax	Description	Page
.drlist	Enables listing of all directive lines (default)	4-33
.drnolist	Suppresses listing of certain directive lines	4-33
.fclist	Allows false conditional code block listing (default)	4-37
.fcnolist	Suppresses false conditional code block listing	4-37
.length [*page length*]	Sets the page length of the source listing	4-50
.list	Restarts the source listing	4-51
.mlist	Allows macro listings and loop blocks (default)	4-57
.mnolist	Suppresses macro listings and loop blocks	4-57
.nolist	Stops the source listing	4-51
.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	4-59
.page	Ejects a page in the source listing	4-61
.sslist	Allows expanded substitution symbol listing	4-65
.ssnolist	Suppresses expanded substitution symbol listing (default)	4-65
.tab *size*	Sets tab to *size* characters	4-74
.title "*string***"**	Prints a title in the listing page heading	4-76
.width [*page width*]	Sets the page width of the source listing	4-50

Table 4–1. Assembler Directives Summary (Continued)

(e) Directives that reference other files

Mnemonic and Syntax	Description	Page
.copy ["]*filename*["]	Includes source statements from another file	4-28
.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	4-42
.global $symbol_1$ [**,** ... **,** $symbol_n$]	Identifies one or more global (external) symbols	4-42
.include ["]*filename*["]	Includes source statements from another file	4-28
.mlib ["]*filename*["]	Defines macro library	4-55
.ref $symbol_1$ [**,** ... **,** $symbol_n$]	Identifies one or more symbols used in the current module that are defined in another module	4-42

(f) Directives that enable conditional assembly

Mnemonic and Syntax	Description	Page
.break [*well-defined expression*]	Ends .loop assembly if *well-defined expression* is true. When using the .loop construct, the .break construct is optional.	4-53
.else	Assembles code block if the .if *well-defined expression* is false. When using the .if construct, the .else construct is optional.	4-45
.elseif *well-defined expression*	Assembles code block if the .if *well-defined expression* is false and the .elseif condition is true. When using the .if construct, the .elseif construct is optional.	4-45
.endif	Ends .if code block	4-45
.endloop	Ends .loop code block	4-53
.if *well-defined expression*	Assembles code block if the *well-defined expression* is true	4-45
.loop [*well-defined expression*]	Begins repeatable assembly of a code block; the loop count is determined by the w*ell-defined expression*.	4-53

Table 4–1. Assembler Directives Summary (Continued)

(g) Structure and Union Definition Directives

Mnemonic and Syntax	Description	Page
.cunion	Acts like .union, but adds padding and alignment like that which is done to structures	4-71
.cstruct	Acts like .struct, but adds padding and alignment like that which is done to structures	4-71
.endunion	Ends a union definition	
.endstruct	Ends a structure definition	4-68
.struct	Begins structure definition	4-68
.tag	Assigns structure attributes to a label	4-68
.union	Begins a union definition	4-71

(h) Symbol Defining Directives

Mnemonic and Syntax	Description	Page
.label *symbol*	Defines a load-time relocatable label in a section	4-49
symbol **.equ** *value*	Equates *value* with *symbol*	4-63
symbol **.set** *value*	Equates *value* with *symbol*	4-63

(i) Substitution Symbol Directives

Mnemonic and Syntax	Description	Page
.asg [**"**]*character string*[**"**]**,** *substitution symbol*	Assigns a character string to *substitution symbol*	4-23
.eval *well-defined expression***,** *substitution symbol*	Performs arithmetic on numeric *substitution symbol*	4-23
.var	adds a local substitution symbol to a macros's parameter list	4-33

(j) Miscellaneous directives

Mnemonic and Syntax	Description	Page
.emsg *string*	Sends user-defined error messages to the output device; produces no .obj file	4-34
.end	Ends program	4-36
.mmsg *string*	Sends user-defined messages to the output device	4-34
.newblock	Undefines local labels	4-58
.wmsg *string*	Sends user-defined warning messages to the output device	4-34

4.2 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 **.data** directive identifies portions of code in the .data section. The .data section usually contains initialized data.
- 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, *Introduction to Common Object File Format*, discusses COFF sections in detail.

Example 4–1 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 4–1 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 4–1. Sections Directives

```
 1                      ************************************************
 2                      *     Start assembling into the .text section    *
 3                      ************************************************
 4 00000000                      .text
 5 00000000 00000001             .word   1,2
   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
```

4.3 Directives That Initialize Constants

Several directives assemble values for the current section:

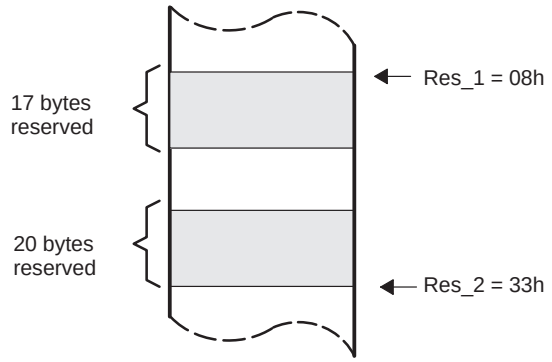
- The **.bes** and **.space** directives reserve a specified number of bytes in the current section. The assembler fills these reserved bytes with 0s.
  - When you use a label with .space, it points to the *first* byte that contains reserved bits.
  - When you use a label with .bes, it points to the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

  Figure 4–1 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 4–1. The .space and .bes Directives



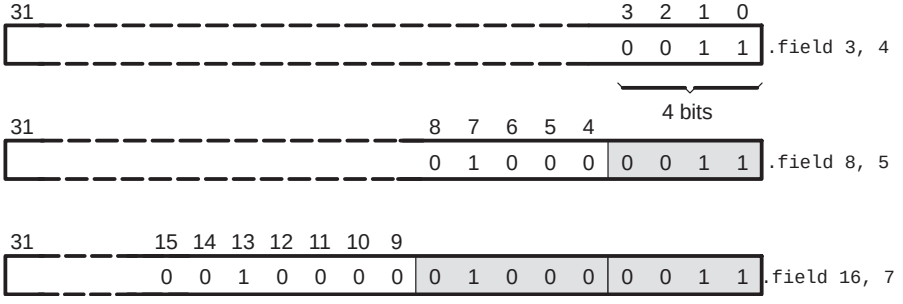
- The **.byte** and **.char** directives place one or more 8-bit values into consecutive bytes of the current section. These directives are similar to .long and .word, except that the width of each value is restricted to eight bits.
- The **.double** directive calculates the double-precision (64-bit) 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 4–2 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 4–2. 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. The .half and .short 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. The .int, .long, and .word directives automatically align to a word boundary.

- The **.string** directive places 8-bit characters from one or more character strings into the current section. This directive is similar to .byte, placing an 8-bit character in each consecutive byte of the current section.

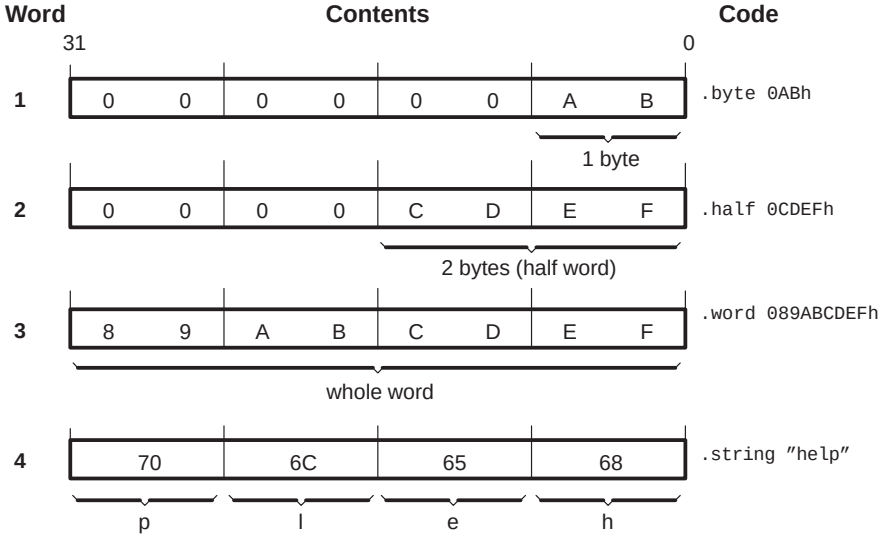
Note: Directives That Initialize Constants When Used in a .struct/.endstruct Sequence

The .byte, .char, .int, .long, .word, .double, .half, .short, .string, .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 about the .struct/.endstruct directives, see page 4-68.

Figure 4–3 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 4–3. Initialization Directives

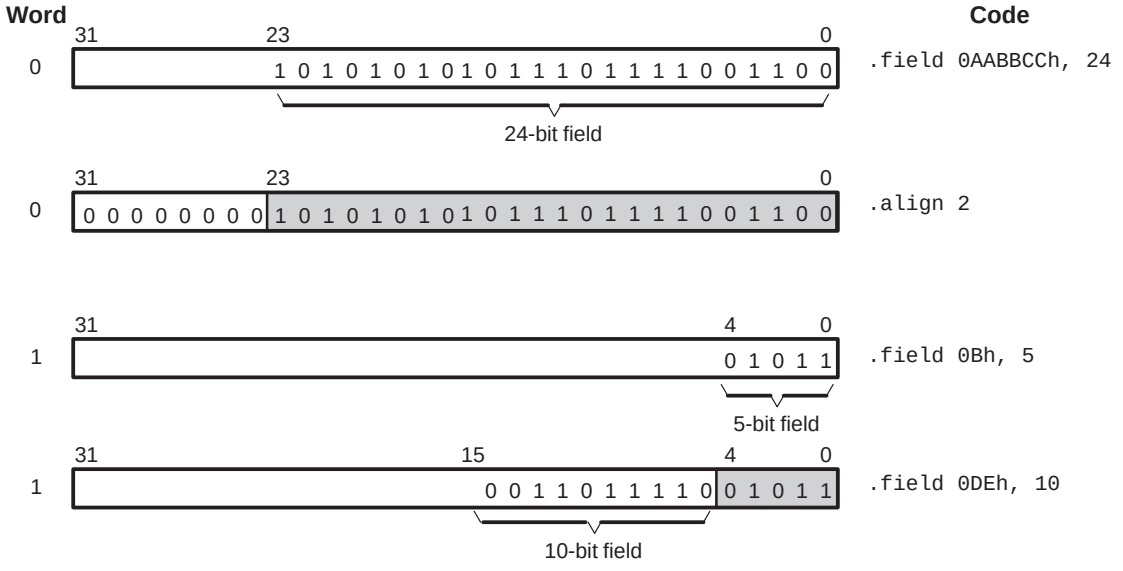


4.4 Directive That Aligns the Section Program Counter

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. Figure 4–4 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 4–4. The .align Directive



4.5 Directives That Format the Output Listing

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:

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

  You can use the .drlist directive to turn the listing on again.

- 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 –x option (see page 3-6).

- 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.

4.6 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 2.7.1, *External Symbols*, on page 2-18). 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.

4.7 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 [*well-defined expression*]	marks the beginning of a conditional block and assembles code if the .if *well-defined expression* is true.
.elseif [*well-defined expression*]	marks a block of code to be assembled if the .if *well-defined expression* is false and the .elseif condition is true.
.else	marks a block of code to be assembled if the .if *well-defined expression* 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 [*well-defined expression*]	marks the beginning of a repeatable block of code. The optional expression evaluates to the loop count.
.break [*well-defined expression*]	tells the assembler to assemble repeatedly when the .break *well-defined expression* 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 3.9.4, *Conditional Expressions*, on page 3-27.

4.8 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 can be redefined.

```
.asg  ”10, 20, 30, 40”, coefficients

.byte coefficients
```

- 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
.loop
.byte    x*10h
.break   x = 4
.eval    x+1, x
.endloop
```

- 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 page 4-49 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   1000h
       .long  bval, bval*2, bval+12
       MVK    bval, A2
```

  The .set and .equ directives produce no object code. The two directives are identical and can be used interchangeably.

- The **.struct/.endstruct** directives set up C-like structure definitions, and the **.tag** directive assigns the C-like structure characteristics to a label.

  The .struct/.endstruct directives allow you to organize your information into structures so that similar elements can be grouped together. Element offset calculation is left up to the assembler. The .struct/.endstruct directives do not allocate memory. They simply create a symbolic template that can be used repeatedly.

  The .tag directive assigns a label to a structure. This simplifies the symbolic representation and also provides the ability to define structures that contain other structures. The .tag directive does not allocate memory, and the structure tag (stag) must be defined before it is used.

```
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.
```

4.9 Miscellaneous Directives

These directives enable miscellaneous functions or features:

- The **.clink** directive sets the STYP_CLINK flag in the type field for the named section. The .clink directive can be applied to initialized or uninitialized sections. The STYP_CLINK flag enables conditional linking by telling the linker to leave the section out of the final COFF output of the linker if there are no references found to any symbol in the section.

- 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 **.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. For more information, see section 3.8.2, *Local Labels*, on page 3-17.

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 5.7, *Producing Messages in Macros*, on page 5-17.

4.10 Directives Reference

The remainder of this chapter is a reference. Generally, the directives are organized alphabetically, one directive per page; however, related directives (such as .if/.else/.endif) are presented together on one page. Following is an alphabetical table of contents for the directives reference:

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 assembler assembles words containing null values (0) up to the next *size in bytes* boundary:

Operand of	1	aligns SPC to byte boundary
	2	aligns SPC to halfword boundary
	4	aligns SPC to word boundary
	8	aligns SPC to doubleword boundary
	128	aligns SPC to page 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
```

Syntax

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

.eval *well-defined expression*, *substitution symbol*

Description

The **.asg** directive assigns 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 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 *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 **.eval** directive performs arithmetic on substitution symbols, which are stored in the substitution symbol table. This directive evaluates the *well-defined 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 *well-defined expression* is an alphanumeric expression in which all symbols have been previously defined in the current source module, so that the result is an absolute.
- 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 ($).

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
```

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 label 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 expression. The assembler allocates size bytes in the .bss section.
- The *alignment* is an optional parameter that ensures that the space allocated to the symbol occurs on the specified boundary. This boundary indicates the size of the slot in bytes and must be set to a power of 2. If the SPC is 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 COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

Example

In this example, the .bss directive is used to allocate 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.

```
 1                      ****************************************
 2                      **  Start assembling into .text section. **
 3                      ****************************************
 4 00000000                     .text
 5 00000000 008001A0            MV      A0,A1
 6
 7                      ****************************************
 8                      **  Allocate 100 bytes in .bss.         **
 9                      ****************************************
10 00000000                     .bss    array,100
11
12                      ****************************************
13                      **  Still in .text                      **
14                      ****************************************
15 00000004 010401A0            MV      A1,A2
16
17                      ****************************************
18                      **  Declare external .bss symbol        **
19                      ****************************************
20                             .global array
```

Syntax

.byte $value_1$ [, ... , $value_n$]
.char $value_1$ [, ... , $value_n$]

Description

The **.byte** and **.char** 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.

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. You can use up to 100 value parameters, but the total line length cannot exceed 200 characters.

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

When you use .byte or .char in a .struct/.endstruct sequence, .byte and .char define a member's size; they do not initialize memory. For more information about .struct/.endstruct, see page 4-68.

Example

In this example, 8-bit values (10, –1, abc, and a) are placed into consecutive bytes in memory with .byte and .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'
  00000007 000000FD
  00000008 00000064
  00000009 00000065
  0000000a 00000066
  0000000b 00000062
```

Syntax

.clink [”*section name*”]

Description

The **.clink** directive sets up conditional linking for a section by setting the STYP_CLINK flag in the type field for *section name*. The .clink directive can be applied to initialized or uninitialized sections.

The *section name* identifies the section. If .clink is used without a section name, it applies to the current initialized section. If .clink is applied to an uninitialized section, the section name is required. The section name is significant to 200 characters and must be enclosed in double quotes. A section name can contain a subsection name in the form *section name*:*subsection name*.

The .clink directive tells the linker to leave the section out of the final COFF output of the linker if there are no references found in a linked section to any symbol defined in the specified section. The –a linker option produces the final COFF output in the form of an absolute, executable output module.

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 COFF output
23 0000000c 00040AF8          CMPLT  A0,A1,A0
```

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 can be 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 –i assembler option
3) Any directories specified by the C6x_A_DIR or A_DIR environment variable

For more information about the –i option, C6x_A_DIR, and A_DIR, see section 3.4, *Naming Alternate Directories for Assembler Input*, on page 3-7.

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. An 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.

copy.asm (source file)	byte2.asm (first include file)	word2.asm (second include file)
.space 29 **.include "byte2.asm"** **Back in original file .string "done"	** In byte2.asm .byte 32,1+ 'A' **.include "word2.asm"** ** Back in byte.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
```

Syntax

```
.data
```

Description

The **.data** directive tells the assembler to begin assembling source code into the .data section; .data becomes the current section. The .data section is normally used to contain tables of data or preinitialized variables.

For more information about COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

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
```

Syntax

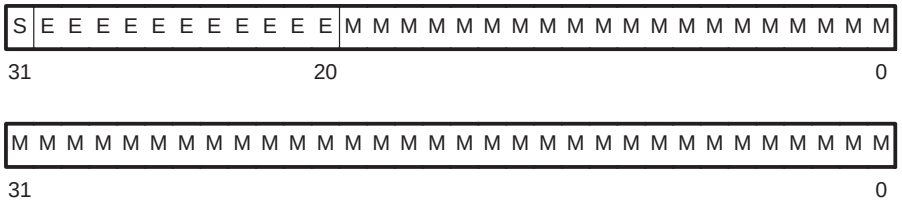
.double $value_1$ [**,** ... **,** $value_n$]

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 a floating-point constant or a symbol that has been equated to a floating-point constant. 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 4–5.

Figure 4–5. Double-Precision Floating-Point Format



Legend: S = sign (1 bit)
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 about .struct/.endstruct, see page 4-68.

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
```

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:

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

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, and it does not prevent the assembler from producing an object file.

Example

In this example, the message ERROR — MISSING PARAMETER is sent 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:

```
*** ERROR!   line 12:  ***** USER ERROR ***** - : ERROR -- MISSING PARAMETER
                .emsg   "ERROR -- MISSING PARAMETER"

 1 Assembly Error, No Assembly Warnings

Errors in source - Assembler Aborted
```

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.

Note: Ending a Macro

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
```

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
```

Syntax

.field *value* [**,** *size in bits*]

Description

The **.field** directive initializes a multiple-bit field within a single word 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. If you do not specify a size, the assembler assumes the 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:

```
*** WARNING! line 21: W0001: Field value truncated to 1
                .field  3, 1
```

Successive .field directives pack values into the specified number of bits starting at the current 32-bit slot. 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.

You can use the .align directive to force the next .field directive to begin packing into a new word.

If you use a label, it points to the byte that contains the specified field.

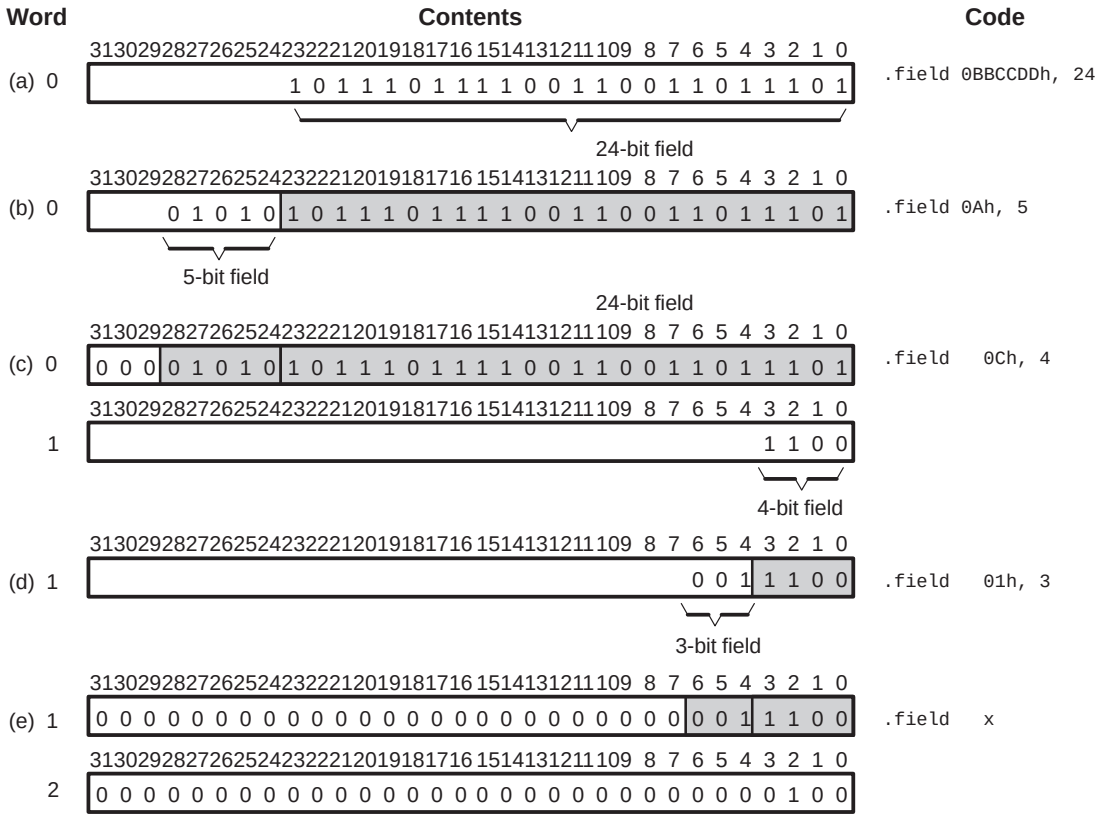
When you use .field in a .struct/.endstruct sequence, .field defines a member's size; it does not initialize memory. For more information about .struct/ .endstruct, see page 4-68.

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. Figure 4–6 shows how the directives in this example affect memory.

```
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 4–6. The .field Directive



Syntax

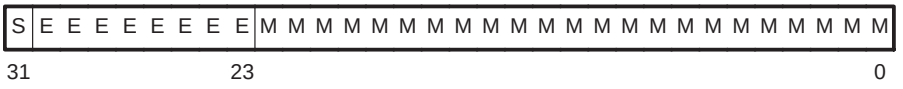
.float *value* [**,** ..., *value*$_n$]

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 a floating-point constant or a symbol that has been equated to a floating-point constant. Each constant is converted to a floating-point value in IEEE single-precision 32-bit format.

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 4–7.

Figure 4–7. Single-Precision Floating-Point Format



value = $(-1)^S$ x (1.0 + mantissa) x $(2)^{exponent-127}$

Legend: S = sign (1 bit)
E = exponent (8-bit biased)
M = mantissa (23-bit normalized fraction)

When you use .float in a .struct/.endstruct sequence, .float defines a member's size; it does not initialize memory. For more information about .struct/.endstruct, see page 4-68.

Example

Following are examples of the .float directive:

```
1 00000000 E9045951       .float  –1.0e25
2 00000004 40400000       .float  3
3 00000008 42F60000       .float  123
```

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. As with all symbols, if a global symbol is defined more than once, the linker issues a multiple-definition error. 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
```

Syntax

.half $value_1$ [, ... , $value_n$]
.short $value_1$ [, ... , $value_n$]

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 slot 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. You can use as many values as fit on a single line, but the total line length cannot exceed 200 characters.

If you use a label with .half or .short, it points to the location where the assembler places the first byte.

The .half and .short 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 or .short in a .struct/.endstruct sequence, they define a member's size; they do not initialize memory. For more information about .struct/.endstruct, see page 4-68.

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
```

Syntax

.if *well-defined expression*
[**.elseif** *well-defined expression*]
[**.else**]
.endif

Description

Four directives provide conditional assembly:

- The **.if** directive marks the beginning of a conditional block. The *well-defined expression* 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 directive is optional in the conditional block, and more than one .elseif can be used. If an expression is false and there is no .elseif statement, 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 **.endif** directive terminates a conditional block.

The .elseif and .else directives can be used in the same conditional assembly block, and the .elseif directive can be used more than once within a conditional assembly block.

For information about relational operators, see subsection 3.9.4, *Conditional Expressions*, on page 3-27.

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
```

Syntax

.int *value*$_1$ [, ... , *value*$_n$]
.long *value*$_1$ [, ... , *value*$_n$]
.**word** *value*$_1$ [, ... , *value*$_n$]

Description

The **.int, .uint**, **.long**, **.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 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.

You can use as many values as fit on a single line (200 characters). If you use a label with .int, .long, or .word, it points to the first word that is initialized.

When you use .int, .long, or .word directives in a .struct/.endstruct sequence, they define a member's size; they do not initialize memory. For more information about .struct/.endstruct, see page 4-68.

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
```

Note: Data Size of longs

For the C6000 C/C++ compiler, a long data value is 40 bits. For the C6000 assembler, a long data value is 32 bits. Therefore, the .long directive treats values assigned to it as 32-bit values.

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.

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
```

For more information about assigning run-time and load-time addresses in the linker, see section 7.9, *Specifying a Section's Run-Time Address*, on page 7-40.

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
```

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 –al option on the command line (see page 3-5), 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
```

Syntax

.loop [*well-defined expression*]
.break [*well-defined expression*]
.endloop

Description

Three directives allow you to repeatedly assemble a block of code:

- The **.loop** directive begins a repeatable block of code. The optional expression evaluates to the loop count (the number of loops to be performed). If there is no *well-defined expression*, the loop count defaults to 1024, unless the assembler first encounters a .break directive with an expression that is true (nonzero) or omitted.
- The **.break** directive, along with its expression, is optional. This means that when you use the .loop construct, you do not have to use the .break construct. The .break directive terminates a repeatable block of code only if the *well-defined expression* is true (nonzero) or omitted, and the assembler breaks the loop and assembles the code after the .endloop directive. If the expression is false (evaluates to 0), the loop continues.
- The **.endloop** directive terminates a repeatable block of code; it executes when the .break directive is true (nonzero) or when the number of loops performed equals the loop count given by .loop.

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
```

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 –i assembler option
3) Any directories specified by the C6X_A_DIR or A_DIR environment variable

For more information about the –i option, C6X_A_DIR, and A_DIR, see section 3.4, *Naming Alternate Directories for Assembler Input*, on page 3-7.

When the assembler encounters a .mlib directive, it opens the library specified by the *filename* and creates a table of the library’s contents. The assembler enters the names of the individual library members into the opcode table 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, but it does not place the source code into the listing. Only macros that are actually called from the library are extracted, and they are extracted only once.

For more information on macros and macro libraries, see Chapter 5, *Macro Language*.

Example

This example creates a macro library that defines two macros, inc1 and dec1. The file inc1.asm contains the definition of inc1, and dec1.asm contains the definition of dec1.

inc1.asm

```
* Macro for incrementing
inc1   .macro   A
       ADD      A,1,A
       .endm
```

dec1.asm

```
* 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 and dec1 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
```

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.

For more information on macros and macro libraries, see Chapter 5, *Macro Language*. For more information about .loop and .endloop, see page 4-53.

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
```

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, cannot be used in expressions, and do not qualify for branch expansion if used with a branch. 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.

For more information on the use of local labels, see subsection 3.8.2, *Local Labels*, on page 3-17.

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
```

Syntax

.option *option*$_1$[**,** *option*$_2$**,** . . .]

Description

The **.option** directive selects options for the assembler output listing. The o*ptions* 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 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 –ax option (see page 3-6).

Options *are not* case sensitive.

Example

This example shows how to limit the listings of the .byte, .char, .int, .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’
   00000020 00000259
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
```

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:

```
        .title   "**** Page Directive Example ****"
;         .
;         .
;         .
        .page
```

Listing file:

```
TMS320C6x COFF Assembler    Version x.xx     Tue Apr 14 17:16:51 1997
Copyright (c) 1996–1997 Texas Instruments Incorporated
**** Page Directive Example ****                                  PAGE    1

       2                    ;        .
       3                    ;        .
       4                    ;        .
TMS320C6x COFF Assembler    Version x.xx     Tue Apr 14 17:16:51 1997
Copyright (c) 1996–1997 Texas Instruments Incorporated
**** Page Directive Example ****                                  PAGE    2


 No Errors, No Warnings
```

Syntax

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

Description

The **.sect** directive defines a named section that can be used like the default .text and .data sections. The .sect directive tells the assembler to begin assembling source code into the named section.

The *section name* identifies the section. The section name is significant to 200 characters and must be enclosed in double quotes. A section name can contain a subsection name in the form *section name***:***subsection name*.

For more information about COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

Example

This example defines one special-purpose section, vars, and assembles code into it.

```
1                    ******************************************
2                    **   Begin assembling into .text section.   **
3                    ******************************************
4 00000000                   .text
5 00000000 000005E0          ZERO    A0
6 00000004 008425E0          ZERO    A1
7
8                    ******************************************
9                    **   Begin assembling into vars section.    **
10                    ******************************************
11 00000000                   .sect   "vars"
12 00000000 4048F5C3  pi      .float  3.14
13 00000004 000007D0  max     .int    2000
14 00000008 00000001  min     .int    1
15
16                    ******************************************
17                    **   Resume assembling into .text section.  **
18                    ******************************************
19 00000008                   .text
20 00000008 010000A8          MVK     1,A2
21 0000000c 018000A8          MVK     1,A3
22
23                    ******************************************
24                    **   Resume assembling into vars section.   **
25                    ******************************************
26 0000000c                   .sect   "vars"
27 0000000c 00000019  count   .short  25
```

Syntax

symbol **.set** *value*
symbol **.equ** *value*

Description

The **.set** and **.equ** directives equate a constant value to a 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 page 4-42). 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
```

Syntax

.space *size in bytes*

.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.

```
 1                      ****************************************************
 2                      **     Begin assembling into the .text section.    **
 3                      ****************************************************
 4 00000000                     .text
 5                      ****************************************************
 6                      **  Reserve 0F0 bytes (60 words in .text section). **
 7                      ****************************************************
 8 00000000                     .space  0F0h
 9 000000f0 00000100            .word   100h, 200h
   000000f4 00000200
10                      ****************************************************
11                      **     Begin assembling into the .data section.    **
12                      ****************************************************
13 00000000                     .data
14 00000000 00000049           .string "In .data"
   00000001 0000006E
   00000002 00000020
   00000003 0000002E
   00000004 00000064
   00000005 00000061
   00000006 00000074
   00000007 00000061
15                      ****************************************************
16                      **     Reserve 100 bytes in the .data section;     **
17                      **         RES_1 points to the first word          **
18                      **          that contains reserved bytes.          **
19                      ****************************************************
20 00000008           RES_1:   .space  100
21 0000006c 0000000F           .word   15
22 00000070 00000008"          .word   RES_1
23                      ****************************************************
24                      **     Reserve 20 bytes in the .data section;      **
25                      **          RES_2 points to the last word          **
26                      **          that contains reserved bytes.          **
27                      ****************************************************
28 00000087           RES_2:   .bes    20
29 00000088 00000036           .word   36h
30 0000008c 00000087"          .word   RES_2
```

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
```

Syntax

.string {*expr*$_1$ | "*string*$_1$"} [, ... , {*expr*$_n$ | "*string*$_n$"}]

Description

The **.string** directive places 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 assembler truncates any values that are greater than eight bits. You can have up to 100 operands, but they must fit on a single source statement line.

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

When you use .string in a .struct/.endstruct sequence, .string defines a member's size; it does not initialize memory. For more information about .struct/.endstruct, see page 4-68.

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
```

Syntax

[*stag*]	**.struct**	[*expr*]
[mem_0]	*element*	[$expr_0$]
[mem_1]	*element*	[$expr_1$]
.	.	.
.	.	.
.	.	.
[mem_n]	**.tag** *stag*	[*exprn*]
.	.	.
.	.	.
.	.	.
[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 *element* is one of the following descriptors: .string, .byte, .char, .int, .half, .short, .word, .long, .double, .float, .tag, or .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.
- 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. A .stag is optional for .struct, but is required for .tag.

Note: Directives That Can Appear in a .struct/.endstruct Sequence

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.

These 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
```

Syntax

[*stag*]	**.cstruct**	[*expr*]
[mem_0]	*element*	[$expr_0$]
[mem_1]	*element*	[$expr_1$]
.	.	.
.	.	.
.	.	.
[mem_n]	**.tag** *stag*	[*exprn*]
.	.	.
.	.	.
.	.	.
[mem_N]	*element*	[$expr_N$]
[*size*]	**.endstruct**	
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 **.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 *element* is one of the following descriptors: .string, .byte, .char, .int, .half, .short, .word, .long, .double, .float, .tag, or .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.
- 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. A .stag is optional for .struct, but is required for .tag.

Example

```
; Given: a structure in C that a user wishes to access
;        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 directive 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 will calculate
; the offsets in the same manner as the C compiler. The
; resulting assembly structure can be used to access the
; elements of the C structure. Notice the different in
; the offsets from those structures defined via .struct
; above, and compare them to 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
```

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
```

Syntax

```
.text
```

Description

The **.text** directive tells the assembler to begin assembling 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 COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

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
```

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:

```
TMS320C6x COFF Assembler    Version x.xx     Tue Apr 14 17:18:21 1997
Copyright (c) 1996–1997 Texas Instruments Incorporated
**** Fast Fourier Transforms ****                                  PAGE    1

       2                    ;        .
       3                    ;        .
       4                    ;        .
TMS320C6x COFF Assembler    Version x.xx     Tue Apr 14 17:18:21 1997
Copyright (c) 1996–1997 Texas Instruments Incorporated
**** Floating–Point Routines ****                                  PAGE    2


 No Errors, No Warnings
```

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* is significant to 200 characters and 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 indicates the size of the slot in bytes and can be set to any 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) end the current section and tell the assembler to 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 COFF sections, see Chapter 2, *Introduction to Common Object File Format*.

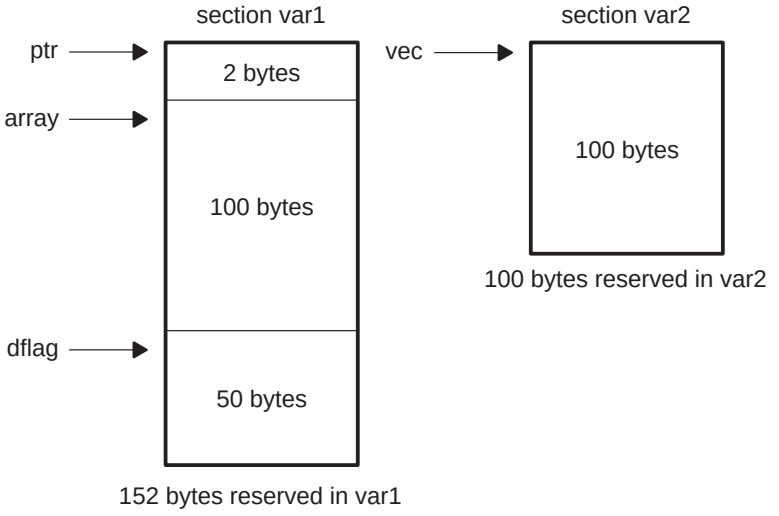
Example

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 4–8 shows how this example reserves space in two uninitialized sections, var1 and var2.

```
 1                    ************************************************
 2                    **   Assemble into .text section              **
 3                    ************************************************
 4 00000000                    .text
 5 00000000 008001A0           MV      A0,A1
 6
 7                    ************************************************
 8                    **   Reserve 2 bytes in var1.                 **
 9                    ************************************************
10 00000000           ptr     .usect  "var1",2
11 00000004 0100004C-         LDH     *+B14(ptr),A2   ; still in .text
12
13                    ************************************************
14                    **   Reserve 100 bytes in var1                **
15                    ************************************************
16 00000002           array   .usect  "var1",100
17 00000008 01800128-         MVK     array,A3        ; still in .text
18 0000000c 01800068-         MVKH    array,A3
19
20                    ************************************************
21                    **   Reserve 50 bytes in var1                 **
22                    ************************************************
23 00000066           dflag   .usect  "var1",50
24 00000010 02003328-         MVK     dflag,A4
25 00000014 02000068-         MVKH    dflag,A4
26
27                    ************************************************
28                    **   Reserve 100 bytes in var1                **
29                    ************************************************
30 00000000           vec     .usect  "var2",100
31 00000018 0000002A-         MVK     vec,B0          ; still in .text
32 0000001c 0000006A-         MVKH    vec,B0
```

Figure 4–8. The .usect Directive



Chapter 5

Macro Language

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**

5.1 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 5.3, *Macro Parameters/Substitution Symbols*, page 5-5, 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:

- ❏ Macros can be defined at the beginning of a *source file* or in an copy/include file. See section 5.2, *Defining Macros*, for more information.
- ❏ 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 5.4, *Macro Libraries*, page 5-13.

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 5.8, *Using Directives to Format the Output Listing*, page 5-19.

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.

5.2 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 page 4-28); they can also be defined in a macro library. For more information, see section 5.4, *Macro Libraries*, page 5-13.

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 5.9, *Using Recursive and Nested Macros*, page 5-21.

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 5.3, *Macro Parameters/Substitution Symbols*, page 5-5.

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.

Example 5–1 shows the definition, call, and expansion of a macro.

Example 5–1. 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
```

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 5.7, *Producing Messages in Macros*, page 5-17, for more information about macro comments.

5.3 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 3.8.6, *Substitution Symbols*, page 3-23).

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 5.3.6, *Substitution Symbols as Local Variables in Macros*, page 5-12.

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 5–2 shows the expansion of a macro with varying numbers of arguments.

Example 5–2. 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
```

5.3.1 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.

  The syntax of the .asg directive is:

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

  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.

Example 5–3 shows character strings being assigned to substitution symbols.

Example 5–3. The .asg Directive

```
   .asg   "A4", RETVAL              ; return value
   .asg   "B14", PAGEPTR            ; global page pointer
   .asg   """Version 1.0""", version
   .asg   "p1, p2, p3", list
```

- The **.eval** directive performs arithmetic on numeric substitution symbols.

  The syntax of the .eval directive is:

  .eval *well-defined expresssion, substitution symbol*

  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.

Example 5–4 shows arithmetic being performed on substitution symbols.

Example 5–4. The .eval Directive

```
.asg   1,counter
.loop  100
.word  counter
.eval  counter + 1,counter
.endloop
```

In Example 5–4, 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.

For more information about the .asg and eval assembler directives, see page 4-23.

5.3.2 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 5–1, *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 5–1. 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 if string *a* is a valid predefined register name 0 if string *a* is not a valid predefined register name

† For more information about predefined register names, see section 3.8.5, *Predefined Symbolic Constants*, on page 3-22.

Example 5–5 shows built-in substitution symbol functions.

Example 5–5. 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
```

5.3.3 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 5–6, 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 5–6. 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
```

5.3.4 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 5–7 shows how the forced substitution operator is used.

Example 5–7. Using the Forced Substitution Operator

```
force    .macro   x
         .loop    8
PORT:x:  .set     x*4
         .eval    x+1, x
         .endloop
         .endm

         .global  portbase
          force    0
```

This generates the following source code:

```
  PORT0  .set     0
  PORT1  .set     4
    .
    .
    .
  PORT7  .set     28
```

5.3.5 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 5–8 and Example 5–9 show built-in substitution symbol functions used with subscripted substitution symbols.

Example 5–8. 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
```

In Example 5–8, subscripted substitution symbols redefine the STW instruction so that it handles immediate.

Example 5–9. 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
```

In Example 5–9, 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.

5.3.6 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 5–8 and Example 5–9, page 5-11.

5.4 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 on page 4-55). 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 5.1, *Using Macros*, on page 5-2, 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 5.8, *Using Directives to Format the Output Listing*, page 5-19 and the .mlist description on page 4-57. 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 Chapter 6, *Archiver Description*.

5.5 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. For more information on the .if/ .elseif/.else/.endif directives, see page 4-45.

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). For more information on the .loop/.break/ .endloop directives, see page 4-53.

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.

Example 5–10, Example 5–11, and Example 5–12 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 5–10. 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 5–11. Nested Conditional Assembly Directives

```
       .asg   1,x
       .loop

       .if (x == 10)    ;  if x == 10 quit loop
       .break           ;  force break
       .endif

       .eval  x+1,x
       .endloop
```

Example 5–12. 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
```

For more information, see section 4.7, *Directives That Enable Conditional Assembly*, on page 4-17.

5.6 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. The syntax for a unique label is:

*label***?**

Example 5–13 shows unique label generation in a macro.

Example 5–13. 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
```

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 –ax option (see page 3-6).

5.7 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 5–14 shows user messages in macros and macro comments that do not appear in the macro expansion.

Example 5–14. 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
```

For more information about the .emsg, .mmsg, and .wmsg assembler directives, see page 4-34.

5.8 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.

5.9 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 5–15 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 5–15. 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 5–16 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 5–16. Using Recursive Macros

```
       .fcnolist

fact1  .macro n

       .if n == 1
          MVK globcnt, A1              ; Leave the answer in the A1 register.

       .else
          .eval n–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
```

5.10 Macro Directives Summary

The following directives 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 5–2. Creating Macros

Mnemonic and Syntax	Description	See Page: Macro Use	See Page: Directive Description
.endm	End macro definition	5-3	5-3
macname **.macro** [*parameter*$_1$] [**,** ... **,** *parameter*$_n$]	Define macro by *macname*	5-3	5-3
.mexit	Go to .endm	5-3	5-3
.mlib *filename*	Identify library containing macro definitions	5-13	4-55

Table 5–3. Manipulating Substitution Symbols

Mnemonic and Syntax	Description	See Page: Macro Use	See Page: Directive Description
.asg [**"**]*character string*[**"**]*, substitution symbol*	Assign character string to substitution symbol	5-6	4-23
.eval *well-defined expression, substitution symbol*	Perform arithmetic on numeric substitution symbols	5-7	4-23
.var *sym*$_1$ [**,***sym*$_2$**,** ... **,***sym*$_n$]	Define local macro symbols	5-12	5-12

Table 5–4. Conditional Assembly

Mnemonic and Syntax	Description	See Page: Macro Use	See Page: Directive Description
.break [*well-defined expression*]	Optional repeatable block assembly	5-14	4-53
.endif	End conditional assembly	5-14	4-45
.endloop	End repeatable block assembly	5-14	4-53
.else	Optional conditional assembly block	5-14	4-45
.elseif *well-defined expression*	Optional conditional assembly block	5-14	4-45
.if *well-defined expression*	Begin conditional assembly	5-14	4-45
.loop [*well-defined expression*]	Begin repeatable block assembly	5-14	4-53

Table 5–5. Producing Assembly-Time Messages

Mnemonic and Syntax	Description	See Page: Macro Use	See Page: Directive Description
.emsg	Send error message to standard output	5-17	4-34
.mmsg	Send assembly-time message to standard output	5-17	4-34
.wmsg	Send warning message to standard output	5-17	4-34

Table 5–6. Formatting the Listing

Mnemonic and Syntax	Description	See Page: Macro Use	See Page: Directive Description
.fclist	Allow false conditional code block listing (default)	5-19	4-37
.fcnolist	Suppress false conditional code block listing	5-19	4-37
.mlist	Allow macro listings (default)	5-19	4-57
.mnolist	Suppress macro listings	5-19	4-57
.sslist	Allow expanded substitution symbol listing	5-19	4-65
.ssnolist	Suppress expanded substitution symbol listing (default)	5-19	4-65

Chapter 6

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**

6.1 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.

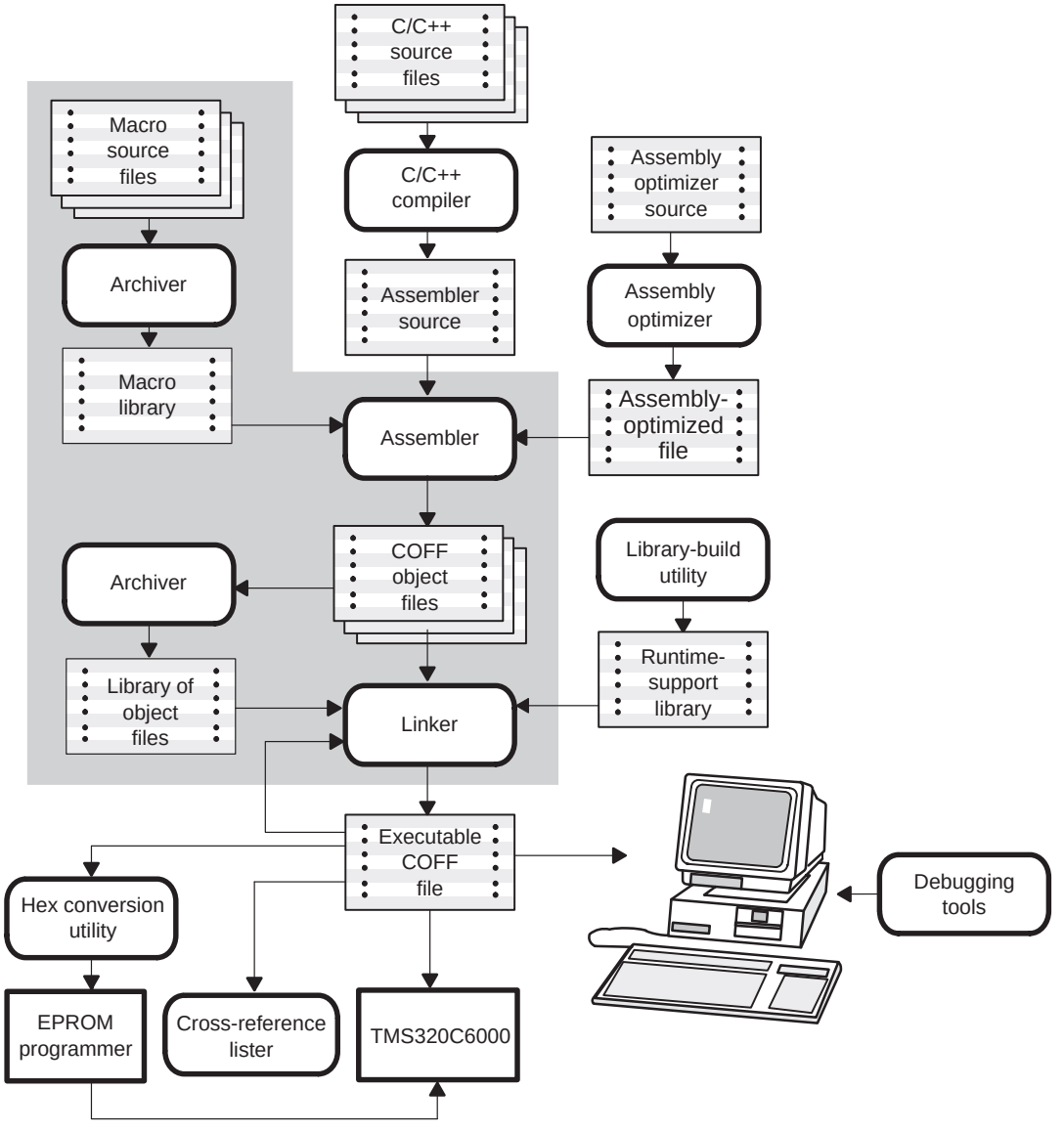
One of the most useful applications of the archiver is building libraries of object modules. For example, you can write several arithmetic routines, assemble them, and use the archiver to collect the object files into a single, logical group. You can then specify the object library as linker input. The 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 5, *Macro Language*, discusses macros and macro libraries in detail, while this chapter explains how to use the archiver to build libraries.

6.2 The Archiver's Role in the Software Development Flow

Figure 6–1 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 6–1. The Archiver in the TMS320C6000 Software Development Flow



6.3 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 *filenames*. 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 page 6-7 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.

Note: Naming Library Members

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.

6.4 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 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 Apr 16 10:00:24 1997
           cos.obj     300   Wed Apr 16 10:00:30 1997
           flt.obj     300   Wed Apr 16 09:59:56 1997
  ```

- 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: '$sin'
  ==> symbol defined: '_cos'
  ==> symbol defined: '$cos'
  ==> symbol defined: '_tan'
  ==> symbol defined: '$tan'
  ==> symbol defined: '_atan
  ==> symbol defined: '$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'
  ```

  This is the modules.cmd 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
  ```

  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.

Chapter 7

Linker Description

The TMS320C6000™ linker creates executable modules by combining COFF object files. This chapter describes the linker options, directives, and statements used to create executable modules. Object libraries, command files, and other key concepts are discussed as well.

The concept of COFF sections is basic to linker operation; Chapter 2, *Introduction to Common Object File Format*, discusses the COFF format in detail.

Topic **Page**

7.1 Linker Overview

The TMS320C6000 linker allows you to configure system memory by allocating output sections efficiently into 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

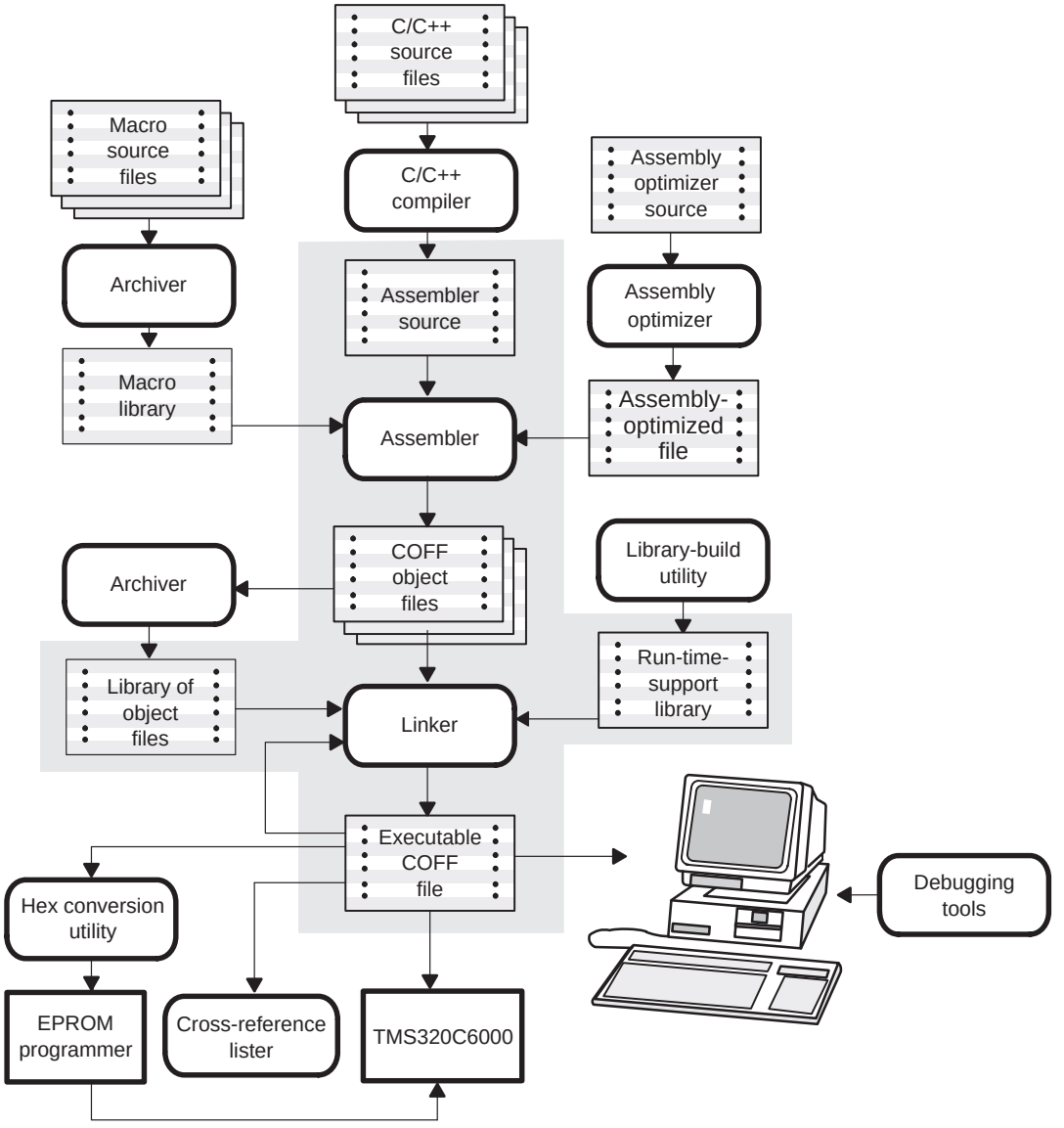
The linker command language controls memory configuration, output section definition, and address binding. The language supports expression assignment and evaluation. You configure system memory by defining and creating a memory model that you design. Two powerful directives, MEMORY and SECTIONS, allow you to:

- ❑ Allocate sections into specific areas of memory
- ❑ Combine object file sections
- ❑ Define or redefine global symbols at link time

7.2 The Linker's Role in the Software Development Flow

Figure 7–1 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 COFF object module that can be downloaded to one of several development tools or executed by a TMS320C6000 device.

Figure 7–1. The Linker in the TMS320C6000 Software Development Flow



7.3 Invoking the Linker

The general syntax for invoking the linker is:

lnk6x [*options*] *filename*$_1$ *... filename*$_n$

lnk6x is the command that invokes the linker.

options can appear anywhere on the command line or in a linker command file. (Options are discussed in section 7.4, *Linker Options*, on page 7-5.)

filename$_1$, *filename*$_n$ can be object files, linker 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 –o option to name the output file.

There are three 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.

  ```
  lnk6x file1.obj file2.obj –o link.out
  ```

- Enter the **lnk6x** command with no filenames or options; the linker prompts for them:

  ```
  Command files :
  Object files [.obj] :
  Output file [ ] :
  Options :
  ```

  - For *command files,* enter one or more linker command filenames.
  - For *object files,* enter one or more object filenames. The default extension is *.obj.* Separate the filenames with spaces or commas; if the last character is a comma, the linker prompts for an additional line of object filenames.
  - The *output file* is the name of the linker output module. This overrides any –o options that you enter. If there are no –o options and you do not answer this prompt, the linker creates an object file with a default filename of *a.out*.
  - The *options* prompt is for additional options, although you can also enter them in a command file. Enter them with hyphens, just as you would on the command line.

- Put filenames and options in a linker command file. For example, assume the file linker.cmd contains the following lines:

```
–o link.out
file1.obj
file2.obj
```

  Now you can invoke the linker from the command line; specify the command filename as an input file:

```
lnk6x 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:

```
lnk6x –m 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.

7.4 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 7–1 summarizes the linker options.

You can string together the options that do not have parameters (for example, lnk6x –ar) or enter them separately (for example, lnk6x –a –r). You must specify options that have parameters separately from other options (for example, lnk6x –i 6xtools –ar).

Table 7–1. Linker Options Summary

Option	Description	Page
–a	Produces an absolute, executable module. This is the default; if neither –a nor –r is specified, the linker acts as if –a were specified.	7-7
–ar	Produces a relocatable, executable object module.	7-7
–b	Disables merge of symbolic debugging information.	7-8
–c	Autoinitializes variables at run time.	7-9
–cr	Initializes variables at load time.	7-9
–e *global_symbol*	Defines a global symbol that specifies the primary entry point for the output module.	7-9
–f *fill_value*	Sets default fill values for holes within output sections; *fill_value* is a 32-bit constant.	7-10
–g *symbol*	Makes *symbol* global (overrides –h).	7-10
–h	Makes all global symbols static.	7-10
–heap *size*	Sets heap size (for the dynamic memory allocation in C) to *size* words and defines a global symbol that specifies the heap size. Default = 1K words.	7-11
–help	Produces help listing (this one).	
–i *pathname*	Alters library-search algorithms to look in a directory named with *pathname* before looking in the default location. This option must appear before the –l option.	7-12
–j	Disables conditional linking.	7-14
–l *filename*	Names an archive library or linker command *filename* as linker input.	7-11
–m *filename*	Produces a map or listing of the input and output sections, including holes, and places the listing in *filename.*	7-14
–o *filename*	Names the executable output module. The default filename is a.out.	7-16
-priority	Satisfies unresolved references by the first library that contains a definition for that symbol.	7-16
–q	Suppresses the banner and all progress information (linker runs in quiet mode).	7-16
–r	Produces a nonexecutable, relocatable output module.	7-7
–s	Strips symbol table information and line number entries from the output module.	7-17
–stack *size*	Sets C system stack size to *size* words and defines a global symbol that specifies the stack size. Default = 1K words.	7-17
–u *symbol*	Places an unresolved external *symbol* into the output module's symbol table.	7-18
–w	Displays a message when an undefined output section is created.	7-18
–x	Forces rereading of libraries, which resolves back references.	7-19

7.4.1 Relocation Capabilities (–a and –r Options)

The linker performs relocation, which is the process of adjusting all references to a symbol when the symbol's address changes. The linker supports two options (–a and –r) that allow you to produce an absolute or a relocatable output module.

❑ **Producing an absolute output module (–a option)**

When you use the –a option without the –r 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 (section 7.13.4, on page 7-56, describes these symbols)
- An optional header that describes information such as the program entry point
- *No* unresolved references

The following example links file1.obj and file2.obj and creates an absolute output module called a.out:

```
lnk6x -a file1.obj file2.obj
```

Note: The –a and –r Options

If you do not use the –a or the –r option, the linker acts as if you specified –a.

❑ **Producing a relocatable output module (–r option)**

When you use the –r option without the –a 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 –r to retain the relocation entries.

The linker produces a file that is not executable when you use the –r option without –a. 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:

```
lnk6x -r 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 7.15, *Partial (Incremental) Linking*, on page 7-65.)

- **Producing an executable relocatable output module (–ar option combination)**

  If you invoke the linker with both the –a and –r 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 and creates an executable, relocatable output module called xr.out:

  ```
  lnk6x –ar file1.obj file2.obj –o xr.out
  ```

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).

7.4.2 Disable Merge of Symbolic Debugging Information (–b 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 –b option if you want the linker to keep such duplicate entries. Using the –b option has the effect of the linker running faster and using less machine memory.

7.4.3 C Language Options (–c and –cr Options)

The –c and –cr options cause the linker to use linking conventions that are required by the C compiler.

- The –c option tells the linker to autoinitialize variables at run time.
- The –cr option tells the linker to initialize variables at load time.

For more information, see section 7.16, *Linking C Code*, on page 7-67, section 7.16.4, *Autoinitialization of Variables at Run Time*, on page 7-69, and section 7.16.5, *Initialization of Variables at Load Time*, on page 7-70.

7.4.4 Define an Entry Point (–e *global_symbol* 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 –e option. The syntax is:

  –e *global_symbol*

  where *global_symbol* defines the entry point and must be as an external symbol of the input files.

- 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.

```
lnk6x –e begin file1.obj file2.obj
```

7.4.5 Set Default Fill Value (–f *fill_value* Option)

The –f option fills the holes formed within output sections. The syntax for the –f option is:

–f *fill_value*

The argument *fill_value* is a 32-bit constant (up to eight hexadecimal digits). If you do not use –f, the linker uses 0 as the default fill value.

This example fills holes with the hexadecimal value ABCDABCD:

```
lnk6x -f 0xABCDABCD file1.obj file2.obj
```

7.4.6 Make a Symbol Global (–g *symbol* Option)

The –h option makes all global symbols static. If you have a symbol that you want to remain global and you use the –h option, you can use the –g option to declare that symbol to be global. The –g option overrides the effect of the –h option for the symbol that you specify. The syntax for the –g option is:

–g *global_symbol*

7.4.7 Make All Global Symbols Static (–h Option)

The –h 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 –h 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 –h 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.

```
lnk6x -h file1.obj file2.obj
```

7.4.8 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 option. The syntax for the –heap option is:

–heap *size*

The *size* must be a constant. This example defines a 4K byte heap:

```
lnk6x –heap 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 and assigns it a value equal to the size of the heap. The default size is 1K bytes.

For more information, see section 7.16, *Linking C/C++ Code*, on page 7-67.

7.4.9 Alter the Library Search Algorithm (–l Option, –i Option, and C_DIR/C6X_C_DIR Environment Variables)

Usually, when you want to specify a library or linker command file as linker input, you simply enter the library or command filename as you would any other input filename; the linker looks for the filename 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:

```
lnk6x file1.obj object.lib
```

If you want to use a library or command file that is not in the current directory, use the –l (lowercase L) linker option. The syntax for this option is:

–l [*pathname*] *filename*

The *filename* is the name of an archive library or linker command file; the space between –l and the filename is optional.

You can augment the linker's directory search algorithm by using the –i linker option or the C_DIR or C6X_C_DIR environment variables. The linker searches for object libraries and command files specified by the –l option in the following order:

1) It searches directories named with the –i linker option. The –i option must appear before the –l option on the command line or in a command file.

2) It searches directories named with C_DIR and C6X_C_DIR.

3) If C_DIR and C6X_C_DIR are not set, it searches directories named with the assembler's A_DIR or C6X_A_DIR environment variable.

4) It searches the current directory.

7.4.9.1 Name an Alternate Library Directory (–i pathname *Option)*

The –i option names an alternate directory that contains object libraries. The syntax for this option is:

–i *pathname*

The *pathname* names a directory that contains object libraries or linker command files; the space between –i and the pathname is optional.

When the linker is searching for object libraries or linker command files named with the –l option, it searches through directories named with –i first. Each –i option specifies only one directory, but you can use several –i options per invocation. When you use the –i option to name an alternate directory, it must precede any –l 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. Assume the following paths for the libraries:

UNIX	/ld/r.lib and /ld2/lib2.lib
Windows	c:\ld\r.lib and c:\ld2\lib2.lib

The following examples show how you can set the –i option and use both libraries during a link:

Operating System	Enter
UNIX	`lnk6x f1.obj f2.obj –i/ld –i/ld2 –lr.lib –llib2.lib`
Windows	`lnk6x f1.obj f2.obj –i\ld –i\ld2 –lr.lib –llib2.lib`

7.4.9.2 Name an Alternate Library Directory (C_DIR and C6X_C_DIR Environment Variables)

An environment variable is a system symbol that you define and assign a string to. The linker uses environment variables named C6X_C_DIR and C_DIR to name alternate directories that contain object libraries. The command syntaxes for assigning the environment variable are:

Operating System	Enter
UNIX	**setenv C_DIR "***pathname*$_1$**;***pathname*$_2$**; . . ."**
Windows	**set C_DIR=** *pathname*$_1$**;***pathname*$_2$**; . . .**

The *pathnames* are directories that contain object libraries. Use the –l (lowercase L) linker option on the command line or in a command file to tell the linker which library or linker command file to search for.

For example, assume that there are two archive libraries called r.lib and lib2.lib. Assume the following paths for the library files:

UNIX	/ld/r.lib and /ld2/lib2.lib
Windows	c:\ld\r.lib and c:\ld2\lib2.lib

The following examples show how to set the environment variable and use both libraries during a link.

Operating System	Enter
UNIX	**setenv C_DIR "/ld ;/ld2"** **lnk6x f1.obj f2.obj –l r.lib –l lib2.lib**
Windows	**set C_DIR=\ld;\ld2** **lnk6x f1.obj f2.obj –l r.lib –l lib2.lib**

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

Operating System	Enter
UNIX	**unsetenv C_DIR**
Windows	**set C_DIR=**

The assembler uses an environment variable named C6X_A_DIR or A_DIR to name alternate directories that contain copy/include files or macro libraries. If C6X_C_DIR or C_DIR is not set, the linker searches for object libraries in the directories named with C6X_A_DIR or A_DIR. For more information about object libraries, see section 7.6 on page 7-23.

7.4.10 Disable Conditional Linking (–j Option)

The –j option disables conditional linking that has been set up with the assembler .clink directive. By default, all sections are unconditionally linked. See page 4-27 for details on setting up conditional linking using the .clink directive.

7.4.11 Create a Map File (–m *filename* Option)

The –m option creates a linker map listing and puts it in *filename.* The syntax for the –m option is:

–m *filename*

The linker map describes:

- Memory configuration
- Input and output section allocation
- The addresses of external symbols after they have been relocated

The map file contains the name of the output module and the entry point; it can also contain up to three tables:

- A table showing the new memory configuration if any nondefault memory is specified (memory configuration). The table has the following columns; this information is generated on the basis of the information in the MEMORY directive in the linker command file:
  - **Name.** This is the name of the memory range specified with the MEMORY directive.
  - **Origin.** This specifies the starting address of a memory range.
  - **Length.** This specifies the length of a memory range.
  - **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.

  - **Fill.** This specifies a fill character for the memory range.

  For more information about the MEMORY directive, see section 7.7, *The MEMORY Directive*, on page 7-25.

- A table showing the linked addresses of each output section and the input sections that make up the output sections (section allocation map). This table has the following columns; this information is generated on the basis of the information in the SECTIONS directive in the linker command file:
  - **Output section.** This is the name of the output section specified with the SECTIONS directive.
  - **Origin.** The first origin listed for each output section is the starting address of that output section. The indented origin value is the starting address of that portion of the output section.
  - **Length.** The first length listed for each output section is the length of that output section. The indented length value is the length of that portion of the output section.
  - **Attributes/input sections.** This lists the input file or value associated with an output section.

  For more information about the SECTIONS directive, see section 7.8, *The SECTIONS Directive*, on page 7-28.

- 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.

This following example links file1.obj and file2.obj and creates a map file called map.out:

```
lnk6x file1.obj file2.obj -m map.out
```

Example 7–13 on page 7-74 shows an example of a map file.

7.4.12 Name an Output Module (–o 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 –o option. The syntax for the –o option is:

–o *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:

```
lnk6x –o run.out file1.obj file2.obj
```

7.4.13 Specify a Quiet Run (–q Option)

The –q option suppresses the linker's banner, but it must be the first option listed. If it is not, the banner displays. This option is useful for batch operation.

7.4.14 Specify an Alternate Search Mechanism for Libraries (-priority Option)

The -priority option 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 and B; A reference B

lnk6X objfile -llib1 -llib2

Under the default linking model, B is taken from lib2 because that is where the first reference to B occurs.

When using the -priority option:

lnk6X objfile -priority -llib1 -llib2

B is taken from lib1 because that is where the first definition occurs.

This option is useful for libraries that want to provide overriding definitions for related sets of functions in other libraries without having to provide a complete version of the whole library.

7.4.15 Strip Symbolic Information (–s Option)

The –s option creates a smaller output module by omitting symbol table information and line number entries. The –s option is useful for production applications when you must create the smallest possible output module.

This example links file1.obj and file2.obj and creates an output module, stripped of line numbers and symbol table information, named nosym.out:

```
lnk6x –o nosym.out –s file1.obj file2.obj
```

Because the –s option strips symbolic information from the output module, using the –s option limits later use of a symbolic debugger and can prevent a file from being relinked.

7.4.16 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 option. The syntax for the –stack option is:

–stack *size*

The *size* must be a constant and is in bytes. This example defines a 4K byte stack:

```
lnk6x –stack 0x1000  /* defines a 4K stack (.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, and assigns it a value equal to the size of the section. The default software stack size is 1K bytes.

7.4.17 Introduce an Unresolved Symbol (–u *symbol* Option)

The –u option introduces 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 –u option *before* it links in the member that defines the symbol. The syntax for the –u option is:

–u *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 –u option as shown below forces the linker to search rts6200.lib for the member that defines symtab and to link in the member.

```
lnk6x -u symtab file1.obj file2.obj rts6200.lib
```

If you do not use –u, this member is not included, because there is no explicit reference to it in file1.obj or file2.obj.

7.4.18 Display a Message When an Undefined Output Section Is Created (–w Option)

In a linker command file, you can set up a SECTIONS directive that describes how input sections are combined into output sections. However, if the linker encounters one or more input sections that do not have a corresponding output section defined in the SECTIONS directive, the linker combines the input sections that have the same name into an output section with that name. By default, the linker does not display a message to tell you that this occurred.

You can use the –w 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 7.8 on page 7-28. For more information about the default actions of the linker, see section 7.12 on page 7-51.

7.4.19 Exhaustively Read Libraries (–x Option)

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 (this is called a *back reference*), the reference is not resolved.

With the –x option, you can force the linker to repeatedly reread all libraries. The linker continues to reread libraries until no more references can be resolved. 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:

```
lnk6x –la.lib –lb.lib –la.lib
```

or you can force the linker to do it for you:

```
lnk6x –x –la.lib –lb.lib
```

Linking with the –x option may be slower than reading input files once each, so you should use it only as needed.

7.4.20 Suppress MVK Warnings (–xm Option)

The –xm option suppresses MVK warnings. In object libraries built with pre-3.0 tools, the linker issues warnings when MVK instructions overflow. These warnings are harmless when MVK is paired with MVKH.

Alternatively, change your source code to use the MVKL instruction. It has the same properties as MVK, except one: the constant expression is not limited to 16-bits. MVKL sign-extends the constant when loading it into the register. Use MVKL only with MVKH, otherwise, use MVK.

Do not use –xm with 3.0 and greater tools-built object libraries.

7.5 Linker Command Files

Linker command files allow you to put linking information in a file; this is useful when you invoke the linker often with the same information. 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 7.7, on page 7-25). The SECTIONS directive controls how sections are built and allocated (see section 7.8 on page 7-28.)
- Assignment statements, which define and assign values to global symbols

To invoke the linker with a command file, enter the lnk6x command and follow it with the name of the command file:

lnk6x *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 7–1 shows a sample linker command file called link.cmd.

Example 7–1. Linker Command File

```
a.obj           /*  First input filename          */
b.obj           /*  Second input filename         */
–o prog.out     /*  Option to specify output file */
–m prog.map     /*  Option to specify map file    */
```

The sample file in Example 7–1 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:

```
lnk6x link.cmd
```

You can place other parameters on the command line when you use a command file:

```
lnk6x –r 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:

```
lnk6x 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 7–2 shows a sample command file that contains linker directives.

Example 7–2. Command File With Linker Directives

```
a.obj b.obj c.obj           /* Input filenames       */
–o prog.out –m prog.map     /* Options               */

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 about the MEMORY directive, see section 7.7, *The MEMORY Directive*, on page 7-25. For more information about the SECTIONS directive, see section 7.8, *The SECTIONS Directive*, on page 7-28.

7.5.1 Reserved Names in Linker Command Files

The following names are reserved as keywords for linker directives. Do not use them as symbol or section names in a command file.

align	group	org
ALIGN	GROUP	origin
attr	l (lowercase L)	ORIGIN
ATTR	len	range
block	length	run
BLOCK	LENGTH	RUN
COPY	load	SECTIONS
DSECT	LOAD	spare
f	MEMORY	type
fill	NOLOAD	TYPE
FILL	o	UNION

7.5.2 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 used in the assembler (see section 3.6, *Constants*, on page 3-13) 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

7.6 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. Chapter 6, *Archiver Description*, 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 –x option to reread libraries until no more references can be resolved (see section 7.4.19, *Exhaustively Read Libraries (–x Option)*, on page 7-19). 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:

```
lnk6x 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:

```
lnk6x 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 –u option to force the linker to include a library member. (See section 7.4.17, *Introduce an Unresolved Symbol (–u* symbol *Option)*, on page 7-18.) The next example creates an undefined symbol rout1 in the linker's global symbol table:

```
lnk6x –u 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. For more information, see section 7.8, *The SECTIONS Directive*, on page 7-28.

Section 7.4.9, *Alter the Library Search Algorithm (–l Option, –i Option, and C_DIR/C6X_C_DIR Environment Variables)* on page 7-11 describes methods for specifying directories that contain object libraries.

7.7 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 2.3, *How the Linker Handles Sections*, on page 2-11 and section 2.4, *Relocation*, on page 2-14.

7.7.1 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 7.12, *Default Allocation Algorithm*, on page 7-51.

7.7.2 MEMORY Directive Syntax

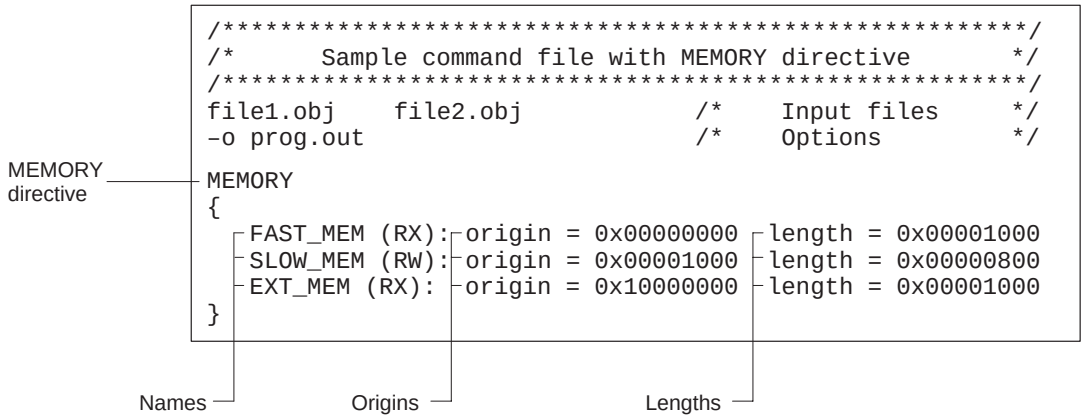
The MEMORY directive identifies ranges of memory that are physically present in the target system and can be used by a program. Each range has several characteristics:

- 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 loading code. 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 7–3 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.

Example 7–3. The MEMORY Directive



The general syntax for the MEMORY directive is:

MEMORY
{
name 1 [**(***attr***)**] **: origin** = *constant*, **length** = *constant* [**, fill** = *constant*]
.
.
name n [**(***attr***)**] **: origin** = *constant*, **length** = *constant* [**, 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 constant and 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 constant and 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 32-bit 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.

Note: Filling Memory Ranges

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 = 0x0020h, l = 0x1000, f = 0xFFFFFFFFh
}
```

You normally use the MEMORY directive in conjunction with the SECTIONS directive to control allocation of output sections. After you use MEMORY to specify the target system's memory model, you can use SECTIONS to allocate 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.

7.8 The SECTIONS Directive

The SECTIONS directive:

- ❑ 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 2.3, *How the Linker Handles Sections*, on page 2-11; section 2.4, *Relocation*, on page 2-14; and section 2.2.4, *Subsections*, on page 2-7. 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 7.12, *Default Allocation Algorithm*, on page 7-51 describes this algorithm in detail.

7.8.1 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.) A section name can be a subsection specification. 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:

- **Load allocation** defines where in memory the section is to be loaded.

  Syntax:

  load = *allocation* or
  allocation or
  > *allocation*

  Allocation represents portions of the syntax that specify how sections are placed in the target memory. See section 7.8.2 on page 7-31 for more information about specifying the *allocation*.

- **Run allocation** defines where in memory the section is to be run.

  Syntax:

  run = *allocation* or
  run > *allocation*

  Allocation represents portions of the syntax that specify how sections are placed in the target memory.

- **Input sections** defines the input sections (object files) that constitute the output section.

  Syntax:

  { *input_sections* **}**

- **Section type** defines flags for special section types.

  Syntax:

  type = COPY or
  type = DSECT or
  type = NOLOAD

  For more information, see section 7.11, *Special Section Types (DSECT, COPY, and NOLOAD)*, on page 7-50.

- **Fill value** defines the value used to fill uninitialized holes.

  Syntax:

  fill = *value* or
  name : [*properties*] **=** *value*

  For more information, see section 7.14, *Creating and Filling Holes*, on page 7-61.

Example 7–4 shows a SECTIONS directive in a sample linker command file.

Example 7–4. The SECTIONS Directive

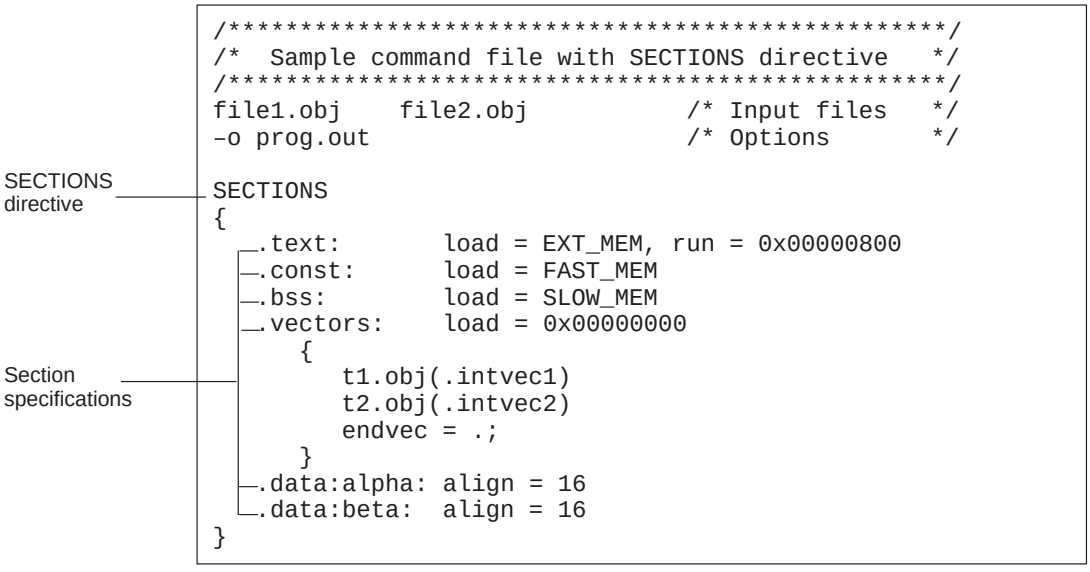
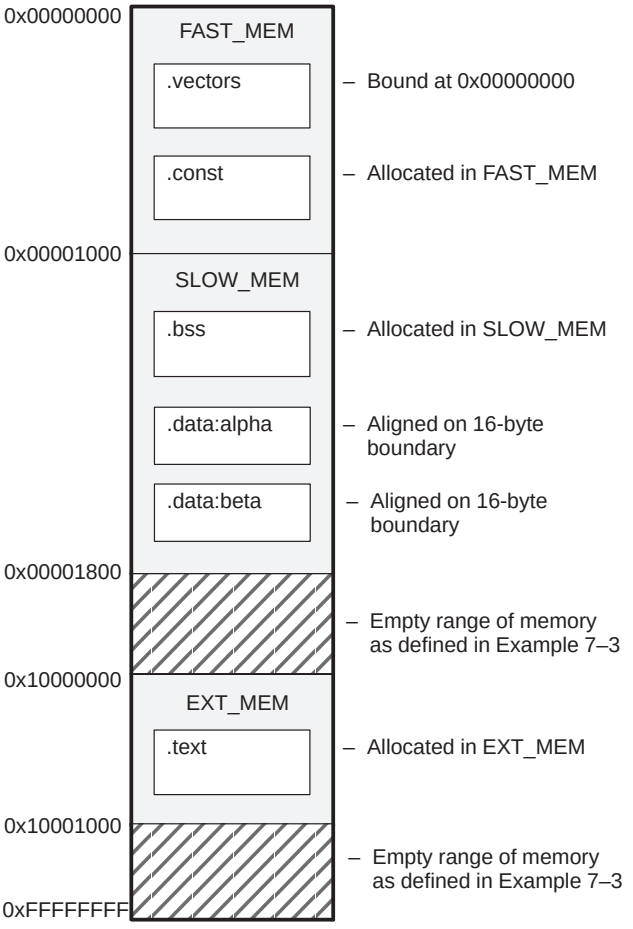


Figure 7–2 shows the six output sections defined by the SECTIONS directive in Example 7–4 (.vectors, .text, .const, .bss, .data:alpha, and .data:beta) and shows how these sections are allocated in memory.

Figure 7–2. Section Allocation Defined by Example 7–4



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.

7.8.2 Allocation

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 allocation. For more information about using separate load and run allocation, see section 7.9, *Specifying a Section's Run-Time Address*, on page 7-40.

If you do not tell the linker how a section is to be allocated, it uses a default algorithm to allocate the section. Generally, the linker puts sections wherever they fit into configured memory. You can override this default allocation for a section by defining it within a SECTIONS directive and providing instructions on how to allocate it.

You control allocation 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 allocation are separate, all parameters following the keyword LOAD apply to load allocation, and those following the keyword RUN apply to run allocation. 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 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 boundaries: if the section is too big, it starts on an address boundary.

```
.text: block(0x100)
```

For the load (usually the only) allocation, you can simply 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. For more information, see section 7.8.3, *Specifying Input Sections*, on page 7-37.

7.8.2.1 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 = 02000h,  length = 01000h
   P_MEM2 :  origin = 04000h,  length = 01000h
   P_MEM3 :  origin = 06000h,  length = 01000h
   P_MEM4 :  origin = 08000h,  length = 01000h
}

SECTIONS
{
   .text  : { } > P_MEM1 | P_MEM2 | P_MEM4
}
```

The | operator is used to specify the multiple memory ranges. The .text output section is allocated as a whole into the first memory range in which it fits. The memory ranges are accessed in the order specified. In this example, the linker first tries to allocate the section in P_MEM1. If that attempt fails, the linker tries to place the section into P_MEM2, and so on. If the output section is not successfully allocated in any of the named memory ranges, the linker issues an error message.

With this type of SECTIONS directive specification, the linker can seamlessly handle an output section that grows beyond the available space of the memory range in which it is originally allocated. Instead of modifying the linker command file, you can let the linker move the section into one of the other areas.

7.8.2.2 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 = 02000h,  length = 01000h
   P_MEM2 :  origin = 04000h,  length = 01000h
   P_MEM3 :  origin = 06000h,  length = 01000h
   P_MEM4 :  origin = 08000h,  length = 01000h
}

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 = 01000h,  length = 08000h
}

SECTIONS
{
  .special: { f1.obj(.text) } = 04000h
  .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 01000h to 04000h, and from the end of f1.obj(.text) to 08000h. 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 = 01000h,  length = 02000h
  P_MEM2 (RWI) : origin = 04000h,  length = 01000h
}

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 output sections should not be split:

- 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
- An output section with separate load and run allocations. The code that copies the output section from its load-time allocation to its run-time location cannot accommodate a split in the output section.
- 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.

If you use the >> operator on any of these sections, the linker issues a warning and ignores the operator.

7.8.2.3 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.

7.8.2.4 Named Memory

You can allocate a section into a memory range that is defined by the MEMORY directive (see section 7.7, *The MEMORY Directive*, on page 7-25). This example names ranges and links sections into them:

```
MEMORY
{
   SLOW_MEM (RIX)  : origin = 0x00000000,  length = 0x00001000
   FAST_MEM (RWIX) : origin = 0x30000000,  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.

7.8.2.5 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:

```
.text: load = align(32)
```

allocates .text so that it falls on a 32-byte boundary.

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:

```
bss: load = block(0x0080)
```

allocates .bss so that the entire section is contained in a single 128-byte page or begins on that boundary.

You can use alignment or blocking alone or in conjunction with a memory area, but alignment and blocking cannot be used together.

7.8.3 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 7–5 shows the most common type of section specification; note that no input sections are listed.

Example 7–5. The Most Common Method of Specifying Section Contents

```
SECTIONS
{
    .text:
    .data:
    .bss:
}
```

In Example 7–5, 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:

```
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.obj             /* Link ALL sections from f3.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 7–5 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 the input files.* This format is useful when:

- ❏ 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.

7.8.3.1 Specifying a Specific Archived Library member

The ability to specify an archive member of a library archive for allocation into a specific output section can be specified inside < > after a library name. Any object files separated by commas or spaces from the specified archive file are legal within the < >. The syntax for allocating archived library members specifically inside of a SECTIONS directive is as follows:

[–l] library name < object file members archived in library name > [(input sections)]

```
SECTIONS
{
      boot  >     BOOT1
      {
            –lrtsXX.lib<boot.obj> (.text)
            –lrtsXX.lib<exit.obj strcpy.obj> (.text)
      }

      .rts  >     BOOT2
      {
            –lrtsXX.lib (.text)
      }

      .text >     RAM
      {
            * (.text)
      }
}
```

The above example specifies that the text sections of boot.obj, exit.obj, and strcpy.obj from the RTS library should be placed in section .boot. The remainder of the .text sections from the RTS library are to be placed in section .rts. Finally, the remainder of all other .text sections are to be placed in section .text.

The –l option (which normally implies a library path search be made for the named file following the option) listed before each library is optional when listing specific archive members inside < >. Using < > implies that you are referring to a library.

7.9 Specifying a Section's Run-Time Address

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 2.5, *Run-Time Relocation*, on page 2-16, for an overview on run-time relocation.

7.9.1 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. 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.

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 7.10.1, *Overlaying Sections With the UNION Statement*, on page 7-45.)

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 below specify load and run addresses:

```
.data: load = SLOW_MEM, align = 32, run = FAST_MEM
```

(align applies only to load)

```
.data: load = (SLOW_MEM align 32), run = FAST_MEM
```

(identical to previous example)

```
.data: run  = FAST_MEM, align 32,
       load = align 16
```

(align 32 in FAST_MEM for run; align 16 anywhere for load)

7.9.2 Uninitialized Sections

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
```

7.9.3 Referring to the Load Address by Using the .label Directive

Normally, any reference to a symbol in a section 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. For more information on the .label directive, see page 4-49.

Example 7–6 shows the use of the .label directive. Figure 7–3 illustrates the run-time execution of Example 7–6.

Example 7–6. Copying a Section From SLOW_MEM to FAST_MEM

(a) Assembly language file

```
       .sect  ".fir"
       .align 4
       .label fir_src
fir

       ;<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
```

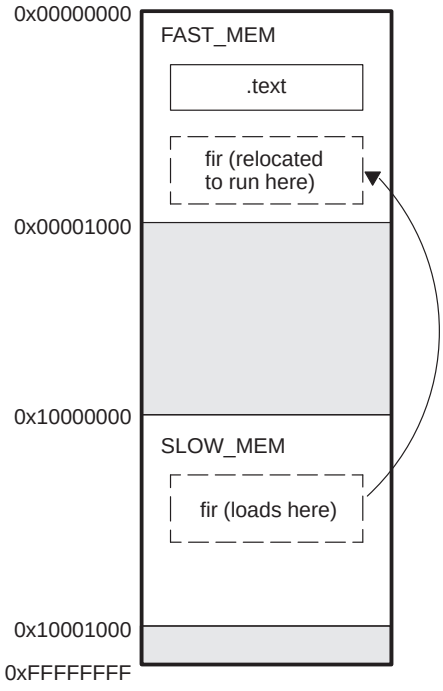
(b) Linker command file

```
/*******************************************************/
/*    PARTIAL LINKER COMMAND FILE FOR FIR EXAMPLE      */
/*******************************************************/

MEMORY
{
   FAST_MEM :  origin = 0x00001000, length = 0x00001000
   SLOW_MEM :  origin = 0x10000000, length = 0x00001000
}

SECTIONS
{
   .text: load = FAST_MEM
   .fir:  load = SLOW_MEM, run FAST_MEM
}
```

Figure 7–3. Run-Time Execution of Example 7–6



7.10 Using UNION and GROUP Statements

Two SECTIONS statements allow you to conserve memory: GROUP and UNION. Unioning sections causes the linker to allocate them to the same run address. Grouping sections causes the linker to allocate them contiguously in memory. Section names can refer to sections, subsections, or archive library members.

7.10.1 Overlaying Sections With the UNION Statement

For some applications, you may want to allocate more than one section to run at the same address. For example, you may have several routines you want in fast external memory at various 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 7–7, 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 7–7. The UNION Statement

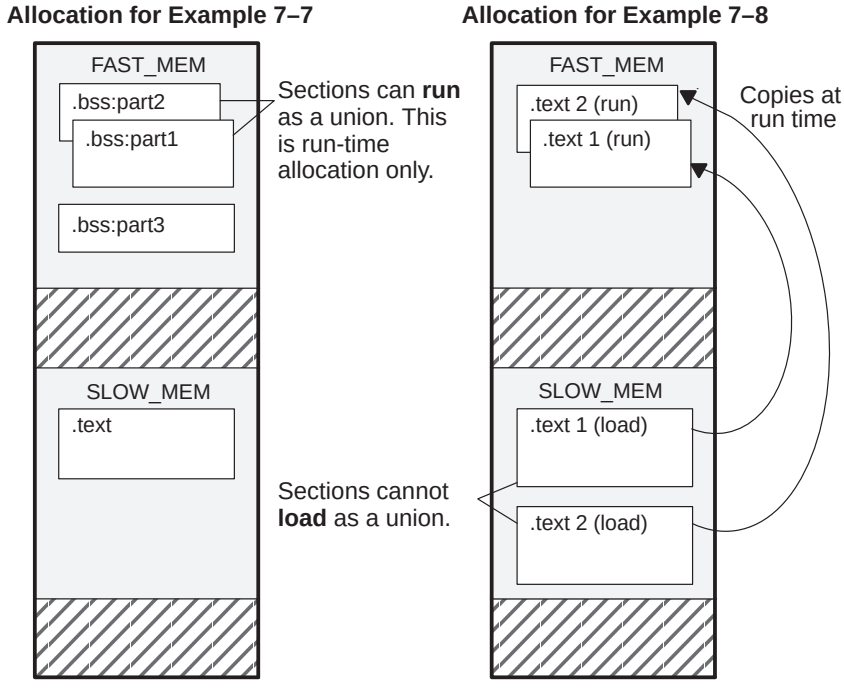
```
SECTIONS
{
   .text: load = SLOW_MEM
   UNION: run  = FAST_MEM
   {
      .bss:part1: { file1.obj(.bss) }
      .bss:part2: { file2.obj(.bss) }
   }
      .bss:part3: run = FAST_MEM { globals.obj(.bss) }
}
```

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 7–8.

Example 7–8. 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 7–4. Memory Allocation Shown in Example 7–7 and Example 7–8



Since the .text sections contain 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.

7.10.2 Grouping Output Sections Together

The SECTIONS directive's GROUP option forces several output sections to be allocated contiguously. 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 7–9. 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 0x00001000. This means that .data is allocated at 0x00001000, and term_rec follows it in memory.

7.10.3 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 7–10 shows how two overlays can be grouped together.

Example 7–10. Nesting GROUP and UNION Statements

```
SECTIONS
{
   GROUP 1000h : 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 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.

7.10.4 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 (i.e., 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.

7.11 Special Section Types (DSECT, COPY, and NOLOAD)

You can assign three special types to output sections: DSECT, COPY, and NOLOAD. 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}
}
```

- 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.

7.12 Default Allocation Algorithm

The MEMORY and SECTIONS directives provide flexible methods for building, combining, and allocating sections. However, any memory locations or sections that 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 definitions in Example 7–11 were specified.

Example 7–11. 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
}
```

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 7.12.1.

7.12.1 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 7.8, *The SECTIONS Directive*, on page 7-28 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 –w linker option (see section 7.4.18, *Display a Message When an Undefined Output Section Is Created (–w Option)*, on page 7-18) 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 7–11. (See section 7.7, *The MEMORY Directive*, on page 7-25 for more information on configuring memory.)

7.12.2 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.

7.13 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.

7.13.1 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 7.13.3, *Assignment Expressions.* 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 */
```

7.13.2 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 7.8, *The SECTIONS Directive*, on page 7-28.)

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 page 4-42), 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 7.14, *Creating and Filling Holes*, on page 7-61.

7.13.3 Assignment Expressions

These rules apply to linker expressions:

- Expressions can contain global symbols, constants, and the C language operators listed in Table 7–2.
- 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 7–2 in order of precedence. Operators in the same group have the same precedence. Besides the operators listed in Table 7–2, 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 expression

```
. = align(16);
```

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.

Table 7–2. Groups of Operators Used in Expressions (Precedence)

Group 1 (Highest Precedence)		**Group 6**	
!	Logical NOT	&	Bitwise AND
~	Bitwise NOT		
–	Negation		
Group 2		**Group 7**	
*	Multiplication	|	Bitwise OR
/	Division		
%	Modulus		
Group 3		**Group 8**	
+	Addition	&&	Logical AND
–	Subtraction		
Group 4		**Group 9**	
>>	Arithmetic right shift	||	Logical OR
<<	Arithmetic left shift		
Group 5		**Group 10 (Lowest Precedence)**	
==	Equal to	=	Assignment
! =	Not equal to	+ =	A + = B → A = A + B
>	Greater than	– =	A – = B → A = A – B
<	Less than	* =	A * = B → A = A * B
< =	Less than or equal to	/ =	A / = B → A = A / B
> =	Greater than or equal to		

7.13.4 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 page 4-42). 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 –c or –cr option is used.

__STACK_SIZE is assigned the size of the .stack section.

__SYSMEM_SIZE is assigned the size of the .sysmem section.

7.13.5 Assigning Exact Start, End, and Size Values of a Section to a Symbol

The code generation tools currently support the ability to load program code in one area of (slow) memory and run it in another (faster) area. This is done by specifying separate load and run addresses for an output section or group in the linker command file. Then execute a sequence of instructions (the copying code in Example 7–6) 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 7–6.

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.

7.13.5.1 Why the "." 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 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. *end_of_s2* cannot reliably be used 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:

```
GROUP
   {
      outsect:
      {
         start_of_outsect = .;
         <input sections>
      }
      dummy: { size_of_outsect = . – start_of_outsect; }
   }
```

7.13.5.2 START(), END(), and SIZE() Linker Command File Operators

Six new operators have been added to the linker command file syntax:

LOAD_START(*sym*) **START(*sym*)**	Define *sym* with load-time start address of related allocation unit.
LOAD_END(*sym*) **END(*sym*)**	Define *sym* with load-time end address of related allocation unit.
LOAD_SIZE(sym) **SIZE(*sym*)**	Define *sym* with load-time size of related allocation unit.
RUN_START(*sym*)	Define *sym* with run-time start address of related allocation unit.
RUN_END(*sym*)	Define *sym* with run-time end address of related allocation unit.
RUN_SIZE(*sym*)	Define *sym* with run-time size of related allocation unit.

Note: Linker Command File Operator Equivalencies

LOAD_START() and START() are equivalent, as are LOAD_END()/END() and LOAD_SIZE()/SIZE()

The new address and dimension operators can be associated with several different kinds of allocation units including input items, output sections, GROUPs, and UNIONs. An example of how the operators are used with each allocation unit is provided below:

Input Items

```
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* will be defined after any necessary padding that needs to be added between the two .text sections. 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 will be applied to the input item that occurs immediately before it.

Output Section

```
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.

GROUP

```
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.

UNION

```
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) }
}
```

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.

In the example above, *union_ld_sz* is going to be equal to the sum of the sizes of all output sections placed in the union. *union_run_size* is equivalent to the largest output section in the union. Both of these symbols incorporate any padding due to blocking or alignment requirements.

7.14 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.

7.14.1 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 page 4-25) and sections defined with the .usect directive (see page 4-77) 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.

7.14.2 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 7.7.2, *MEMORY Directive Syntax*, on page 7-25.

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 7.13, *Assigning Symbols at Link Time*, on page 7-53.

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.

7.14.3 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 –f option (see section 7.4.5, *Set Default Fill Value (–f* fill_value *Option)*, on page 7-10). 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 –f option:

```
lnk6x -f 0xFFFFFFFF link.cmd
```

This fills the hole with 0xFFFFFFFF.

4) If you do not invoke the linker with the –f 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.

7.14.4 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 */
}
```

Note: Filling Sections

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.

7.15 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 –r option when you link the file the first time. (See section 7.4.1, *Relocation Capabilities (–a and –r Options)*, on page 7-7.)
- Intermediate files *must* have symbolic information. By default, the linker retains symbolic information in its output. Do not use the –s option if you plan to relink a file, because –s strips symbolic information from the output module. (See section 7.4.15, *Strip Symbolic Information (–s Option)*, on page 7-17.)
- Intermediate link steps 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 step.
- 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 –h option (see section 7.4.7, *Make All Global Symbols Static (–h Option)*, on page 7-10).
- If you are linking C code, do not use –c or –cr until the final link step. Every time you invoke the linker with the –c or –cr option, the linker attempts to create an entry point. (See section 7.4.3, *C Language Options (–c and –cr Options)*, on page 7-9.)

The following example shows how you can use partial linking:

Step 1: Link the file file1.com; use the –r option to retain relocation information in the output file tempout1.out.

```
lnk6x –r –o tempout1 file1.com
```

file1.com contains:

```
SECTIONS
{
   ss1:   {
          f1.obj
          f2.obj
           .
           .
           .
          fn.obj
          }
}
```

Step 2: Link the file file2.com; use the –r option to retain relocation information in the output file tempout2.out.

```
lnk6x –r –o tempout2 file2.com
```

file2.com contains:

```
SECTIONS
{
   ss2:   {
          g1.obj
          g2.obj
           .
           .
           .
          gn.obj
          }
}
```

Step 3: Link tempout1.out and tempout2.out.

```
lnk6x –m final.map –o final.out tempout1.out tempout2.out
```

7.16 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:

```
lnk6x -c –o prog.out prog1.obj prog2.obj ... rts6200.lib
```

The –c option tells the linker to use special conventions that are defined by the C/C++ environment.

The archive libraries listed below contain C/C++ run-time-support functions:

rts6200.lib	rts6400.lib	rts6700.lib
rts6200e.lib	rts6400e.lib	rts6700e.lib

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.*

7.16.1 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 –c 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 –c or –cr option).

7.16.2 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.

7.16.3 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 or –stack option and specifying the size of the section as a 4-byte constant immediately after the option. The default size for both, if the options are not used, is 1K words.

See section 7.4.8, *Define Heap Size (–heap* size *Option)*, on page 7-11 and section 7.4.16, *Define Stack Size (–stack* size *Option)*, on page 7-17 for more information on setting stack sizes.

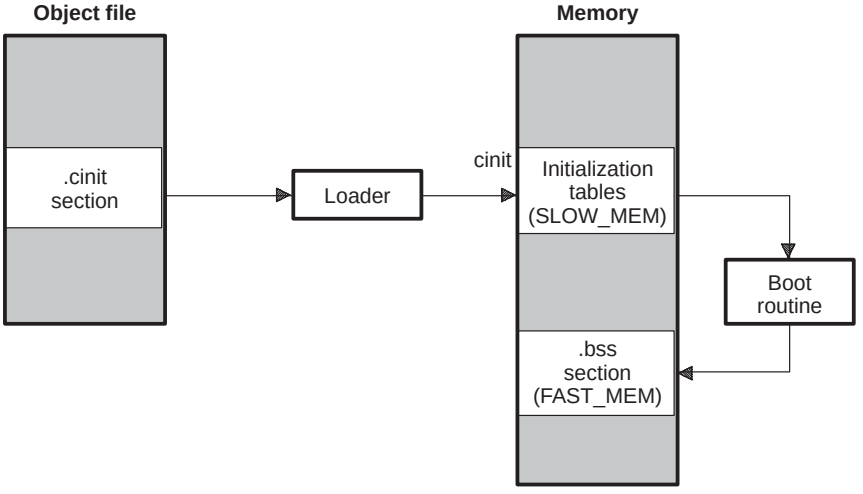
7.16.4 Autoinitialization of Variables at Run Time

Autoinitializing variables at run time is the default method of autoinitialization. To use this method, invoke the linker with the –c 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 7–5 illustrates autoinitialization at run time. Use this method in any system where your application runs from code burned into slow external memory.

Figure 7–5. Autoinitialization at Run Time



7.16.5 Initialization of Variables at Load Time

Initialization of variables at load time enhances performance by reducing boot time and by saving the memory used by the initialization tables. To use this method, invoke the linker with the –cr option.

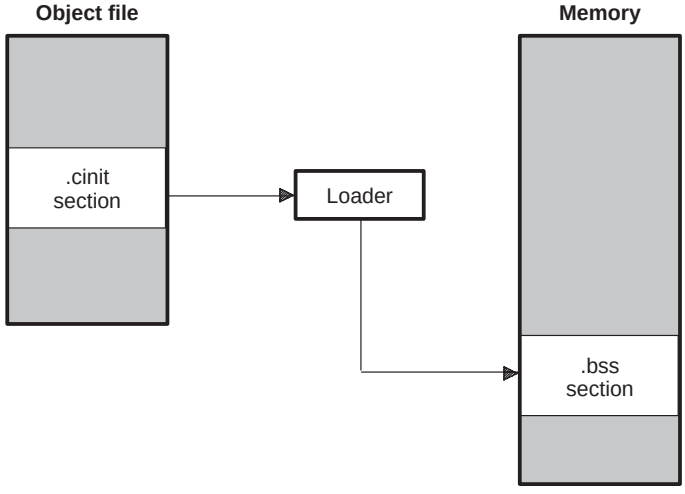
When you use the –cr linker option, the linker sets the STYP_COPY bit in the .cinit section's header. This tells the loader not to load the .cinit section into memory. (The .cinit section occupies no space in the memory map.) The linker also sets the cinit symbol to –1 (normally, cinit points to the 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 7–6 illustrates the initialization of variables at load time.

Figure 7–6. Initialization at Load Time



7.16.6 The –c and –cr Linker Options

The following list outlines what happens when you invoke the linker with the –c or –cr 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 autoinitialize at run time (–c 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.
- When you initialize at load time (–cr 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.

7.17 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 configuration:

Program Memory

Address Range	Contents
0x00000000 to 0x00001000	SLOW_MEM
0x00001000 to 0x00002000	FAST_MEM
0x08000000 to 0x08000400	EEPROM

The output sections are constructed from the following input sections:

- 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 7–12 shows the linker command file for this example. Example 7–13 shows the map file.

Example 7–12. Linker Command File, demo.cmd

```
/*************************************************************************/
/****                     Specify Linker Options                      ****/
/*************************************************************************/
-e SETUP                      /*   Define the program entry point     */
-o demo.out                   /*   Name the output file               */
-m demo.map                   /*   Create an output map               */
/*************************************************************************/
/****                    Specify the Input Files                      ****/
/*************************************************************************/
demo.obj
ctrl.obj
tables.obj
/*************************************************************************/
/****                 Specify the Memory Configuration                ****/
/*************************************************************************/
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_vars 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:

lnk6x demo.cmd

This creates the map file shown in Example 7–13 and an output file called demo.out that can be run on a TMS320C6000.

Example 7–13. 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]
```

Chapter 8

Absolute Lister Description

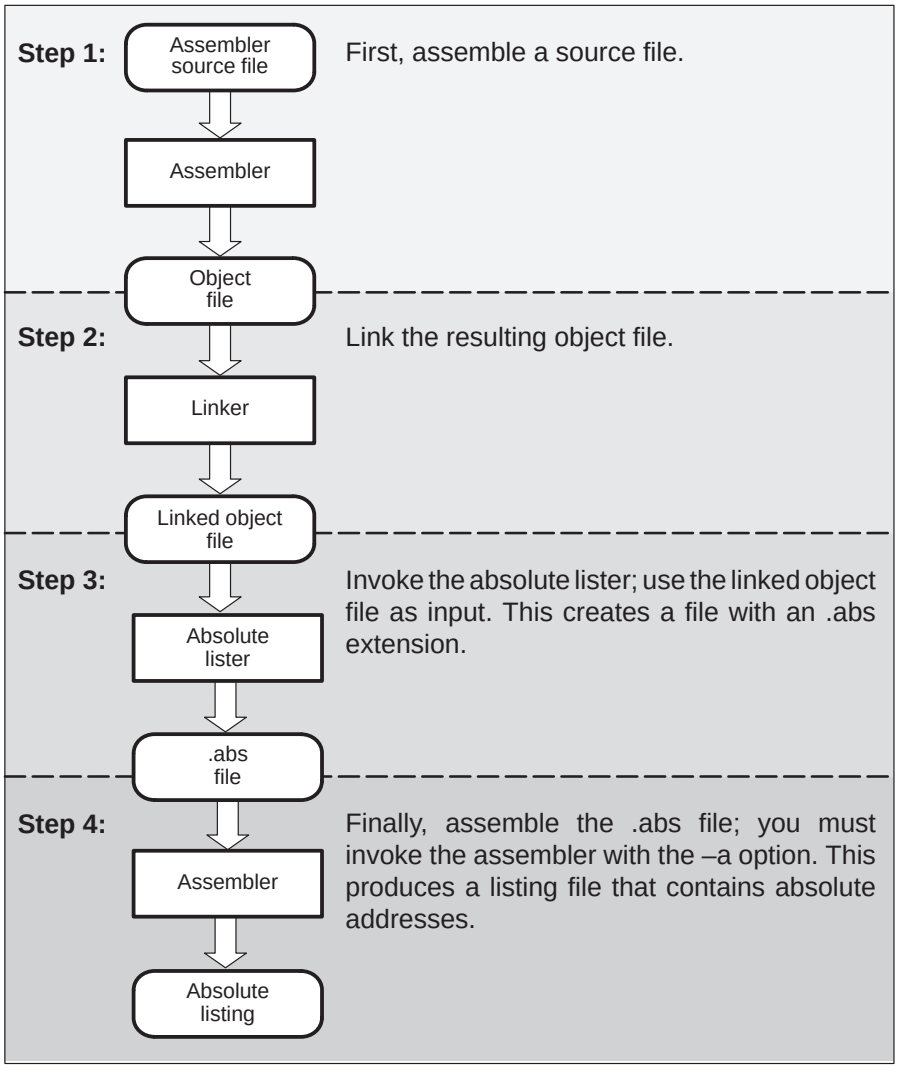
The TMS320C6000™ absolute lister is a debugging tool that accepts linked object files as input and creates .abs files as output. These .abs files can be assembled to produce a listing that shows the absolute addresses of object code. Manually, this could be a tedious process requiring many operations; however, the absolute lister utility performs these operations automatically.

Topic **Page**

8.1 Producing an Absolute Listing

Figure 8–1 illustrates the steps required to produce an absolute listing.

Figure 8–1. Absolute Lister Development Flow



8.2 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 three options are listed below.

- –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)

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 –aa assembler option as follows to create the absolute listing:

```
cl6x –aa 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 (–g 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.

8.3 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:

```
–o bttest.out
–m 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:

lnk6x bttest.cmd

This command creates an executable object file called bttest.out; use this new 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 when you invoke it in 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 tell the assembler which assembly language source file to include.

The .setsym and .setsect directives are not useful in normal assembly; they are useful only for creating absolute listings.

Step 4: Finally, assemble the .abs files created by the absolute lister (remember that you must use the –aa option when you invoke the assembler):

```
cl6x  –aa  module1.abs
cl6x  –aa  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 Figure 8–2) and module2.lst (see Figure 8–3).

Figure 8–2. module1.lst

```
TMS320C6x COFF Assembler         Version x.xx       Mon Jan  5 11:34:00 1998
Copyright (c) 1996–1998 Texas Instruments Incorporated
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
```

Figure 8–3. module2.lst

```
TMS320C6x COFF Assembler         Version x.xx       Mon Jan  5 11:34:05 1998
Copyright (c) 1996–1998 Texas Instruments Incorporated
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
```

Chapter 9

Cross-Reference Lister Description

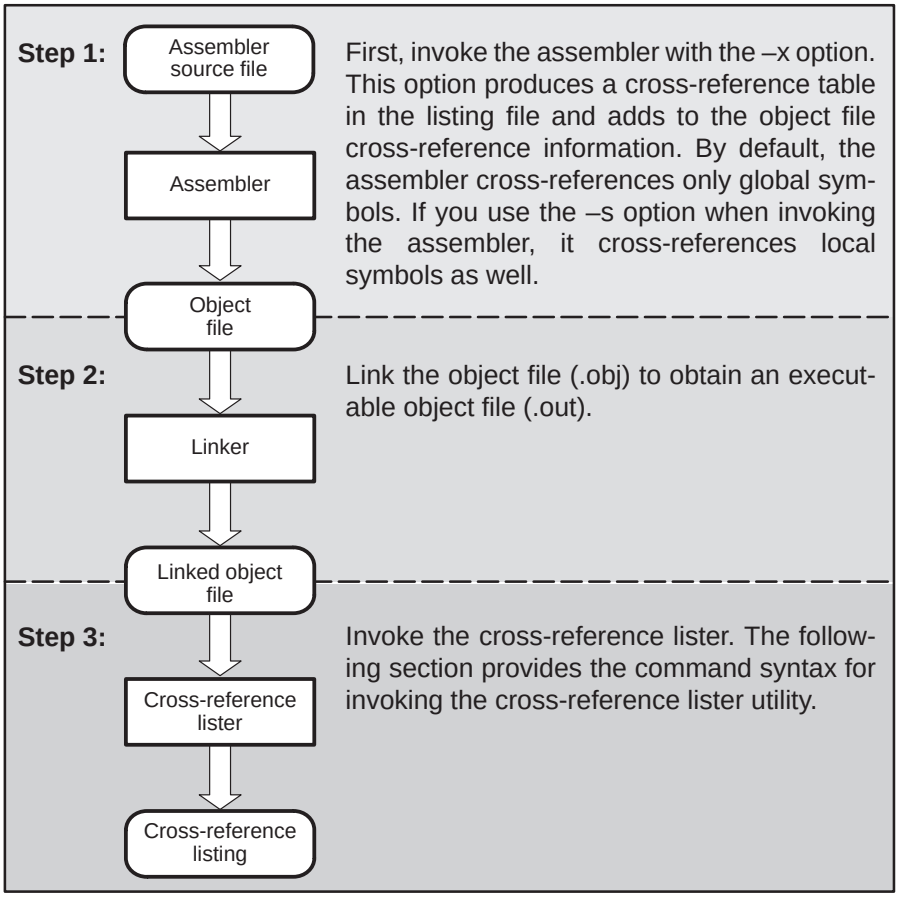
The TMS320C6000™ cross-reference lister is a debugging tool. This utility accepts linked object files as input and produces a cross-reference listing as output. This listing shows symbols, their definitions, and their references in the linked source files.

Topic **Page**

9.1 Producing a Cross-Reference Listing

Figure 9–1 illustrates the steps required to produce a cross-reference listing.

Figure 9–1. The Cross-Reference Lister in the TMS320C6000 Software Development Flow



9.2 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 –ax 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 –as 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. Precede each option with a hyphen (–). The cross-reference lister options are as follows:

- **–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.

9.3 Cross-Reference Listing Example

The following is an example of cross-reference listing:

Example 9–1. 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 9–1 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 9–1. 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

Chapter 10

Hex Conversion Utility Description

The TMS320C6000™ assembler and linker create object files that are in common object file format (COFF). COFF is a binary object file format that encourages modular programming and provides powerful and flexible methods for managing code segments and target system memory.

Most EPROM programmers do not accept COFF object files as input. The hex conversion utility converts a COFF 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 a COFF object file (for example, when using debuggers and loaders).

The hex conversion utility can produce these output file formats:

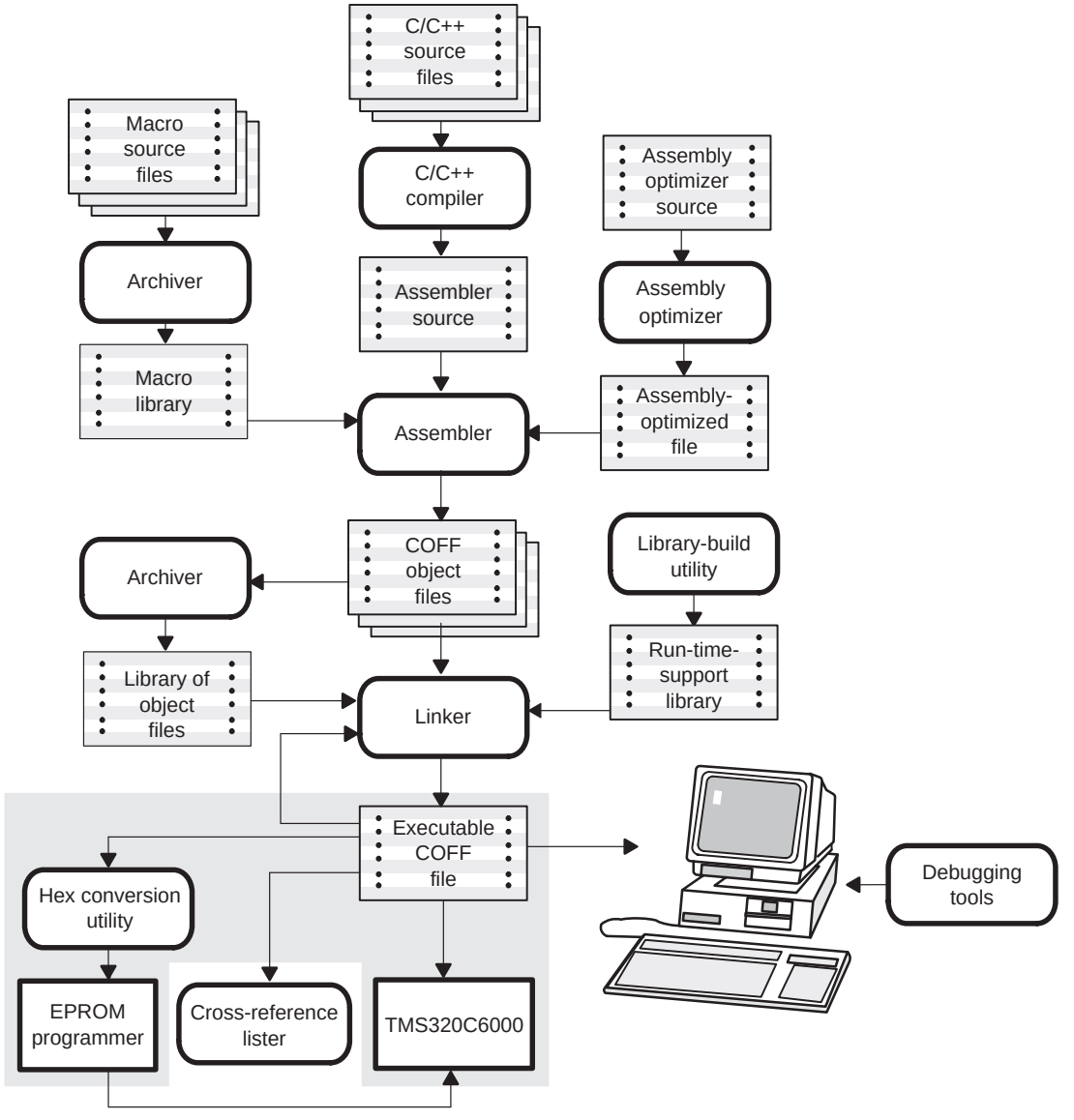
- ASCII-Hex, supporting 16-bit addresses
- Extended Tektronix (Tektronix)
- Intel MCS-86 (Intel)
- Motorola Exorciser (Motorola-S), supporting 16-bit addresses
- Texas Instruments SDSMAC (TI-Tagged), supporting 16-bit addresses

Topic **Page**

10.1 The Hex Conversion Utility's Role in the Software Development Flow

Figure 10–1 highlights the role of the hex conversion utility in the software development process.

Figure 10–1. The Hex Conversion Utility in the TMS320C6000 Software Development Flow



10.2 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
  ```

- **Specify the options and filenames in a command file.** You can create a batch 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.

10.2.1 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 10–1 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 multicharacter 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 –q (quiet) option, which must be used before any other options.

filename names a COFF object file or a command file (for more information, see section 10.2.2, *Invoking the Hex Conversion Utility With a Command File*, on page 10-5). If you do not specify a filename, the utility prompts you for one.

Table 10–1. Basic Hex Conversion Utility Options

General Options	Option	Description	Page
Control the overall operation of the hex conversion utility	–byte	Number output file locations by bytes rather than using target addressing	10-25
	–map *filename*	Generate a map file	10-17
	–o *filename*	Specify an output filename	10-21
	–q	Run quietly (when used, it must appear *before* other options)	10-5
Image Options	**Option**	**Description**	**Page**
Create a continuous image of a range of target memory	–fill *value*	Fill holes with *value*	10-24
	–image	Specify image mode	10-23
	–zero	Reset the address origin to 0 in image mode	10-25
Memory Options	**Option**	**Description**	**Page**
Configure the memory widths for your output files	–memwidth *value*	Define the system memory word width (default 32 bits)	10-8
	–romwidth *value*	Specify the ROM device width (default depends on format used)	10-10
	–order L	Output file is in little endian format	10-12
	–order M	Output file is in big endian format	10-12
Output Formats	**Option**	**Description**	**Page**
Specify the output format	–a	Select ASCII-Hex	10-27
	–i	Select Intel	10-28
	–m	Select Motorola-S	10-29
	–t	Select TI-Tagged	10-30
	–x	Select Tektronix (default)	10-31

10.2.2 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. (For more information, see section 10.4, *The ROMS Directive*, on page 10-13.)
- **SECTIONS directive.** The hex conversion utility SECTIONS directive specifies which sections from the COFF object file are selected. (For more information, see section 10.5, *The SECTIONS Directive*, on page 10-19.)
- **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 **–q 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  */
-t             /* TI-Tagged   */
-o   firm.lsb  /* output file */
-o   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   */
-i                /* 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:
}
```

10.3 Understanding Memory Widths

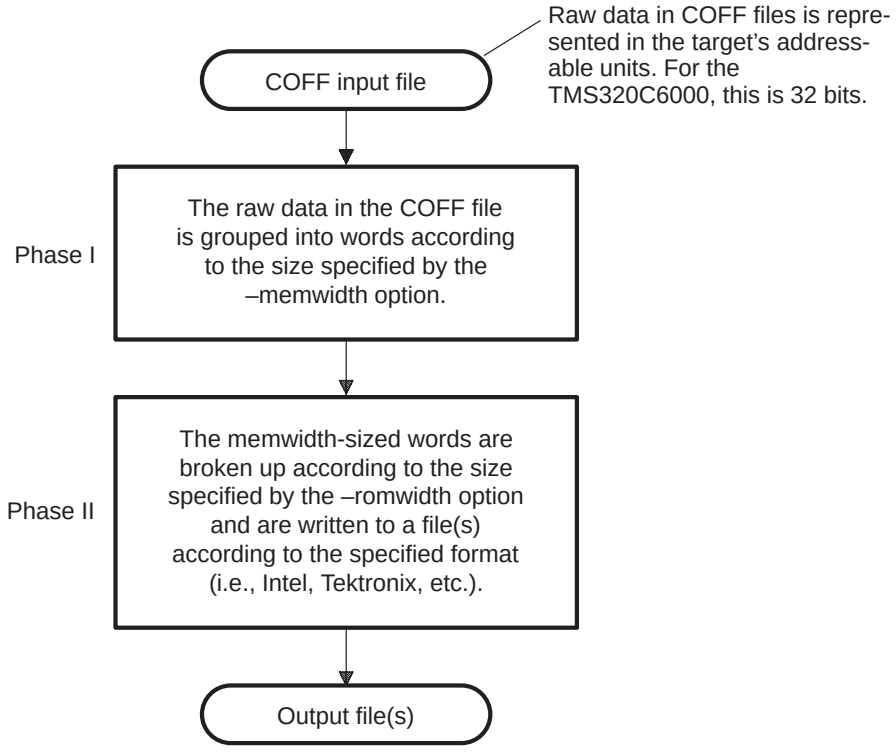
The hex conversion utility makes your memory architecture more flexible by allowing you to specify memory and ROM widths. In order to use the hex conversion utility, *you must understand how the utility treats word widths*. Three widths are important in the conversion process:

- Target width
- Memory width
- ROM width

The terms target word, memory word, and ROM word refer to a word of such a width.

Figure 10–2 illustrates the two separate and distinct phases of the hex conversion utility's process flow.

Figure 10–2. Hex Conversion Utility Process Flow



10.3.1 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.

10.3.2 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, narrower memory words.

The hex conversion utility defaults memory width to the target width (in this case, 32 bits).

You can change the memory width by:

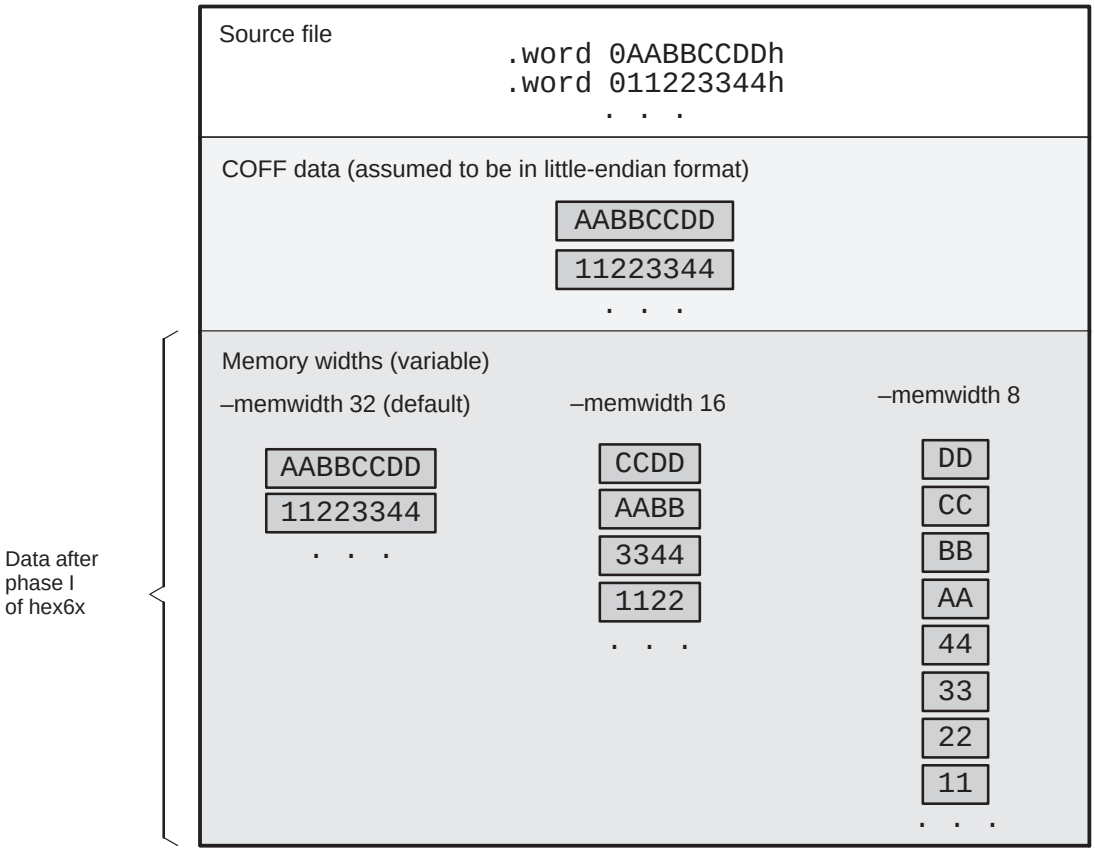
- Using the **–memwidth** option. This changes the memory width value for the entire file.
- Setting the **memwidth** parameter of the ROMS directive. This changes the memory width value for the address range specified in the ROMS directive and overrides the –memwidth option for that range. See section 10.4, *The ROMS Directive*, on page 10-13.

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.

Figure 10–3 demonstrates how the memory width is related to COFF data.

Figure 10–3. COFF Data and Memory Widths



10.3.3 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 COFF 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 $\geq$ ROM width:

  number of files = memory width $\div$ 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.

Note: The TI-Tagged Format Is 16 Bits Wide

You cannot change the ROM width of the TI-Tagged format. The TI-Tagged format supports a 16-bit ROM width only.

You can change ROM width (except for TI-Tagged format) by:

- Using the **–romwidth** option. This option changes the ROM width value for the entire COFF 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 10.4, *The ROMS Directive*, on page 10-13.

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 10–4 illustrates how the COFF data, memory, and ROM widths are related to one another.

Memory width and ROM width are used only for grouping the COFF data; they do not represent values. Thus, the byte ordering of the COFF 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:

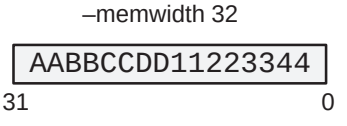
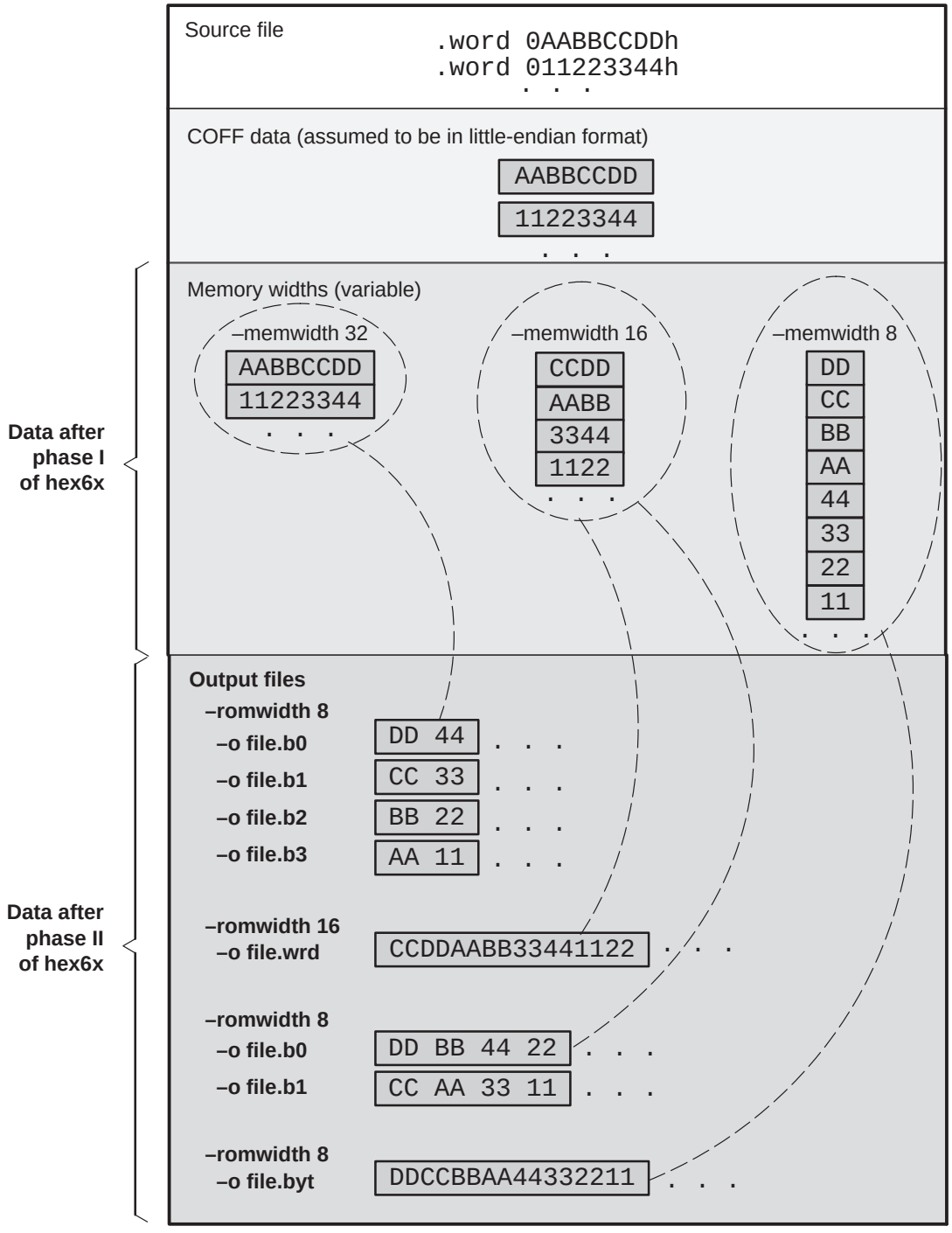


Figure 10–4. Data, Memory, and ROM Widths



10.3.4 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 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.

10.4 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={filename1, filename2, ...}]

      romname: [origin=value,] [length=value,] [romwidth=value,]
               [memwidth=value,] [fill=value,]
               [files={filename1, filename2, ...}]
   ...
}
```

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. (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 10.3.3, *Partitioning Data Into Output Files*, on page 10-9). 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 10.3.2, *Specifying the Memory Width*, on page 10-8). 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 10.5, *The SECTIONS Directive*, on page 10-19.)

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 10.7.2, *Specifying a Fill Value*, on page 10-24.

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, refer to section 10.3.3, *Partitioning Data Into Output Files*, on page 10-9. 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.

10.4.1 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. In this way, 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.

10.4.2 An Example of the ROMS Directive

The ROMS directive in Example 10–1 shows how 16K bytes of 16-bit memory could be partitioned for two 8K-byte × 8-bit EPROMs. Figure 10–5 illustrates the input and output files.

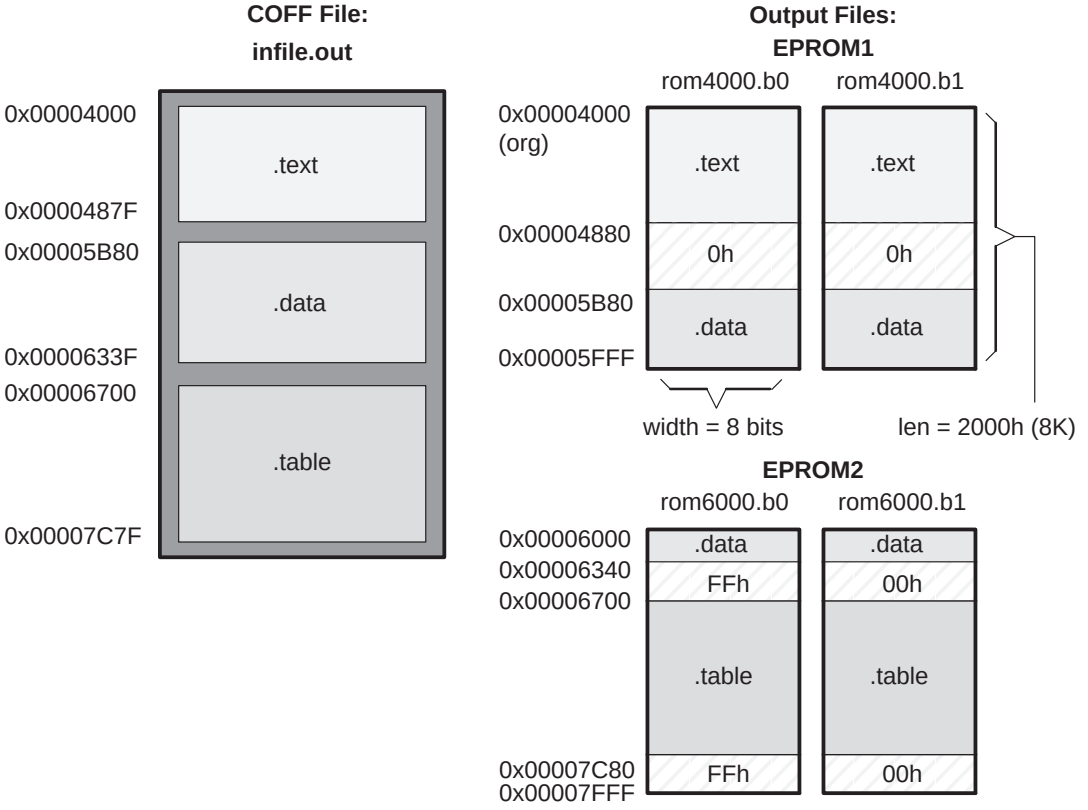
Example 10–1. A ROMS Directive Example

```
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 10–5. 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 10–2 is a segment of the map file resulting from the example in Example 10–1.

Example 10–2. Map File Output From Example 10–1 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. The range contains 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). The data from this range is 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. The range contains 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

10.5 The SECTIONS Directive

You can convert specific sections of the COFF 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 COFF file
- Do not use a SECTIONS directive, the utility converts all initialized sections that fall within the configured memory. The TMS320C6000 compiler-generated initialized sections are .text, .const, and .cinit

Uninitialized sections are *never* converted, whether or not you specify them in a SECTIONS directive.

Note: Sections Generated by the C/C++ Compiler

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. (For more information, see section 10.2.2, *Invoking the Hex Conversion Utility With a Command File*, on page 10-5.) The general syntax for the SECTIONS directive is:

```
SECTIONS
{
   sname[:] [paddr=value][,]
   sname[:] [paddr=value][,]
   ...
}
```

SECTIONS begins the directive definition.

sname identifies a section in the COFF 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 will be located. This value overrides the section load address given by the linker. The value must be a decimal, octal, or hexadecimal constant. If one section uses this option, then all sections must use the option.

The commas separating section names are optional. For more similarity with the linker's SECTIONS directive, you can use colons after the section names.

For example, the COFF 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 }
```

10.6 Assigning Output Filenames

When the hex conversion utility translates your COFF 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 COFF 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 –o options.** You can specify names for the output files by using the –o option. If no filenames are listed in the ROMS directive and you use –o options, the utility takes the filename from the list of –o options. The following line has the same effect as the example above using the ROMS directive:

   ```
   –o xyz.b0 –o xyz.b1 –o xyz.b2 –o xyz.b3
   ```

   If both the ROMS directive and –o options are used together, the ROMS directive overrides the –o 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 COFF input file plus a 2- to 3-character extension. The extension has three parts:

   a) A format character, based on the output format:

      a for ASCII-Hex
      i for Intel
      m for Motorola-S
      t for TI-Tagged
      x for Tektronix

      See section 10.9, *Description of the Object Formats*, on page 10-26 for more information.

   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 coff.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 coff.i0, coff.i1, coff.i2, coff.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 ...
coff.i00, coff.i01, coff.i01	0x00001000 through 0x00001FFF
coff.i02, coff.i03	0x00002000 through 0x00002FFF

10.7 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.

10.7.1 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.

A COFF 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.

Note: Defining the Ranges of Target Memory

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—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.

10.7.2 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 0FFFFh results in a fill pattern of 0000FFFFh. 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.

10.7.3 Steps to Follow in Using Image Mode

Step 1: Define the ranges of target memory with a ROMS directive. See section 10.4, *The ROMS Directive*, on page 10-13 for details.

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.

10.8 Controlling the ROM Device Address

The hex conversion utility output address corresponds to the ROM device address. The EPROM programmer burns the data in the location specified by the address field in the hex conversion utility output file. 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 where the data is burned.

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 a hex conversion utility output file is the load address (as given in the linker command file).

2) **The paddr option inside the SECTIONS directive.** When the paddr option is specified for a section (described on page 10-19), 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 record represents offsets from the beginning of the file (the address within 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 0. If you specify the –zero option without the –image option, the utility issues a warning and ignores the option.

4) **The –byte option.** Some EPROM programmers require the output file address field to contain a byte count rather than a word count. If you use the –byte option, the output file address increments once for each byte. For example, if the starting address is 0h, the first line contains eight words, and you use no –byte option, the second line would start at address 8 (08h). If the starting address is 0h, the first line contains eight words, and you use the –byte option, the second line would start at address 16 (010h). The data in both examples are the same; –byte affects only the calculation of the output file address field, not the actual target processor address of the converted data.

   The –byte option causes the address records in an output file to refer to byte locations within the file, whether or not the target processor is byte-addressable.

10.9 Description of the Object Formats

The hex conversion utility has options that identify each format and Table 10–2 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 (–x option).

Table 10–2. Options for Specifying Hex Conversion Formats

Option	Format	Address Bits	Default Width
–a	ASCII-Hex	16	8
–i	Intel	32	8
–m	Motorola-S	32	8
–t	TI-Tagged	16	16
–x	Tektronix	32	8

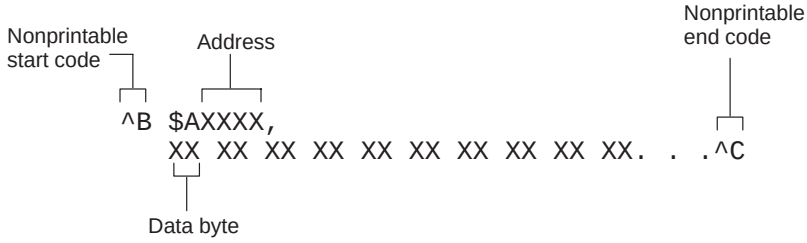
Address bits determine how many bits of the address information the format supports. Formats with 16-bit addresses support addresses up to 64K only. The utility truncates target addresses to fit in the number of available bits.

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.

10.9.1 ASCII-Hex Object Format (–a Option)

The ASCII-Hex object format supports 16-bit addresses. The format consists of a byte stream with bytes separated by spaces. Figure 10–6 illustrates the ASCII-Hex format.

Figure 10–6. ASCII-Hex Object Format



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 $AXXXX, in which XXXX is a 4-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.

10.9.2 Intel MCS-86 Object Format (–i 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

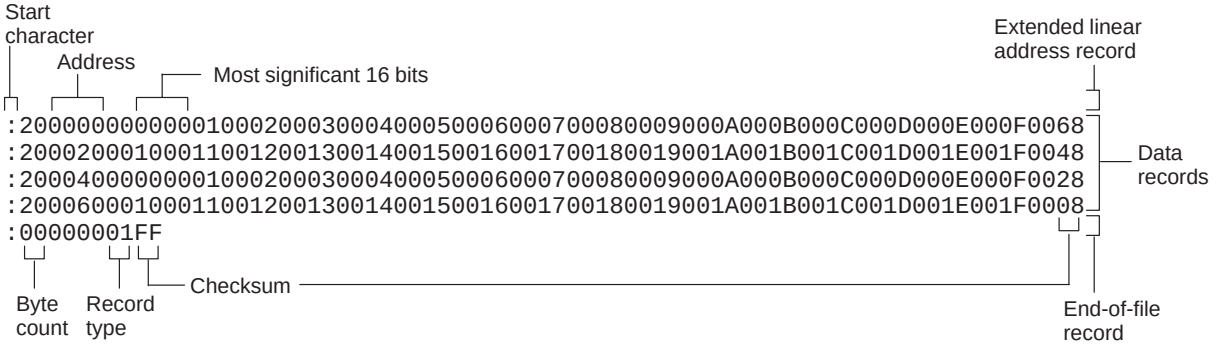
Record type 00, the data record, begins with a colon (:) and is followed by the byte count, the address of the first data byte, the record type (00), and the checksum. The address is the least significant 16 bits of a 32-bit address; this value is concatenated with the value from the most recent 04 (extended 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 10–7 illustrates the Intel hexadecimal object format.

Figure 10–7. Intel Hexadecimal Object Format



10.9.3 Motorola Exorciser Object Format (–m Option)

The Motorola-S format supports 32-bit addresses. It consists 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:

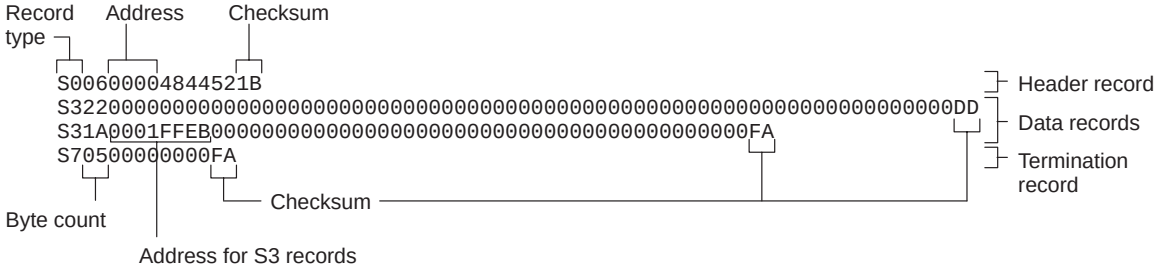
Record Type	Description
S0	Header record
S3	Code/data record
S7	Termination record

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 10–8 illustrates the Motorola-S object format.

Figure 10–8. Motorola-S Format



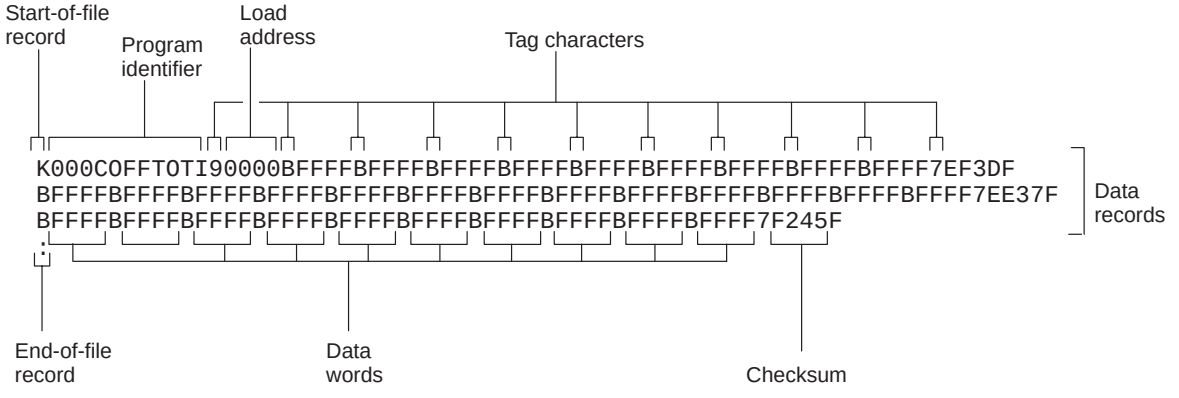
10.9.4 Texas Instruments SDSMAC Object Format (–t Option)

The Texas Instruments SDSMAC (TI-Tagged) object format supports 16-bit addresses. It consists of a start-of-file record, data records, and end-of-file record. Each of the data records consists of a series of small fields and is signified by a tag character. The significant tag characters are:

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 10–9 illustrates the tag characters and fields in TI-Tagged object format.

Figure 10–9. TI-Tagged Object Format



If any data fields appear before the first address, the first field is assigned address 0000h. Address fields may be expressed for any data byte, but none is required. The checksum field, which is 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 (:).

10.9.5 Extended Tektronix Object Format (–x 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.

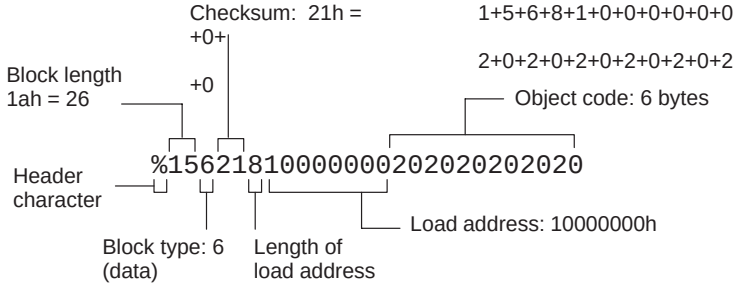
The header field in the data record contains the following information:

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 10–10 illustrates the Tektronix object format.

Figure 10–10. Extended Tektronix Object Format



10.10 Hex Conversion Utility Error Messages

section mapped to reserved memory message

Description A section is mapped into a reserved memory area as listed in the processor memory map.

Action Correct the section's allocationor boot-loader address. For valid memory locations, refer to the *TMS320C6200 CPU and Instruction Set Reference Guide*.

sections overlapping

Description Two or more COFF section load addresses overlap or a boot table address overlaps another section.

Action This problem may be caused by an incorrect translation (from the load address to the hexadecimal output file address) that is performed by the hex conversion utility when the memory width is less than the data width. See section 10.3, *Understanding Memory Widths*, on page 10-7 and section 10.8, *Controlling the ROM Device Address*, on page 10-25.

unconfigured memory error

Description The COFF file contains a section whose load address falls outside the memory range defined in the ROMS directive.

Action Correct the ROM range as defined by the ROMS directive to cover the memory range as needed, or modify the section load address. Remember that if the ROMS directive is not used, the memory range defaults to the entire processor address space. For this reason, removing the ROMS directive could also be a workaround.

Appendix A

Common Object File Format

The assembler and linker create object files in common object file format (COFF). COFF is an implementation of an object file format of the same name that was developed by AT&T for use on UNIX-based systems. This format is used because it encourages modular programming and provides powerful and flexible methods for managing code segments and target system memory.

Sections are a basic COFF concept. Chapter 2, *Introduction to Common Object File Format*, discusses COFF sections in detail. If you understand section operation, you can use the assembly language tools more efficiently.

This appendix contains technical details about TMS320C6000™ COFF object file structure. Much of this information pertains to the symbolic debugging information that is produced by the C compiler. The purpose of this appendix is to provide supplementary information on the internal format of COFF object files.

Topic **Page**

A.1 COFF File Structure

The elements of a COFF object file describe the file's sections and symbolic debugging information. These elements include:

- A file header
- Optional header information
- A table of section headers
- Raw data for each initialized section
- Relocation information for each initialized section
- Line number entries for each initialized section
- A symbol table
- A string table

The assembler and linker produce object files with the same COFF structure; however, a program that is linked for the final time does not usually contain relocation entries. Figure A–1 illustrates the object file structure.

Figure A–1. COFF File Structure

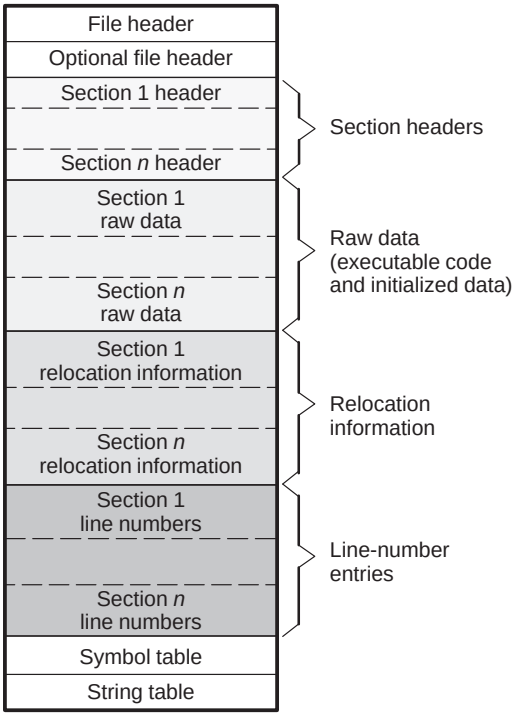
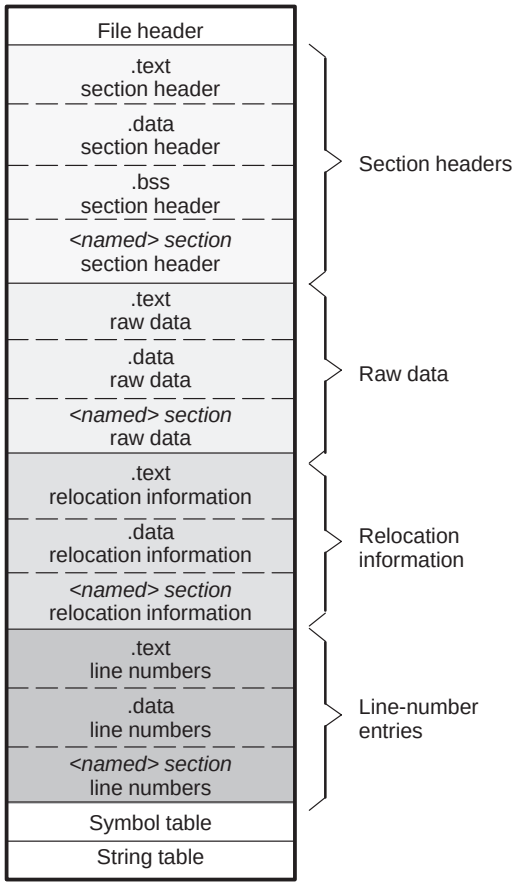


Figure A–2 shows a typical example of a COFF object file that contains the three default sections, .text, .data, and .bss, and a named section (referred to as <named>). By default, the tools place sections into the object file in the following order: .text, .data, initialized named sections, .bss, and uninitialized named sections. Although uninitialized sections have section headers, notice that they have no raw data, relocation information, or line number entries. This is because the .bss and .usect directives simply reserve space for uninitialized data; uninitialized sections contain no actual code.

Figure A–2. Sample COFF Object File



A.2 File Header Structure

The file header contains 22 bytes of information that describe the general format of an object file. Table A–1 shows the structure of the C6000 COFF file header.

Table A–1. File Header Contents

Byte Number	Type	Description
0–1	Unsigned short	Version ID; indicates version of COFF file structure
2–3	Unsigned short	Number of section headers
4–7	Integer	Time and date stamp; indicates when the file was created
8–11	Integer	File pointer; contains the symbol table's starting address
12–15	Integer	Number of entries in the symbol table
16–17	Unsigned short	Number of bytes in the optional header. This field is either 0 or 28; if it is 0, there is no optional file header.
18–19	Unsigned short	Flags (see Table A–2)
20–21	Unsigned short	Target ID; magic number (0099h) indicates the file can be executed in a C6000 system

Table A–2 lists the flags that can appear in bytes 18 and 19 of the file header. Any number and combination of these flags can be set at the same time (for example, if bytes 18 and 19 are set to 0003h, F_RELFLG and F_EXEC are both set.)

Table A–2. File Header Flags (Bytes 18 and 19)

Mnemonic	Flag	Description
F_RELFLG	0001h	Relocation information was stripped from the file.
F_EXEC	0002h	The file is relocatable (it contains no unresolved external references).
F_LNNO	0004h	Line numbers were stripped from the file.
F_LSYMS	0008h	Local symbols were stripped from the file.
F_LITTLE	0100h	The target is a little-endian device.
F_BIG	0200h	The target is a big-endian device.

A.3 Optional File Header Format

The linker creates the optional file header and uses it to perform relocation at download time. Partially linked files do not contain optional file headers. Table A–3 illustrates the optional file header format.

Table A–3. Optional File Header Contents

Byte Number	Type	Description
0–1	Short	Optional file header magic number (0108h)
2–3	Short	Version stamp
4–7	Integer	Size (in bytes) of executable code
8–11	Integer	Size (in bytes) of initialized data
12–15	Integer	Size (in bytes) of uninitialized data
16–19	Integer	Entry point
20–23	Integer	Beginning address of executable code
24–27	Integer	Beginning address of initialized data

A.4 Section Header Structure

COFF object files contain a table of section headers that define where each section begins in the object file. Each section has its own section header. Table A–4 shows the structure of each section header.

Table A–4. Section Header Contents

Byte Number	Type	Description
0–7	Character	This field contains one of the following: 1) An 8-character section name padded with nulls 2) A pointer into the string table if the symbol name is longer than eight characters
8–11	Integer	Section's physical address
12–15	Integer	Section's virtual address
16–19	Integer	Section size in bytes
20–23	Integer	File pointer to raw data
24–27	Integer	File pointer to relocation entries
28–31	Integer	File pointer to line number entries
32–35	Unsigned integer	Number of relocation entries
36–39	Unsigned integer	Number of line number entries
40–43	Unsigned integer	Flags (see Table A–5)
44–45	Unsigned short	Reserved
46–47	Unsigned short	Memory page number

Table A–5 lists the flags that can appear in bytes 36 through 39 of the section header.

Table A–5. Section Header Flags (Bytes 40 Through 43)

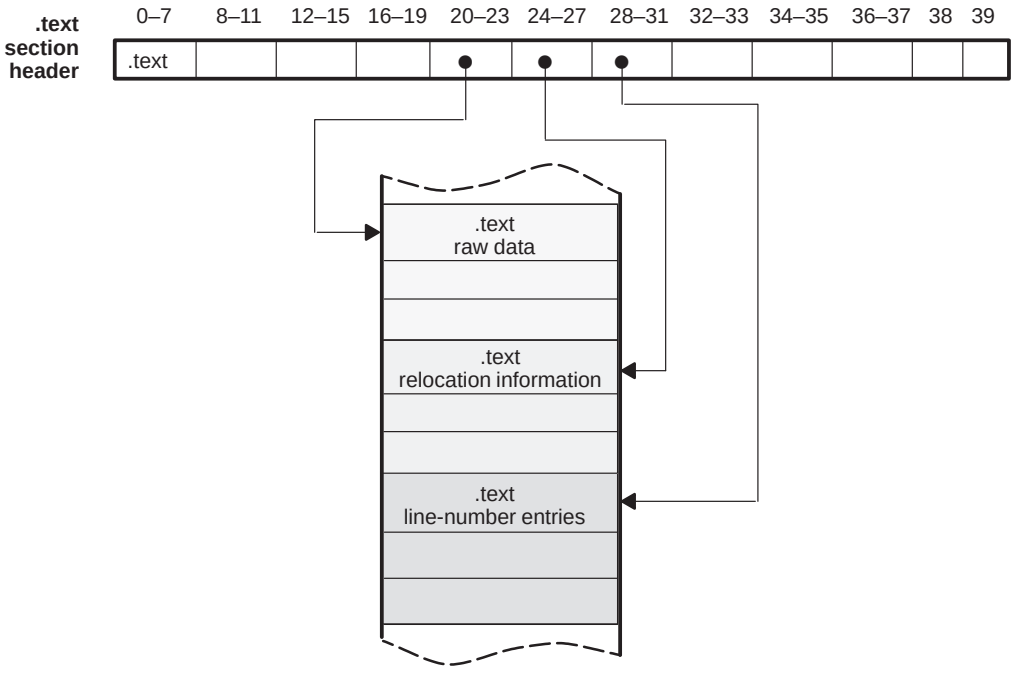
Mnemonic	Flag	Description
STYP_REG	00000000h	Regular section (allocated, relocated, loaded)
STYP_DSECT	00000001h	Dummy section (relocated, not allocated, not loaded)
STYP_NOLOAD	00000002h	Noload section (allocated, relocated, not loaded)
STYP_BLOCK	0x1000	Alignment used as a blocking factor
STYP_PASS	0x2000	Section should pass these unchanged
STYP_VECTOR	0x8000	Section contains vector table
STYP_PADDED	0x10000	Section has been padded
STYP_COPY	00000010h	Copy section (relocated, loaded, but not allocated; relocation and line number entries are processed normally)
STYP_TEXT	00000020h	Section contains executable code
STYP_DATA	00000040h	Section contains initialized data
STYP_BSS	00000080h	Section contains uninitialized data
STYP_CLINK	00004000h	Section requires conditional linking

Note: The term *loaded* means that the raw data for this section appears in the object file.

The flags listed in Table A–5 can be combined; for example, if the flag's word is set to 024h, both STYP_GROUP and STYP_TEXT are set.

Figure A–3 illustrates how the pointers in a section header point to the elements in an object file that are associated with the .text section.

Figure A–3. Section Header Pointers for the .text Section



As Figure A–2 on page A-3 shows, uninitialized sections (created with the .bss and .usect directives) vary from this format. Although uninitialized sections have section headers, they have no raw data, relocation information, or line number information. They occupy no actual space in the object file. Therefore, the number of relocation entries, the number of line number entries, and the file pointers are 0 for an uninitialized section. The header of an uninitialized section simply tells the linker how much space for variables it should reserve in the memory map.

A.5 Structuring Relocation Information

A COFF object file has one relocation entry for each relocatable reference. The assembler automatically generates relocation entries. The linker reads the relocation entries as it reads each input section and performs relocation. The relocation entries determine how references within each input section are treated.

COFF file relocation information entries use the 10-byte format shown in Table A–6.

Table A–6. Relocation Entry Contents

Byte Number	Type	Description
0–3	Integer	Virtual address of the reference
4–5	short	Symbol table index (0–65 535)
6–7	Unsigned short	Reserved
8–9	Unsigned short	Relocation type (see Table A–7)

The **virtual address** is the symbol's address in the current section *before* relocation; it specifies *where* a relocation must occur. (This is the address of the field in the object code that must be patched.)

Following is an example of code that generates a relocation entry:

```
2                          .global X
3 00000000 !00000012     b       X
```

In this example, the virtual address of the relocatable field is 0001.

The **symbol table index** is the index of the referenced symbol. In the preceding example, this field contains the index of X in the symbol table. The amount of the relocation is the difference between the symbol's current address in the section and its assembly-time address. The relocatable field must be relocated by the same amount as the referenced symbol. In the example, X has a value of 0 before relocation. Suppose X is relocated to address 2000h. This is the relocation amount (2000h – 0 = 2000h), so the relocation field at address 1 is patched by adding 2000h to it.

You can determine a symbol's relocated address if you know which section it is defined in. For example, if X is defined in .data and .data is relocated by 2000h, X is relocated by 2000h.

If the symbol table index in a relocation entry is –1 (0FFFFh), this is called an *internal relocation.* In this case, the relocation amount is simply the amount by which the current section is being relocated.

The **relocation type** specifies the size of the field to be patched and describes how the patched value is calculated. The type field depends on the addressing mode that was used to generate the relocatable reference. In the preceding example, the actual address of the referenced symbol X is placed in an 8-bit field in the object code. This is an 8-bit address, so the relocation type is R_RELBYTE. Table A–7 lists the relocation types.

Table A–7. Relocation Types (Bytes 8 and 9)

Mnemonic	Flag	Relocation Type
R_ABS	0000h	No relocation
R_RELBYTE	000Fh	8-bit direct reference to symbol's address
R_RELWORD	0010h	16-bit direct reference to symbol's address
R_RELLONG	0011h	32-bit direct reference to symbol's address
R_C60BASE	0050h	Data page pointer-based offset
R_C60DIR15	0051h	Load or store long displacement
R_C60PCR21	0052h	21-bit packet, PC relative
R_C60LO16	0054h	MVK instruction low half register
R_C60HI16	0055h	MVKH or MVKLH high half register
R_C60SECT	0056h	Section-based offset
R_C60PCR10	0053h	10-bit Packet PC Relative (BDEC, BPOS)
R_C60S16	0057h	Signed 16-bit offset for MVK
R_C60PCR7	0070h	7-bit Packet PC Relative (ADDKPC)
R_C60PCR12	0071h	12-bit Packet PC Relative (BNOP)
RE_ADD	4000h	Operator instruction +
RE_SUB	4001h	Operator instruction –
RE_NEG	4002h	Operator instruction unary –
RE_MPY	4003h	Operator instruction *
RE_DIV	4004h	Operator instruction /
RE_MOD	4005h	Operator instruction %
RE_SR	4006h	Unsigned shift right
RE_ASR	4007h	Signed shift right

Mnemonic	Flag	Relocation Type
RE_SL	4008h	Shift left
RE_AND	4009h	AND function
RE_OR	400Ah	OR function
RE_XOR	400Bh	Exclusive OR function
RE_NOTB	400Ch	~
RE_ULDFLD	400Dh	Unsigned relocation field load
RE_SLDFLD	400Eh	Signed relocation field load
RE_USTFLD	400Fh	Unsigned relocation field store
RE_SSTFLD	4010h	Signed relocation field store
RE_XSTFLD	4016h	Signed state is not relevant
RE_PUSH	4011h	Push symbol on the stack
RE_PUSHSV	c011h	Push symbol: SEGVALUE flag is set
RE_PUSHSK	4012h	Push signed constant on the stack
RE_PUSHUK	4013h	Push unsigned constant on the stack
RE_PUSHPC	4014h	Push current section PC on the stack
RE_DUP	4015h	Duplicate tos and push copy

A.6 Line Number Table Structure

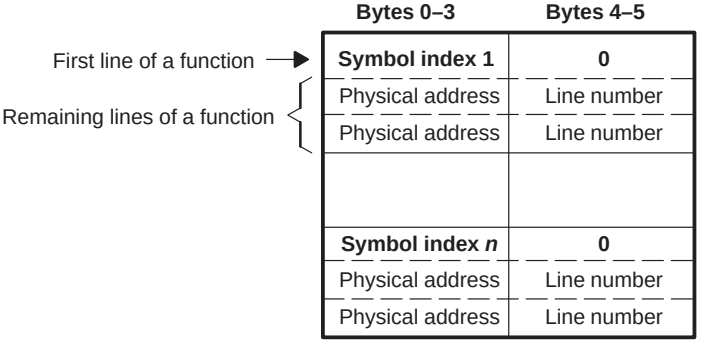
The object file contains a table of line number entries that are useful for symbolic debugging. When the C/C++ compiler produces several lines of assembly language code, it creates a line-number entry that maps these lines back to the original line of C/C++ source code that generated them. Each single line-number entry contains six bytes of information. Table A–8 shows the format of a line-number entry.

Table A–8. Line Number Entry Format

Byte Number	Type	Description
0–3	Integer	This entry can have one of two values: 1) If it is the first entry in a block of line-number entries, the value is an index that points to a symbol entry in the symbol table. 2) If it is not the first entry in a block, it is the physical address of the line indicated by bytes 4–5.
4–5	Unsigned short	This entry may have one of two values: 1) If the value of this field is 0, this is the first line of a function entry. 2) If the value of this field is *not* 0, this is the line number of a line of C/C++ source code.

Figure A–4 shows how line number entries are grouped into blocks.

Figure A–4. Line Number Blocks



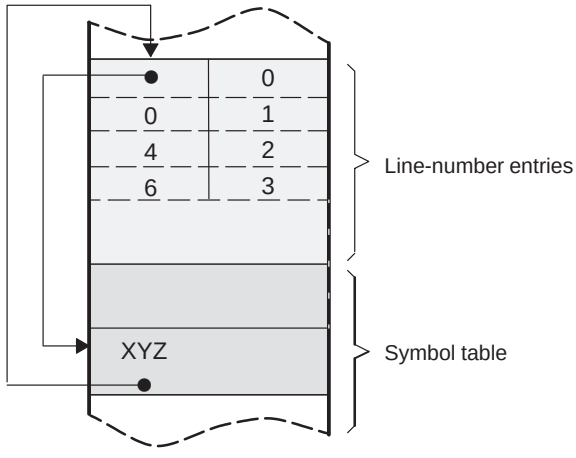
As Figure A–4 shows, each entry is divided into halves:

- For the *first line* of a function, bytes 0–3 point to the name of a symbol or a function in the symbol table, and bytes 4–5 contain a 0, which indicates the beginning of a block.
- For the *remaining lines* in a function, bytes 0–3 show the physical address (the number of bytes created by a line of C/C++ source), and bytes 4–5 show the address of the original C/C++ source, relative to its appearance in the C/C++ source program.

The line-number entry table can contain many of these blocks.

Figure A–5 illustrates line number entries for a function named XYZ. As shown, the function name is entered as a symbol in the symbol table. The first portion on XYZ's block of line number entries points to the function name in the symbol table. Assume that the original function in the C source contained three lines of code. The code associated with the first line is located at byte offset 0 from the beginning of the function. The code for line 2 begins at offset 4, and the code associated with line 3 is 6 bytes from the beginning of the function.

Figure A–5. Line Number Entries



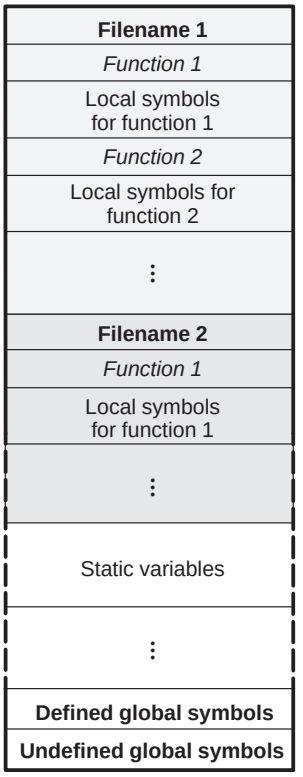
(The symbol table entry for XYZ has a field that points back to the beginning of the line number block.)

Because line numbers are not often needed, the linker provides an option (–s) that strips line number information from the object file; this provides a more compact object module. (For more information on the –s option, see section 7.4.15, *Strip Symbolic Information (–s Option)*, page 7-17.)

A.7 Symbol Table Structure and Content

The order of symbols in the symbol table is very important; they appear in the sequence shown in Figure A–6.

Figure A–6. Symbol Table Contents



Static variables refer to symbols defined in C/C++ that have storage class static outside any function. If you have several modules that use symbols with the same name, making them static confines the scope of each symbol to the module that defines it (this eliminates multiple-definition conflicts).

The entry for each symbol in the symbol table contains the symbol's:

- Name (or an offset into the string table)
- Type
- Value
- Section it was defined in
- Storage class
- Basic type (integer, character, etc.)
- Derived type (array, structure, etc.)
- Dimensions
- Line number of the source code that defined the symbol

Section names are also defined in the symbol table.

All symbol entries, regardless of class and type, have the same format in the symbol table. Each symbol table entry contains the 18 bytes of information listed in Table A–9. Each symbol may also have an 18-byte auxiliary entry; the special symbols listed in Table A–10, page A-16, always have an auxiliary entry. Some symbols may not have all the characteristics listed above; if a particular field is not set, it is set to null.

Table A–9. Symbol Table Entry Contents

Byte Number	Type	Description
0–7	Char	This field contains one of the following: 1) An 8-character symbol name, padded with nulls 2) A pointer into the string table if the symbol name is longer than eight characters
8–11	Integer	Symbol value; storage class dependent
12–13	Short	Section number of the symbol
14–15	Unsigned short	Basic and derived type specification
16	Char	Storage class of the symbol
17	Char	Number of auxiliary entries (always 0 or 1)

A.7.1 Special Symbols

The symbol table contains some special symbols that are generated by the compiler, assembler, and linker. Each special symbol contains ordinary symbol table information as well as an auxiliary entry. Table A–10 lists these symbols.

Several of these symbols appear in pairs:

- The .bb/.eb symbols indicate the beginning and end of a block.
- The .bf/.ef symbols indicate the beginning and end of a function.
- The *n*fake/.eos symbols name and define the limits of structures, unions, and enumerations that were not named. The .eos symbol is also paired with named structures, unions, and enumerations.

Table A–10. Special Symbols in the Symbol Table

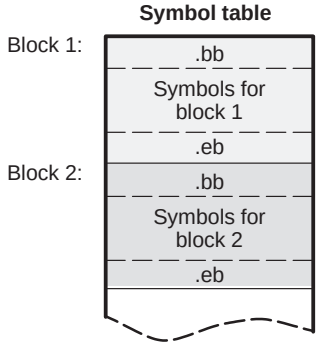
Symbol	Description
.text	Address of the .text section
.data	Address of the .data section
.bss	Address of the .bss section
.bb	Address of the beginning of a block
.eb	Address of the end of a block
.bf	Address of the beginning of a function
.ef	Address of the end of a function
.target	Pointer to a structure or union that is returned by a function
.*n*fake†	Dummy tag name for a structure, union, or enumeration
.eos	End of a structure, union, or enumeration
etext	Next available address after the end of the .text output section
edata	Next available address after the end of the .data output section
end	Next available address after the end of the .bss output section

† When a structure, union, or enumeration has no tag name, the compiler assigns it a name so that it can be entered into the symbol table. These names are of the form *n*fake, where *n* is an integer. The compiler begins numbering these symbol names at 0.

A.7.1.1 Symbols and Blocks

In C/C++, a block is a compound statement that begins and ends with braces. A block always contains symbols. The symbol definitions for any particular block are grouped together in the symbol table and are delineated by the .bb/.eb special symbols. Blocks can be nested in C/C++, and their symbol table entries can be nested correspondingly. Figure A–7 shows how block symbols are grouped in the symbol table.

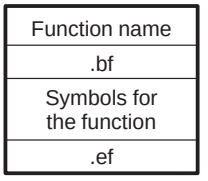
Figure A–7. Symbols for Blocks



A.7.1.2 Symbols and Functions

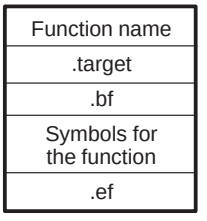
The symbol definitions for a function appear in the symbol table as a group, delineated by .bf/.ef special symbols. The symbol table entry for the function name precedes the .bf special symbol. Figure A–8 shows the format of symbol table entries for a function.

Figure A–8. Symbols for Functions



If a function returns a structure or union, a symbol table entry for the special symbol .target appears between the entries for the function name and the .bf special symbol, as shown in Figure A–9.

Figure A–9. Symbols for Functions That Return a Structure or Union



A.7.2 Symbol Name Format

The first eight bytes of a symbol table entry (bytes 0–7) indicate a symbol's name:

- If the symbol name is eight characters or less, this field has type *character.* The name is padded with nulls (if necessary) and stored in bytes 0–7.
- If the symbol name is greater than eight characters, this field is treated as two integers. The entire symbol name is stored in the string table. Bytes 0–3 contain 0, and bytes 4–7 are an offset into the string table.

A.7.3 String Table Structure

Symbol names that are longer than eight characters are stored in the string table. The field in the symbol table entry that would normally contain the symbol's name contains, instead, a pointer to the symbol's name in the string table. Names are stored contiguously in the string table, delimited by a null byte. The first four bytes of the string table contain the size of the string table in bytes; thus, offsets into the string table are greater than or equal to 4.

Figure A–10 is a string table that contains two symbol names, *Adaptive-Filter* and *Fourier-Transform*. The index in the string table is 4 for Adaptive-Filter and 20 for Fourier-Transform.

Figure A–10. String Table Entries for Sample Symbol Names

38 bytes

4 bytes			
'A'	'd'	'a'	'p'
't'	'i'	'v'	'e'
'-'	'F'	'i'	'l'
't'	'e'	'r'	'\0'
'F'	'o'	'u'	'r'
'i'	'e'	'r'	'-'
'T'	'r'	'a'	'n'
's'	'f'	'o'	'r'
'm'	'\0'		

A.7.4 Storage Classes

Byte 16 of the symbol table entry indicates the storage class of the symbol. Storage classes refer to the method in which the C/C++ compiler accesses a symbol. Table A–11 lists valid storage classes.

Table A–11. Symbol Storage Classes

Mnemonic	Value	Storage Class	Mnemonic	Value	Storage Class
C_NULL	0	No storage class	C_ENTAG	15	Enumeration tag
C_AUTO	1	Automatic variable	C_MOE	16	Member of an enumeration
C_EXT	2	External definition	C_REGPARM	17	Register parameter
C_STAT	3	Static	C_FIELD	18	Bit field
C_REG	4	Register variable	C_UEXT	19	Tentative external definition
C_EXTREF	5	External reference	C_STATLAB	20	Static load time label
C_LABEL	6	Label	C_EXTLAB	21	External load time label
C_ULABEL	7	Undefined label	C_BLOCK	100	Beginning or end of a block; used only for the .bb and .eb special symbols
C_MOS	8	Member of a structure			
C_ARG	9	Function argument	C_FCN	101	Beginning or end of a function; used only for the .bf and .ef special symbols
C_STRTAG	10	Structure tag			
C_MOU	11	Member of a union	C_EOS	102	End of structure; used only for the .eos special symbol
C_UNTAG	12	Union tag	C_FILE	103	Filename; used only for filename symbols
C_TPDEF	13	Type definition	C_LINE	104	Used only by utility programs
C_USTATIC	14	Undefined static			

Some special symbols are restricted to certain storage classes. Table A–12 lists these symbols and their storage classes.

Table A–12. Special Symbols and Their Storage Classes

Special Symbol	Restricted to This Storage Class	Special Symbol	Restricted to This Storage Class
.bb	C_BLOCK	.eos	C_EOS
.eb	C_BLOCK	.text	C_STAT
.bf	C_FCN	.data	C_STAT
.ef	C_FCN	.bss	C_STAT

A.7.5 Symbol Values

Bytes 8–11 of a symbol table entry indicate a symbol's value. A symbol's value depends on the symbol's storage class; Table A–13 summarizes the storage classes and related values.

Table A–13. Symbol Values and Storage Classes

Storage Class	Value Description	Storage Class	Value Description
C_AUTO	Stack offset in bits	C_UNTAG	0
C_EXT	Relocatable address	C_TPDEF	0
C_STAT	Relocatable address	C_ENTAG	0
C_REG	Register number	C_MOE	Enumeration value
C_LABEL	Relocatable address	C_REGPARM	Register number
C_MOS	Offset in bits	C_FIELD	Bit displacement
C_ARG	Stack offset in bits	C_BLOCK	Relocatable address
C_STRTAG	0	C_FCN	Relocatable address
C_MOU	Offset in bits	C_FILE	0

The value of a relocatable symbol is its virtual address. When the linker relocates a section, the value of a relocatable symbol changes accordingly.

A.7.6 Section Number

Bytes 12–13 of a symbol table entry contain a number that indicates which section the symbol was defined in. Table A–14 lists these numbers and the sections they indicate.

Table A–14. Section Numbers

Mnemonic	Section Number	Description
N_DEBUG	–2	Special symbolic debugging symbol
N_ABS	–1	Absolute symbol
N_UNDEF	0	Undefined external symbol
None	1	.text section (typical)
None	2	.data section (typical)
None	3	.bss section (typical)
None	4–32 767	Section number of a named section, in the order in which the named sections are encountered

If there were no .text, .data, or .bss sections, the numbering of named sections would begin with 1.

If a symbol has a section number of 0, –1, or –2, it is not defined in a section. A section number of –2 indicates a symbolic debugging symbol, which includes structure, union, and enumeration tag names, type definitions, and the filename. A section number of –1 indicates that the symbol has a value but is not relocatable. A section number of 0 indicates a relocatable external symbol that is not defined in the current file.

A.7.7 Type Entry

Bytes 14–15 of the symbol table entry define the symbol's type. Each symbol has one basic type and one to six derived types.

Following is the format for this 16-bit type entry:

	Derived type 6	Derived type 5	Derived type 4	Derived type 3	Derived type 2	Derived type 1	Basic type
Size (in bits):	2	2	2	2	2	2	4

Bits 0–3 of the type field indicate the basic type. Table A–15 lists valid basic types.

Table A–15. Basic Types

Mnemonic	Value	Type
CT_VOID	0	Void type
CT_SCHAR1	1	Character (explicitly signed)
CT_CHAR	2	Character (implicitly signed)
CT_SHORT	3	Short
CT_INT	4	Integer
CT_LONG	5	Integer
CT_FLOAT	6	Floating point
CT_DOUBLE	7	Double floating point
CT_STRUCT	8	Structure
CT_UNION	9	Union
CT_ENUM	10	Enumeration
CT_LDOUBLE	11	Long double floating point
CT_UCHAR	12	Unsigned character
CT_USHORT	13	Unsigned short
CT_UINT	14	Unsigned integer
CT_ULONG	15	Unsigned integer

Bits 4–15 of the type field are arranged as six 2-bit fields, each of which can indicate a derived type. Table A–16 lists the possible derived types.

Table A–16. Derived Types

Mnemonic	Value	Type
DCT_NON	0	No derived type
DCT_PTR	1	Pointer
DCT_FCN	2	Function
DCT_ARY	3	Array

An example of a symbol with several derived types would be a symbol with a type entry of 0000 0000 1101 0011_2. This entry indicates that the symbol is an array of pointers to shorts.

A.7.8 Auxiliary Entries

Each symbol table entry can have *one* or *no* auxiliary entry. An auxiliary symbol table entry contains the same number of bytes as a symbol table entry (18), but the format of an auxiliary entry depends on the symbol's type and storage class. Table A–17 summarizes these relationships.

Table A–17. Auxiliary Symbol Table Entries Format

		Type Entry		
Name	**Storage Class**	**Derived Type 1**	**Basic Type**	**Auxiliary Entry Format**
.text, .data, .bss	C_STAT	DCT_NON	CT_VOID	Section (see Table A–18)
tagname	C_STRTAG C_UNTAG C_ENTAG	DCT_NON	CT_STRUCT CT_UNION CT_ENUM	Tag name (see Table A–19)
.eos	C_EOS	DCT_NON	CT_VOID	End of structure (see Table A–20)
fcname	C_EXT C_STAT	DCT_FCN	Any	Function (see Table A–21)
arrname	See note 1	DCT_ARY	See note 2	Array (see Table A–22)
.bb, .eb	C_BLOCK	DCT_NON	CT_VOID	Beginning and end of a block (see Table A–23 and Table A–24)
.bf, .ef	C_FCN	DCT_NON	CT_VOID	Beginning and end of a function (see Table A–23 and Table A–24)
Name related to a structure, union, or enumeration	See note 1	DCT_PTR DCT_ARR DCT_NON	CT_STRUCT CT_UNION CT_ENUM	Name related to a structure, union, or enumeration (see Table A–25)

Notes: 1) C_AUTO, C_STAT, C_MOS, C_MOU, C_TPDEF, C_EXT
2) Any except CT_VOID

In Table A–17, *tagname* refers to any symbol name (including the special symbol *n*fake); *fcname* and *arrname* also refer to any symbol name. Typically, tagname refers to a structure, fcname refers to a function, and arrname refers to an array.

A symbol that satisfies more than one condition in Table A–17 must have a union format in its auxiliary entry. A symbol that satisfies none of these conditions cannot have an auxiliary entry.

A.7.8.1 Sections

Table A–18 illustrates the format of auxiliary table entries.

Table A–18. Section Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	Integer	Section length
4–5	Unsigned short	Number of relocation entries
6–7	Unsigned short	Number of line number entries
8–17	—	Not used (zero filled)

A.7.8.2 Tag Names

Table A–19 illustrates the format of auxiliary table entries for tag names.

Table A–19. Tag Name Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	—	Unused (zero filled)
4–7	Integer	Size of structure, union, or enumeration
8–11	—	Unused (zero filled)
12–15	Integer	Index of next entry beyond this function
16–17	—	Unused (zero filled)

A.7.8.3 End of Structure

Table A–20 illustrates the format of auxiliary table entries for ends of structures.

Table A–20. End-of-Structure Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	Integer	Tag index
4–7	Integer	Size of structure, union, or enumeration
8–17	—	Unused (zero filled)

A.7.8.4 Functions

Table A–21 illustrates the format of auxiliary table entries for functions.

Table A–21. Function Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	Integer	Tag index
4–7	Integer	Size of function (in bits)
8–11	Integer	File pointer to line number
12–15	Integer	Index of next entry beyond this function
16–17	—	Unused (zero filled)

A.7.8.5 Arrays

Table A–22 illustrates the format of auxiliary table entries for arrays.

Table A–22. Array Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	Integer	Tag index
4–7	Integer	Size of array
8–9	Unsigned short	First dimension
10–11	Unsigned short	Second dimension
12–13	Unsigned short	Third dimension
14–15	Unsigned short	Fourth dimension
16–17	—	Unused (zero filled)

A.7.8.6 End of Blocks and Functions

Table A–23 illustrates the format of auxiliary table entries for the ends of blocks and functions.

Table A–23. End-of-Blocks/Functions Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	—	Unused (zero filled)
4–5	Unsigned short	C/C++ source line number
6–17	—	Unused (zero filled)

A.7.8.7 Beginning of Blocks and Functions

Table A–24 illustrates the format of auxiliary table entries for the beginnings of blocks and functions.

Table A–24. Beginning-of-Blocks/Functions Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	Integer	Register save mask
4–5	Unsigned short	C/C++ source line number of block begin
6–7	Unsigned short	Number line entries for function
8–11	Integer	Size of local frame for function
12–15	Integer	Index of next entry past this block
16–17	—	Unused (zero filled)

A.7.8.8 Names Related to Structures, Unions, and Enumerations

Table A–25 illustrates the format of auxiliary table entries for the names of structures, unions, and enumerations.

Table A–25. Structure, Union, and Enumeration Names Format for Auxiliary Table Entries

Byte Number	Type	Description
0–3	Integer	Tag index
4–7	Integer	Size of the structure, union, or enumeration
8–17	—	Unused (zero filled)

Appendix B

Symbolic Debugging Directives

The assembler supports several directives that the TMS320C6000 C/C++ compiler uses for symbolic debugging:

- 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.

These symbolic debugging directives are not usually listed in the assembly language file that the compiler creates. If you want them to be listed, and you want to retain the assembly language file, invoke the compiler shell with the –g and –k options, as shown below:

```
cl6x –gk input file
```

This appendix contains an alphabetical directory of the symbolic debugging directives. With the exception of the .file directive description, each directive contains an example of C source and the resulting assembly language code.

For information on the C/C++ compiler, refer to the *TMS320C6000 Optimizing Compiler User's Guide*.

Syntax

.block [*beginning line number*]
.endblock [*ending line number*]

Description

The **.block** and **.endblock** directives specify the beginning and end of a C/C++ block. The *line numbers* are optional; they specify the location in the source file where the block is defined.

Block definitions can be nested. The assembler detects improper block nesting.

Example

Following is an example of C source that defines a block and the resulting assembly language code.

C source:

```
main()
{
   int i = 10;
   {
      int y = i + 3;
      foo(y);
   }
}
```

Resulting assembly language code:

```
_main:
           STW     .D2     B3,*SP--(12)
        .sym _i,4,4,1,32
        .line   3
           MVK     .S1     10,A0
           STW     .D2     A0,*+SP(4)
        .block  6
        .sym    _y,8,4,1,32
           MV      .L2X    A0,B4
           ADD     .L2     3,B4,B4
           STW     .D2     B4,*+SP(8)
        .line   7
           B       .S1     _foo
           NOP             3
           MVK     .S2     RL0,B3

           MV      .L1X    B4,A4
||         MVKH    .S2     RL0,B3
RL0:       ; CALL OCCURS
        .endblock     9
        .line   10
           LDW     .D2     *++SP(12),B3
           NOP             4
           B       .S2     B3
           NOP             5
           ; BRANCH OCCURS
        .endfunc        10,000080000h,12
```

Syntax

.file "*filename***"**

Description

The **.file** directive allows a debugger to map locations in memory back to lines in a C/C++ source file. The *filename* is the name of the file that contains the original C/C++ source program. Filenames can be arbitrarily long.

You can also use the .file directive in assembly code to provide a name in the file and improve program readability.

Example

In the following example the file named text.c contained the C source that produced this directive.

```
.file     "text.c"
```

Syntax

.func [*beginning line number*]
.endfunc [*ending line number*[**,** *register mask*[**,** *frame size*]]]

Description

The **.func** and **.endfunc** directives specify the beginning and end of a C/C++ function. The *line numbers* are optional; they specify the location in the source file where the function is defined. Function definitions cannot be nested.

The .func directive has two additional optional operands:

- The *register mask* indicates which SOE registers are saved by this function.
- The *frame size* is the maximum size of the local frame. It specifies how much stack space is needed by this function.

Example

Following is an example of C source that defines a function and the resulting assembly language code.

C source:

```
power(x, n)    /*  Beginning of a function */
int x,n;
{
   int i, p;
   p = 1;
   for (i =1; i <= n; ++i)
      p = p *x;
   return p;   /*  End of a function       */
}
```

Resulting assembly language code:

```
FP      .set    A15
DP      .set    B14
SP      .set    B15

;       opt6x –O2 func.if func.opt
        .file   ”func.c”
        .sect   ”.text”
        .align  32
        .global _power
        .sym    _power,_power,35,2,0
        .func   2

;*************************************************************
;* FUNCTION NAME: _power                                     *
;*                                                           *
;*   Regs Modified     : A0,A3,A4,B0,B5                      *
;*   Regs Used         : A0,A3,A4,B0,B3,B4,B5                *
;*   Local Frame Size  : 0 Args + 0 Auto + 0 Save = 0 byte   *
;*************************************************************
_power:
;* BB ----------------------------------------------------
        .sym    _x,4,4,17,32
        .sym    _n,20,4,17,32
        .sym    _p,4,3,4,16
        .sym    _x,0,3,4,16
        .sym    _x,4,4,4,32
        .sym    _n,20,4,4,32
        .sym    L$1,16,4,4,32
```

```
    .line  3
           EXT     .S1     A4,16,16,A0
    .line  6
           MVK     .S1     0x1,A4
    .line  7
           EXT     .S2     B4,16,16,B5
           CMPGT   .L2     B5,0,B0
   [!B0]   B       .S1     L4
           NOP             5
           ; BRANCH OCCURS
;* BB ------------------------------------------------------
    .line  8
           EXT     .S2     B4,16,16,B0
;* BB ------------------------------------------------------
L3:
           MPY     .M1     A0,A4,A3
           NOP             1
           EXT     .S1     A3,16,16,A4
    .line  7
           SUB     .L2     B0,1,B0
   [ B0]   B       .S1     L3
           NOP             5
           ; BRANCH OCCURS
;* BB ------------------------------------------------------
L4:
    .line  9
;* BB ------------------------------------------------------
    .line  10
           B       .S2     B3
           NOP             5
           ; BRANCH OCCURS
    .endfunc   11,000000000h,0
```

Syntax

.line *line number* [**,** *address*]

Description

The **.line** directive creates a line number entry in the object file. Line number entries are used in symbolic debugging to associate addresses in the object code with the lines in the source code that generated them.

The .line directive has two operands:

- The *line number* indicates the line of the C/C++ source that generated a portion of code. Line numbers are relative to the beginning of the current function. This is a required parameter.
- The *address* is an expression that is the address associated with the line number. This is an optional parameter; if you do not specify an address, the assembler uses the current SPC value.

Example

The .line directive is followed by the assembly language source statements that are generated by the indicated line of C/C++ source. For example, assume that the lines of C source below are lines 4 through 6 in the original C source; line 5 produces the assembly language source statements that are shown below.

C source:

```
for (i = 1; i <= n; ++i)
   p = p * x;
return p;
```

Resulting assembly language code:

```
FP  .set   A15
DP  .set   B14
SP  .set   B15

;   opt6x –O2 line.if line.opt
    .file  ”line.c”
    .sect  ”.text”
    .align 32
    .global_main
    .sym   _main,_main,36,2,0
    .func  2

;*************************************************************
;* FUNCTION NAME: _main                                      *
;*                                                           *
;*   Regs Modified     : A3,A4,A5,B0,B1,B4                   *
;*   Regs Used         : A0,A3,A4,A5,B0,B1,B3,B4             *
;*   Local Frame Size  : 0 Args + 0 Auto + 0 Save = 0 byte   *
;*************************************************************
```

```
_main:
;* BB ------------------------------------------------------
    .sym   _x,0,4,4,32
    .sym   _n,16,4,4,32
    .sym   _p,4,4,4,32
    .sym   L$1,16,4,4,32
    .line  5
           CMPGT   .L2     B0,0,B1
   [!B1]   B       .S1     L4
           NOP             5
           ; BRANCH OCCURS
;* BB ------------------------------------------------------
    .line  6
;* BB ------------------------------------------------------
L3:
           MPYLH   .M1     A0,A4,A5
           MPYLH   .M1     A4,A0,A3
           MV      .L2X    A0,B4

           ADD     .L1     A5,A3,A4
||         MPYU    .M2X    B4,A4,B4

           SHL     .S1     A4,0x10,A4
           ADD     .L1X    B4,A4,A4
    .line  5
           SUB     .L2     B0,1,B0
   [ B0]   B       .S1     L3
           NOP             5
           ; BRANCH OCCURS
;* BB ------------------------------------------------------
L4:
    .line  8
;* BB ------------------------------------------------------
    .line  9
           B       .S2     B3
           NOP             5
           ; BRANCH OCCURS
    .endfunc   10,000000000h,0
```

Syntax

.member *name*, *value* [, *type*, *storage class*, *size*, *tag*, *dims*]

Description

The **.member** directive defines a member of a structure, union, or enumeration. It is valid only when it appears in a structure, union, or enumeration definition.

- The *name* is the name of the member that is put in the symbol table. The first 128 characters of the name are significant.
- The *value* is the value associated with the member. Any legal expression (absolute or relocatable) is acceptable.
- The *type* is the C/C++ type of the member. Appendix A, *Common Object File Format*, contains more information about C/C++ types.
- The *storage class* is the C/C++ storage class of the member. Appendix A, *Common Object File Format*, contains more information about C/C++ storage classes.
- The *size* is the number of bits of memory required to contain this member.
- The *tag* is the name of the type (if any) or structure of which this member is a type. This name *must* have been previously declared by a .stag, .etag, or .utag directive.
- The *dims* is one to four expressions separated by commas; these expressions describe the dimensions of the member.

The order of parameters is significant. The *name* and *value* are required parameters. All other parameters may be omitted or empty. (Adjacent commas indicate an empty entry.) This allows you to skip a parameter and specify a parameter that occurs later in the list. Operands that are omitted or empty assume a null value.

Example

Following is an example of a C structure definition and the corresponding assembly language statements:

C source:

```
struct doc
{
     char  title;
     char  group;
     int   job_number;
}  doc_info;
```

Resulting assembly language code:

```
FP      .set    A15
DP      .set    B14
SP      .set    B15

;       ac6x member member.if
        .file   ”member.c”
        .stag   _doc,64
        .member _title,0,2,8,8
        .member _group,8,2,8,8
        .member _job_number,32,4,8,32
        .eos
        .global _doc_info
        .bss    _doc_info,8,4
        .sym    _doc_info,_doc_info,8,2,64,_doc
```

Syntax

.**stag** *name* [**,** *size*]
    member definitions
.eos
.etag *name* [**,** *size*]
    member definitions
.eos
.utag *name* [**,** *size*]
    member definitions
.eos

Description

The **.stag** directive begins a structure definition. The **.etag** directive begins an enumeration definition. The **.utag** directive begins a union definition. The **.eos** directive ends a structure, enumeration, or union definition.

- The *name* is the name of the structure, enumeration, or union. The first 128 characters of the name are significant. This is a required parameter.
- The *size* is the number of bits the structure, enumeration, or union occupies in memory. This is an optional parameter; if omitted, the size is unspecified.

The .stag, .etag, or .utag directive is followed by a number of .member directives, which define members in the structure. The .member directive is the only directive that can appear inside a structure, enumeration, or union definition.

The assembler does not allow nested structures, enumerations, or unions. The C/C++ compiler unwinds nested structures by defining them separately and then referencing them from the structure they are referenced in.

Example 1 Following is an example of a structure definition.

C source:

```
struct doc
{
    char title;
    char group;
    int  job_number;
} doc_info;
```

Resulting assembly language code:

```
FP      .set    A15
DP      .set    B14
SP      .set    B15

;       ac6x stag1 stag1.if
        .file   ”stag1.c”
        .stag   _doc,64
        .member _title,0,2,8,8
        .member _group,8,2,8,8
        .member _job_number,32,4,8,32
        .eos
        .global _doc_info
        .bss    _doc_info,8,4
        .sym    _doc_info,_doc_info,8,2,64,_doc
```

Example 2 Following is an example of a union definition.

C source:

```
union u_tag {
    int   val1;
    float val2;
    char  valc;
} valu;
```

Resulting assembly language code:

```
FP      .set    A15
DP      .set    B14
SP      .set    B15

;       ac6x stag2 stag2.if
        .file   ”stag2.c”
        .utag   _u_tag,32
        .member _val1,0,4,11,32
        .member _val2,0,6,11,32
        .member _valc,0,2,11,8
        .eos
        .global _valu
        .bss    _valu,4,4
        .sym    _valu,_valu,9,2,32,_u_tag
```

Example 3 Following is an example of an enumeration definition.

C source:

```
{
    enum o_ty { reg_1, reg_2, result } optypes;
}
```

Resulting assembly language code:

```
FP      .set    A15
DP      .set    B14
SP      .set    B15

;       ac6x stag3 stag3.if
        .file   ”stag3.c”
        .sect   ”.text”
        .global _main
        .sym    _main,_main,36,2,0
        .func   1

;*************************************************************
;* FUNCTION NAME: _main                                      *
;*                                                           *
;*   Regs Modified     : SP                                  *
;*   Regs Used         : B3,SP                               *
;*   Local Frame Size  : 0 Args + 4 Auto + 0 Save = 4 byte   *
;*************************************************************
_main:
         SUB.L2    SP,4,SP
        .etag   _o_ty,32
        .member _reg_1,0,4,16,32
        .member _reg_2,1,4,16,32
        .member _result,2,4,16,32
        .eos
        .sym    _optypes,4,10,1,32,_o_ty
        .line   4
         B.S2X     B3
         NOP       4
         ADD.L2    4,SP,SP
*        branch occurs
        .endfunc        4,000000000h,4
```

Syntax

.sym *name*, *value* [, *type*, *storage class*, *size*, *tag*, *dims*]

Description

The **.sym** directive specifies symbolic debug information about a global variable, local variable, or a function.

- The *name* is the name of the variable that is put in the object symbol table. The first 128 characters of the name are significant.
- The *value* is the value associated with the variable. Any legal expression (absolute or relocatable) is acceptable.
- The *type* is the C/C++ type of the variable. Appendix A, *Common Object File Format*, contains more information about C/C++ types.
- The *storage class* is the C/C++ storage class of the variable. Appendix A, *Common Object File Format*, contains more information about C/C++ storage classes.
- The *size* is the number of words of memory required to contain this variable.
- The *tag* is the name of the type (if any) or structure of which this variable is a type. This name *must* have been previously declared by a .stag, .etag, or .utag directive.
- The *dims* is one to four expressions separated by commas; these expressions describe the dimensions of the member.

The order of parameters is significant. The *name* and *value* are required parameters. All other parameters may be omitted or empty (adjacent commas indicate an empty entry). This allows you to skip a parameter and specify a parameter that occurs later in the list. Operands that are omitted or empty assume a null value.

Example

These lines of C source produce the .sym directives shown below:

C source:

```
struct s { int member1, member2; } str;
int   ext;
int   array[5][10];
long  *ptr;
int   strcmp();

main(arg1,arg2)
   int   arg1;
   char  *arg2;
{
   register r1;
}
```

Resulting assembly language code:

```
FP      .set    A15
DP      .set    B14
SP      .set    B15

;       opt6x –O2 sym.if sym.opt
        .file   ”sym.c”
        .stag   _s,64
        .member _member1,0,4,8,32
        .member _member2,32,4,8,32
        .eos
        .sect   ”.text”
        .global _main
        .sym    _main,_main,36,2,0
        .func   7

;*****************************************************************
;* FUNCTION NAME: _main                                          *
;*                                                               *
;*   Regs Modified     :                                         *
;*   Regs Used         : B3                                      *
;*   Local Frame Size  : 0 Args + 0 Auto + 0 Save = 0 byte       *
;*****************************************************************
_main:
        .sym    _arg1,4,4,17,32
        .sym    _arg2,20,18,17,32
        .line   6
           B       .S2     B3
           NOP             5
           ; BRANCH OCCURS
        .endfunc        12,000000000h,0


        .global _array
        .bss    _array,200,4
        .sym    _array,_array,244,2,1600,,5,10
        .global _ptr
        .bss    _ptr,4,4
        .sym    _ptr,_ptr,21,2,32
        .global _str
        .bss    _str,8,4
        .sym    _str,_str,8,2,64,_s
        .global _ext
        .bss    _ext,4,4
        .sym    _ext,_ext,4,2,32
```

Appendix C

Assembler Error Messages

When the assembler completes its second pass, it reports any errors that it encountered during the assembly. It also prints these errors in the listing file (if one is created); an error is printed following the source line that incurred it. You should attempt to correct the first error that occurs in your code first; a single error condition can cause a cascade of spurious errors.

If you have received an assembler error message, use this appendix to find possible solutions to the problem that you encountered. First, locate the error message class number. (The class numbers are listed in numerical order.) Then, locate the error message that you encountered within that class. (Each class number has an alphabetical list of error messages that are associated with it.) Each class has a *Description* of the problem and an *Action* that suggests possible remedies.

E0000

Comma required to separate arguments
Comma required to separate parameters
Left parenthesis expected
Left parenthesis is missing
Matching right parenthesis is missing
Missing matching right bracket for condition
Missing right quote of string constant
No matching right parenthesis
Right parenthesis expected
Syntax error
Unrecognized character type
Unrecognized special character

Description These are errors about general syntax. The required syntax is not present.

Action Correct the source per the error message text.

E0002

Illegal mnemonic specified
Invalid mnemonic specification

Description These are errors about invalid mnemonics. The specified instruction, macro, or directive was not recognized.

Action Check the directive or instruction used, then correct the source.

E0003

Cluttered string constant operand encountered
Constant out of range
Illegal conditional operand
Illegal memaddr specification
Illegal register for conditional
Illegal register pair specification
Invalid binary constant specified
Invalid constant specification
Invalid decimal constant specified
Invalid float constant specified
Invalid hex constant specified
Invalid octal constant specified
Memory operand missing offset amount

Description These are errors about invalid operands. The instruction, parameter, or other operand specified was not recognized.

Action Correct the source per the error message text.

E0004

Absolute, well-defined integer value expected
Cannot use A side register for dest
Conditional not allowed
Identifier expected
Identifier operand expected
IFR illegal as destination register
IN illegal as destination register
Illegal character argument specified
Illegal offset mode for 15 bit const
Illegal operand
Illegal register for branch
Illegal string constant operand specified
Illegal structure reference
Instruction cannot use control register
Invalid data size for relocation
Invalid float constant specified
Invalid identifier, *%s*, specified
Invalid macro parameter specified
Invalid operand, *%c*
Must have one control register
No parameters available for macro arguments
Operand must be register indirect
PC illegal as destination register
Register expected
Single character operand expected
String constant or substitution symbol expected
String operand expected

Structure/Union tag symbol expected
Substitution symbol operand expected

Description These are errors about illegal operands. The instruction, parameter or other operand specified was not legal for this syntax.

Action Correct the source per the error message text.

E0005

Missing field value operand
Missing operand
Missing operand(s)
Operand missing

Description These are errors about missing operands; a required operand is not supplied.

Action Correct the source so that all required operands are declared.

E0006

.break must occur within a loop
Conditional assembly mismatch
Matching .endloop missing
No matching .endif specified
No matching .endloop specified
No matching .if specified
No matching .loop specified
Open block(s) inside macro
Unmatched .endloop directive
Unmatched .if directive

Description These are errors about unmatched conditional assembly directives. A directive was encountered that requires a matching directive, but the assembler could not find the matching directive.

Action Correct the source per the error message text.

E0007

Conditional nesting is too deep
Loop count out of range

Description These are errors about conditional assembly loops. Conditional block nesting cannot exceed 32 levels.

Action Correct the .macro/.endmacro, .if/.elseif/.else/.endif, or .loop/.break/.endloop source.

E0008

Bad use of .access directive
Matching .struct directive is not present
Matching .union directive is not present

Description This is an error about unmatched structure definition directives. In a .struct/.endstruct sequence, a directive was encountered that requires a matching directive, but the assembler could not find the matching directive.

Action Check the source for mismatched structure definition directives and correct.

E0009

B14 or B15 required as long displacement base register
Base address register expected
Base register and index register must be from same file
Base register expected
Can't use relocatable expression in scaled addressing mode
Cannot apply bitwise NOT to floats
Cannot use register offset in unscaled addressing mode
Constant out of range
Illegal struct/union reference dot operator
Matching right bracket is missing
Missing structure/union member or tag
Structure or union tag symbol expected
Structure or union tag symbol not found
Unary operator must be applied to a constant

Description These are errors about an illegally used operator. The operator specified was not legal for the given operands.

Action Correct the source per the error message text so that all required operands are declared.

E0100

.setsym requires a label
Label missing
Label required

Description These are errors about required labels. The given directive requires a label, but none is specified.

Action Correct the source by specifying the required label.

E0101

Standalone labels not permitted in structure/union defs

Description This is an error about an invalid labels. Structure and union definitions do not permit a label, but one is specified.

Action Remove the invalid label.

E0102

Local label *%d* defined differently in each pass
Local label *%d* is multiply defined
Local label *%d* is not defined in this section
Local labels can't be used with directives

Description These are errors about the illegal use of local labels.

Action Correct the source per the error message text. Use .newblock to reuse local labels.

E0200

Bad term in expression
Binary operator can't be applied
Difference between segment symbols not permitted
Divide by zero
Operation can't be performed on given operands
Unary operator cannot be applied
Well-defined expression required

Description These are errors about general expressions. An illegal operand combination was used, or an arithmetic type is required but not present.

Action Correct the source per the error message text.

E0201

Absolute operands required for FP operations!
Floating-point divide by zero
Floating-point expression required
Floating-point overflow
Floating-point underflow
Illegal floating-point expression
Invalid floating-point operation

Description These are errors about floating-point expressions. A floating-point expression was used where an integer expression is required, an integer expression was used where a floating-point expression is required, or a floating-point value is invalid.

Action Correct the source per the error message text.

E0300

***%s* is not defined in this source file**
***%s* is operand to both .ref and .def**
Can't tag an undefined symbol
Can't use relocation expression here
Cannot equate an external symbol to an external symbol
Cannot redefine this section name
Empty structure or union definition
Illegal structure or union tag

Missing closing '}' for repeat block
Redefinition of *%s* attempted
Structure tag can't be global
Structure/union member, *%s*, not found
Symbol *%s* has already been defined
Symbol can't be defined in terms of itself
Symbol expected in label field
Symbol expected
Symbol, *%s*, has already been defined
The following symbols are undefined:
Union member previously defined
Union tag can't be global

Description These are errors about general symbols. An attempt was made to redefine a symbol or to define a symbol illegally.

Action Correct the source per the error message text.

E0301

Cannot redefine local substitution symbol
Substitution stack overflow
Substitution symbol not found

Description These are errors about general substitution symbols. An attempt was made to redefine a symbol or to define a symbol illegally.

Action Correct the source per the error message text. Make sure that the operand of a substitution symbol is defined either as a macro parameter or with a .asg or .eval directive.

E0400

Symbol table entry is not balanced

Description A symbolic debugging directive does not have a complementing directive (for example, a .block without a .endblock).

Action Check the source for mismatched conditional assembly directives and correct.

E0500

Macro argument string is too long
Missing macro name
Too many variables declared in macro

Description These are errors about general macros.

Action Correct the source per the error message text.

E0501

.mexit directive outside macro definition
Macro definition not terminated with .endm
Matching .endm missing
Matching .macro missing
No active macro definition

Description These are errors about macro definition directives. A macro directive does not have a complementing directive (that is, a .macro is used without a .endm).

Action Correct the source per the error message text.

E0600

***%s* is not in archive format**
***%s* macro library not found**
Bad archive entry for *%s*
Bad archive name
Can't read a line from archive entry
Macro library is not in archive format

Description These are errors about accessing a macro library. A problem was encountered reading from or writing to a macro library archive file. It is likely that the creation of the archive file was not done properly.

Action Make sure that the macro libraries are unassembled assembler source files. Also make sure that the macro name and member name are the same and that the extension of the file is .asm.

E0700

.sym not allowed inside structure/union
Cannot use –g on assembly code with .line directives
Illegal structure/union member
No structure/union currently open

Description These are errors about the illegal use of symbolic debugging directives; a symbolic debugging directive is not used in an appropriate place.

Action Correct the source per the error message text.

E0800

A/B register file mismatch
Cannot perform operation on specified unit
Could not find a valid unit for instruction
Erroneous use of X unit
Illegal destination
Illegal form for LDDW
Illegal functional unit
Illegal memory operand register for unit

Illegal operand combination
Illegal suffix specified for branch
Illegal use of parallel operator
Instruction cannot use X unit
Instructions not permitted in structure/union definitions
Offset too large
Unit specifier disagrees with operation

Description These are errors about illegal operands. The instruction, parameter or other operand specified was not legal for this syntax.

Action Correct the source per the error message text.

E0801

Processor resource allocation conflict

Description Not all instructions from the packet could be allocated to a distinct functional unit.

Action Check the source and ensure that all instructions in the packet are of a legal form and that the instructions can be legally placed in parallel.

E0801

Too many branches to labels in this packet
Too many multi-cycle NOPs in this packet
Too many reads from one register in this packet

Description These errors are caused by having too many instructions in parallel, using too many resources, or by putting in parallel instructions which can be assembled in parallel.

Action Check the source for parallel instruction problems and correct per the error message text.

E0900

.var allowed only within macro definitions
Can't include a file inside a loop or macro
Cannot change version after 1st instruction
Illegal structure definition contents
Illegal structure member
Illegal union definition contents
Illegal union member
Invalid load-time label
Invalid structure/union contents

Description These are errors about illegally used directives. Specific directives were encountered where they are not permitted. (The directives are not permitted in that position because they will cause a corruption of the object file.) Many directives are not permitted inside structure or union definitions.

Action Correct the source per the error message text.

E1000

Include/Copy file not found or opened

Description The specified filename cannot be found.

Action Check spelling, pathname, environment variables, etc. and correct the source.

E1300

Copy limit has been reached
Exceeded limit for macro arguments
Macro nesting limit exceeded

Description These errors are about general assembler limits that have been exceeded. The nesting of .copy/.include files in limited to 10 levels. Macro arguments are limited to 32 parameters. Macro nesting is limited to 32 levels.

Action Check the source to determine how limits have been exceeded and correct as indicated.

E9999

***%s* defined differently in each pass**

Description A symbol in the symbol table did not have the same value in pass1 and pass2. You likely have an error in a directive, macro, or label.

Action Check the source to determine what caused the problem and correct the source.

E9999

Can't push *%s* on expr stack
Pass conflict

Description These are internal assembler errors. If they occur repeatedly, the assembler may be corrupt or confused.

Action Assemble a smaller file. If a smaller file does not assemble, reinstall the assembler.

W0000

Delay slot count must be 1 to 9, 1 assumed
Half-word offsets must be divisible by 2, truncated
Invalid page number specified – ignored
No operands expected. Operands ignored
Specified alignment is outside accessible memory – ignored
Too many operands
Trailing Operands Ignored
Word offsets must be divisible by 4, truncated

Description These are warnings about operands. The assembler encountered operands that it did not expect.

Action Check the source to determine what caused the problem and whether you need to correct the source.

W0001

Field value truncated to *%ld*
Field width truncated to *%d*
Maximum alignment is to 32K boundary—alignment ignored
Power of 2 required, *%ld* assumed
Section Name is limited to 8 characters
Section name, *%s*, truncated to 8 characters
String is too long—will be truncated
Value truncated to *%d*-bit width
Value truncated to byte size
Value truncated

Description These are warnings about truncated values. The expression given was too large to fit within the instruction opcode or the required number of bits.

Action Check the source to make sure the result is acceptable or change the source if an error has occurred.

W0002

Address expression will wrap-around
Expression will overflow, value truncated

Description These are warnings about arithmetic expressions. The assembler has done a calculation that produces the indicated result, which may or may not be acceptable.

Action Verify that the result is acceptable or change the source if an error has occurred.

W0003

.sym for *function name* required before .func

Description This is a warning about problems with symbolic debugging directives. A .sym directive defining the function does not appear before the .func directive.

Action Correct the source per the error message text..

W0004

.access only allowed in top-most structure definition
Access point has already been defined
Illegal unit specifier, ignored
Open block(s) at EOF

Description These are warnings about problems with structure definitions.

Action Correct the source per the error message text.

W9999

Open branch delay slot at end of section *%s*

Description This is a warning about problems with branch definitions.

Action Correct the source to remove the open branch delay slot.

Appendix D

Linker Error Messages

This appendix lists the linker error messages in alphabetical order according to the error message. In these listings, the symbol (...) represents the name of an object that the linker is attempting to interact with when an error occurs.

A

absolute symbol (...) being redefined

Description An absolute symbol cannot be redefined.

Action Check the syntax of all expressions and check the input directives for accuracy.

adding name (...) to multiple output sections

Description An input section is mentioned more than once in the SECTIONS directive.

Action Modify the SECTIONS directive in your linker command file.

ALIGN illegal in this context

Description Alignment of a symbol is performed outside of a SECTIONS directive.

Action Modify your linker command file and move the align specification inside the SECTIONS directive.

alignment for (...) must be a power of 2

Description Section alignment was not specified as a power of 2.

Action Make sure that in hexadecimal values all powers of 2 consist of the integers 1, 2, 4, or 8 followed by a series of 0 or more 0s.

alignment for (...) redefined

Description More than one alignment is supplied for a section.

Action Modify your linker command file by specifying only one alignment for each section.

attempt to decrement DOT

Description A statement such as .–= value is supplied; this is illegal. Assignments to the . symbol can be used only to create holes.

Action Modify your linker command file.

B

bad fill value

Description The fill value must be a 16-bit constant.

Action Modify the fill specifications in your linker command file.

binding address (...) for section (...) is outside all memory on page (...)

Description Each section must fall within memory configured with the MEMORY directive.

Action If you are using a linker command file, check that the MEMORY and SECTIONS directives allow enough room to ensure that no sections are placed in unconfigured memory.

binding address (...) for section (...) overlays (...) at (...)

Description Two sections overlap and cannot be allocated.

Action If you are using a linker command file, check that the MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

binding address for (...) redefined

Description More than one binding value is supplied for a section.

Action Modify your linker command file and remove all binding values except one.

binding address (...) incompatible with alignment for section (...)

Description The section has an alignment requirement from an .align directive or previous link. The binding address violates this requirement.

Action Modify your linker command file.

blocking for (...) must be a power of 2

Description Section blocking is not a power of 2.

Action Make sure that in hexadecimal values all powers of 2 consist of the integers 1, 2, 4, or 8 followed by a series of 0 or more 0s.

blocking for (...) redefined

Description More than one blocking value is supplied for a section.

Action Modify your linker command file and remove all blocking values except one.

C

–c requires fill value of 0 in .cinit (... overridden)

Description The .cinit tables must be terminated with 0; therefore, the fill value of the .cinit section must be 0.

Action Modify your linker command file to ensure the fill value of the .cint section is 0.

cannot complete output file (...), write error

Description This usually means that the file system is out of space.

Action Check the disk volume; delete files or add more disk space.

cannot create output file (...)

Description This usually indicates an illegal filename.

Action Check spelling and pathname used with the –o option on the command line or in your linker command file. Also, check environment variables. The filename must conform to operating system conventions.

cannot resize (...), section has initialized definition in (...)

Description An *initialized* input section named .stack or .heap exists, preventing the linker from resizing the section.

Action Modify your linker command file to remove the initialized definition of the .stack or .sysmem section. These sections must be uninitialized.

cannot specify a page for a section within a GROUP

Description A section was specified to a specific page within a group. The entire group is treated as one unit, so the group can be specified to a page of memory, but the sections making up the group cannot be handled individually.

Action Modify your linker command file so that no section within a group is treated separately.

cannot specify both binding and memory area for (...)

Description Both binding and named memory were specified. The two are mutually exclusive.

Action If you want the code to be placed at a specific address, use binding only. If you want the code to be placed into a range defined in the MEMORY directive, use named memory only.

can't align a section within GROUP – (...) not aligned

Description A section in a group was specified for individual alignment. The entire group is treated as one unit, so the group can be aligned or bound to an address, but the sections making up the group cannot be handled individually.

Action Modify your linker command file so that no section in the group is treated separately.

can't align within UNION – section (...) not aligned

Description A section in a union was specified for individual alignment. The entire union is treated as one unit, so the union can be aligned or bound to an address, but the sections making up the union cannot be handled individually.

Action Modify your linker command file so that no section in the group is treated separately.

can't allocate (...), size ... (page ...)

Description A section cannot be allocated, because no existing configured memory area is large enough to hold it.

Action If you are using a linker command file, check that the MEMORY and SECTIONS directives allow enough room to ensure that no sections are being placed in unconfigured memory.

can't create map file (...)

Description This usually indicates an illegal filename.

Action Check spelling and pathname used with the –m option on the command line in your linker command file. Also, check environment variables. The filename must conform to operating system conventions.

can't find input file *filename*

Description The file, *filename*, is not in your PATH, is misspelled, etc.

Action Check spelling and pathname used with the input files on the command line in your linker command file. Also, check environment variables. The filename must conform to operating system conventions.

can't open (...)

Description The specified file does not exist.

Action Check spelling and pathname used with options on the command line in your linker command file. Also, check environment variables. The filename must conform to operating system conventions.

can't open *filename*

Description Specified filename cannot be opened for some reason; file does not exist, wrong file type, etc.

Action Check spelling and pathname used with options on the command line in your linker command file. Also, check environment variables.

can't read (...)

Description The file may be corrupt.

Action Try reassembling the input file.

can't seek (...)

Description The file may be corrupt.

Action Try reassembling the input file.

can't write (...)

Description The disk may be full or protected.

Action Check the disk volume and protection; ensure that the disk is not write protected or create space as needed.

command file nesting exceeded with file (...)

Description Command file nesting is allowed up to 16 levels.

Action Modify your linker command file to reduce the number of nesting levels.

E

–e flag does not specify a legal symbol name (...)

Description The –e option is not supplied with a valid symbol name as an operand.

Action Use a valid symbol name with the –e option.

entry point other than _c_int00 specified

Description For –c or –cr option only. A program entry point other than the value of _c_int00 was supplied. The runtime conventions of the compiler assume that _c_int00 is the only entry point.

Action No action is required. To avoid this warning, do not redefine the program entry point at the same time you use the –c or –cr option.

entry point symbol (...) undefined

Description The symbol used with the –e option is not defined.

Action Be sure that the symbol name that you use with the –e option is defined.

errors in input – (...) not built

Description Previous linker errors prevent the creation of an output file.

Action Correct the other errors that the linker lists, then relink the files.

F

fail to copy (...)

Description The file may be corrupt.

Action Try reassembling the input file.

fail to read (...)

Description The file may be corrupt.

Action Try reassembling the input file.

fail to seek (...)

Description The file may be corrupt.

Action Try reassembling the input file.

fail to skip (...)

Description The file may be corrupt.

Action Try reassembling the input file.

fail to write (...)

Description The disk may be full or protected.

Action Check disk volume and protection; ensure that the disk is not write protected or create space as needed.

file (...) has no relocation information

Description You have attempted to relink a file that was not linked with –r.

Action Use the –r linker option to link all files that you plan to relink; this retains the necessary relocation information.

file (...) is of unknown type, magic number = (...)

Description The binary input file is not a COFF file.

Action Be sure that all input files to the linker are in the C6000 COFF format.

fill value for (...) redefined

Description More than one fill value is supplied for an output section. Individual holes can be filled with different values with the section definition.

Action Modify your linker command file.

I

–i path too long (...)

Description The maximum number of characters in an –i path is 256.

Action Use a pathname that is 256 characters or less.

illegal input character

Description There is a control character or other unrecognized character in the command file.

Action Modify your linker command file.

illegal memory attributes for (...)

Description The attributes of the memory directive are not some combination of R, W, I, and X.

Action Modify the memory directive of your linker command file.

illegal operator in expression

Description The linker detected an illegal expression operator.

Action Review legal expression operators shown in Table 7–2 on page 7-55 and modify your code accordingly.

illegal option within SECTIONS

Description An invalid option was used within the SECTIONS directive.

Action Use only the –l (lowercase L) option within a SECTIONS directive.

illegal relocation type (...) found in section(s) of file (...)

Description The binary file is corrupt.

Action Inspect the object file(s) and rebuild the file(s) as necessary.

internal error (...)

Description This linker has an internal error.

Action Contact the microcontroller hotline.

invalid archive size for file (...)

Description The archive file is corrupt.

Action Inspect the archive file and rebuild it as necessary.

invalid path specified with –i flag

Description The operand of the –i option (flag) is not a valid pathname.

Action Be sure that the pathname you use with the –i option is valid.

invalid value for –f flag

Description The value for –f option (flag) is not a 4-byte (32-bit) constant.

Action Use a 4-byte constant with the –f option.

invalid value for –heap flag

Description The value for –heap option (flag) is not a 4-byte (32-bit) constant.

Action Use a 4-byte constant with the –heap option.

invalid value for –stack flag

Description The value for –stack option (flag) is not a 4-byte (32-bit) constant.

Action Use a 4-byte constant with the –stack option.

invalid value for –v flag

Description The value for –v option (flag) is not a constant.

Action Use a constant with the –v option.

I/O error on output file (...)

Description The disk may be full or protected.

Action Check the disk volume and protection; ensure that the disk is not write protected or create space as needed.

L

length redefined for memory area (...)

Description A memory area in a MEMORY directive has more than one length.

Action Modify your linker command file.

library (...) member (...) has no relocation information

Description The library member has no relocation information. It is possible for a library member to not have relocation information; this means that it cannot satisfy unresolved references in other files when linking.

Action This warning requires no action. The library member serves no purpose since it has no relocation information, and the linker ignores it.

line number entry found for absolute symbol

Description The input file may be corrupt.

Action Try reassembling the input file.

linking files for incompatible targets

Description The object files are a mixture of big-endian and little-endian files.

Action Do not mix big-endian and little-endian files; link only big-endian or little-endian files.

load address for uninitialized section (...) ignored

Description A load address is supplied for an uninitialized section. Uninitialized sections have no load addresses, only run addresses.

Action Modify your linker command file and remove the load address specification for the uninitialized section.

load address for UNION ignored

Description UNION refers only to the section's run address.

Action Modify your linker command file.

load allocation required for initialized UNION member (...)

Description A load address is supplied for an initialized section in a union. UNIONs refer to runtime allocation only.

Action Specify the load address for all sections within a union separately. Modify your linker command file accordingly.

M

–m flag does not specify a valid filename

Description You did not specify a valid filename for the file you are writing the output map file to.

Action Be sure that the filename you use with the –m option is a valid filename.

making aux entry *filename* for symbol *n* out of sequence

Description The input file may be corrupt.

Action Try reassembling the input file.

memory area for (...) redefined

Description More than one named memory allocation is supplied for an output section.

Action Modify your linker command file.

memory page for (...) redefined

Description More than one page allocation is supplied for a section.

Action Modify your linker command file.

memory attributes redefined for (...)

Description More than one set of memory attributes is supplied for an output section.

Action Modify your linker command file.

memory types (...) and (...) on page (...) overlap

Description Memory ranges on the same page overlap.

Action If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections are placed in unconfigured memory.

missing filename on –l; use –l <filename>

Description No filename operand is supplied for the –l (lowercase L) option.

Action You must specify a filename with the –l option to name a library that is not in the current directory.

misuse of DOT symbol in assignment instruction

Description The . symbol is used in an assignment statement that is outside the SECTIONS directive.

Action Modify your linker command file.

multiple sections with name (...)

Description This is a warning. There are multiple sections with the same name. Result of link phase is undefined.

Action Rename one section.

N

no allocation allowed for uninitialized UNION member

Description A load address was supplied for an uninitialized section in a union. An uninitialized section in a union gets its run address from the UNION statement and has no load address, so no load allocation is valid for the member.

Action Modify your linker command file.

no allocation allowed with a GROUP–allocation for section (...) ignored

Description A section in a group was specified for individual allocation. The entire group is treated as one unit, so the group can be aligned or bound to an address, but the sections making up the group cannot be handled individually.

Action Modify your linker command file and remove that allocation specification.

no input files

Description No COFF files were supplied. The linker cannot operate without at least one input COFF file.

Action Name at least one COFF file as input when you invoke the linker.

no load address specified for (...); using run address

Description No load address is supplied for an initialized section. If an initialized section has a run address only, the section is allocated to run and load at the same address.

Action No action is required. The linker automatically assumes that you want the the load address to be the same as the run address.

no run allocation allowed for union member (...)

Description A UNION defines the run address for all of its members; therefore, individual run allocations are illegal.

Action Modify your linker command file.

no string table in file *filename*

Description The input file may be corrupt.

Action Try reassembling the input file.

no symbol map produced – not enough memory

Description Available memory is insufficient to produce the symbol list. This is a nonfatal condition that prevents the generation of the symbol list in the map file.

Action Increase the available memory in your system.

O

–o flag does not specify a valid file name : (...)

Description The filename used with the –o option does not follow the operating system file naming conventions.

Action Be sure the filename that you specify with the –o option follows the operating system file naming conventions.

origin missing for memory area (...)

Description An origin is not specified with the MEMORY directive.

Action Modify your linker command file and include an origin value in the MEMORY directive to specify the starting address of a memory range.

out of memory, aborting

Description Your system does not have enough memory to perform all required tasks.

Action Try breaking the assembly language files into multiple smaller files and do partial linking. See section 7.15, *Partial (Incremental) Linking*, page 7-65.

output file has no .bss section

Description This is a warning. The .bss section is usually present in a COFF file. There is no real requirement for it to be present.

Action To avoid this warning, specify the .bss section in your linker command file.

output file has no .data section

Description This is a warning. The .data section is usually present in a COFF file. There is no real requirement for it to be present.

Action To avoid this warning, specify the .data section in your linker command file.

output file has no .text section

Description This is a warning. The .text section is usually present in a COFF file. There is no real requirement for it to be present.

Action To avoid this warning, specify the .text section in your linker command file.

output file (...) not executable

Description The output file created may have unresolved symbols or other problems stemming from other errors. This condition is not fatal.

Action No action is required. This warning tells you that your code will not be linked fully.

overwriting aux entry *filename* of symbol *n*

Description The input file may be corrupt.

Action Try reassembling the input file.

P

PC-relative displacement overflow. Located in the file.obj, section (...), SPC offset (...)

Description The relocation of a PC-relative operand resulted in a displacement too large to encode in the instruction. In the named object file, in the identified section, there is a PC-relative branch instruction which is trying to reach a call destination that is too far away. The SPC offset is the section program counter (SPC) offset within the section where the branch occurs. For C/C++ code, the section name is .text (unless a CODE_SECTION pragma is in effect).

Action Modify the memory map so that displacements are within range or use the large model in your C/C++ code (see the *TMS320C6000 Optimizing Compiler User's Guide* for information on large model code).

R

–r incompatible with –s (–s ignored)

Description Both the –r option and the –s option were used. Since the –s option strips the relocation information and –r requests a relocatable object file, these options are in conflict with each other.

Action To avoid this warning, do not use the –s option with the –r option. If you use these options together, the –s option is ignored.

relocation entries out of order in section (...) of file (...)

Description The input file may be corrupt.

Action Try reassembling the input file.

relocation symbol not found: index (...), section (...), file (...)

Description The input file may be corrupt.

Action Try reassembling the input file.

relocation value truncated at (...), section (...), file (...)

Description The computed value of a relocation expression does not fit in the number of bits reserved for it.

Action To find the source line with the problem, use the –l option on the named file to create a listing file with the extension .lst. Examine the file, find the named section, and then match the SPC field of the listing (the second field) with the address given in the error message. You have to rewrite the expression, or change the definition of the symbols in the expression, so the final computed result will fit in the space reserved. For more information about creating a listing file, see section 3.10, *Source Listings*, on page 3-30.

S

section (...) at (...) overlays at address (...)

Description Two sections overlap and cannot be allocated.

Action If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections overlap.

section (...) enters unconfigured memory at address (...)

Description A section cannot be allocated because no existing configured memory area is large enough to hold it.

Action If you are using a linker command file, check that MEMORY and SECTIONS directives allow enough room to ensure that no sections are placed in unconfigured memory.

section (...) not built

Description There is a syntax error in the SECTIONS directive.

Action Inspect and modify the SECTIONS directive defined in your linker command file.

section (...) not found

Description An input section specified in a SECTIONS directive was not found in the input file.

Action Modify your linker command file and ensure that the input section specified exists in one of the input files.

section (...) won't fit into configured memory

Description A section cannot be allocated, because no configured memory area exists that is large enough to hold it.

Action If you are using a linker command file, check that the MEMORY and SECTIONS directives allow enough room to ensure that no sections are placed in unconfigured memory.

seek to (...) failed

Description The input file may be corrupt.

Action Try reassembling the input file.

semicolon required after assignment

Description There is a syntax error in the command file.

Action Modify your linker command file.

statement ignored

Description There is a syntax error in an expression.

Action Modify your linker command file.

symbol referencing errors — (...) not built

Description Symbol references could not be resolved. Therefore, an object module could not be built.

Action Be sure that all references are satisfied by the input files in order to build an executable.

symbol (...) from file (...) being redefined

Description A defined symbol is redefined in an assignment statement.

Action No action is required. To avoid this warning, remove one of the symbol definitions in the linker command file.

T

too many arguments – use a command file

Description You used too many arguments on a command line or in response to prompts.

Action Create a linker command file to name all of the arguments that you want to pass to the linker.

too many –i options, 7 allowed

Description More than seven –i options were used.

Action Use the C_DIR or A_DIR environment variable to name additional search directories.

type flags for (...) redefined

Description More than one section type is supplied for a section. Note that type COPY has all of the attributes of type DSECT, so DSECT need not be specified separately.

Action Modify your linker command file.

type flags not allowed for GROUP or UNION

Description A type is specified for a section in a group or union. Special section types apply to individual sections only.

Action Modify your linker command file and supply only one section type for a section.

U

–u does not specify a legal symbol name

Description You did not specify a symbol name with the –u option.

Action Be sure to specify a valid symbol name with the –u option.

unexpected EOF(end of file)

Description There is a syntax error in the linker command file.

Action Modify your linker command file.

undefined symbol (...) first referenced in file (...)

Description Either a referenced symbol is not defined, or the –r option was not used. Unless the –r option is used, the linker requires that all referenced symbols be defined. This condition prevents the creation of an executable output file.

Action Link using the –r option or define the symbol.

undefined symbol in expression

Description An assignment statement contains an undefined symbol.

Action Modify your linker command file.

unrecognized option (...)

Description You tried to use an option that the linker did not recognize.

Action Check the list of valid options. See Table 7–1 on page 7-6.

Z

zero or missing length for memory area (...)

Description A memory range defined with the MEMORY directive did not have a nonzero length.

Action Modify your linker command file.

Appendix E

Glossary

A

absolute address: An address that is permanently assigned to a TMS320C6000 memory location.

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.

American Standard Code for Information Interchange (ASCII): A standard computer code for representing and exchanging alphanumeric information.

archive library: A collection of individual files that have been grouped into a single file.

archiver: A software program that allows you to collect several individual files into a single file called an archive library. The archiver also allows you to delete, extract, or replace members of the archive library, as well as to add new members.

assembler: A software program that creates a machine-language program from a source file that contains assembly language instructions, directives, and macro directives. 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.

assignment statement: A statement that assigns a value to a variable.

autoinitialization: The process of initializing global C variables (contained in the .cinit section) before beginning program execution.

auxiliary entry: The extra entry that a symbol may have in the symbol table and that contains additional information about the symbol (whether it is a filename, a section name, a function name, etc.).

B

binding: A process in which you specify a distinct address for an output section or a symbol.

big endian: An addressing protocol in which bytes are numbered from left to right within a word. More significant bytes in a word have lower numbered addresses. Endian ordering is hardware-specific and is determined at reset. See also *little endian*

block: A set of declarations and statements that are grouped together with braces.

.bss: One of the default COFF sections. You can use the .bss directive to reserve a specified amount of space in the memory map that can later be used for storing data. The .bss section is uninitialized.

byte: A sequence of eight adjacent bits operated upon as a unit.

C

C/C++ compiler: A program that translates C/C++ source statements into assembly language source statements.

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 is used to document or improve readability of a source file. Comments are not compiled, assembled, or linked; they have no effect on the object file.

common object file format (COFF): A binary object file format configured by a standard developed by AT&T. All COFF sections are independently relocatable in memory space; you can place any section into any allocated block of target memory.

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 numeric value that does not change and that can be used as an operand.

cross-reference listing: An output file created by the assembler and appended to the end of the listing file. The cross reference information lists the symbols that were defined, what line they were defined on, which lines referenced them, and the values as determined by the input assembly source file.

D

.data: One of the default COFF 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).

E

emulator: A hardware development system that emulates TMS320C6200 operation.

entry point: The starting execution point in target memory.

executable module: An object file that has been linked and can be executed in a TMS320C6000 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 is defined in a different program module.

F

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.

file header: A portion of a COFF object file that contains general information about the object file, such as the number of section headers, the type of system the object file can be downloaded to, the number of symbols in the symbol table, and the symbol table's starting address.

G

global symbol: A kind of symbol that is either 1) defined in the current module and accessed in another, or 2) 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).

H

hex conversion utility: A program that accepts COFF files and converts them 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 containing no actual code or data. This area is between the input sections that compose an output section.

I

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.

initialized section: A COFF section that contains executable code or initialized data. An initialized section can be built up with the .data, .text, or .sect directive.

input section: A section from an object file that will be linked into an executable module.

L

label: A symbol that begins in column 1 of a source statement and corresponds to the address of that statement.

line-number entry: An entry in a COFF output module that maps lines of assembly code back to the original C source file that created them.

linker: A software tool that combines object files to form an object module that can be allocated into TMS320C6000 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 SPC.

little endian: An addressing protocol in which bytes are numbered from right to left within a word. More significant bytes in a word have higher numbered addresses. Endian ordering is hardware-specific and is determined at reset. See also *big endian*

loader: A device that loads an executable module into TMS320C6000 system memory.

M

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 source statements that are substituted for the macro call and are subsequently assembled.

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.

magic number: A COFF file header entry that identifies an object file as a module that can be executed by the TMS320C6000.

map file: An output file, created by the linker, that shows the memory configuration, section composition, and section allocation, as well as symbols and the addresses at which they were defined.

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.

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.

N

named section: An initialized section that is defined with a .sect directive.

O

object file: A file that has been assembled or linked and contains machine-language object code.

object library: An archive library made up of individual object files.

operands: The arguments, or parameters, of an assembly language instruction, assembler directive, or macro directive.

optional header: A portion of a COFF object file that the linker uses to perform relocation at download time.

options: Command parameters that allow you to request additional or specific functions when you invoke a software tool.

output module: A linked, executable object file that can be downloaded and executed on a target system.

output section: A final, allocated section in a linked, executable module.

P

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.

Q

quiet run: An option that suppresses the normal banner and the progress information.

R

raw data: Executable code or initialized data in an output section.

relocation: A process in which the linker adjusts all the references to a symbol when the symbol's address changes.

run address: The address where a section runs.

S

section: A relocatable block of code or data that will ultimately occupy contiguous space in the TMS320C6000 memory map.

section header: A portion of a COFF object file that contains information about a section in the file. Each section has its own header; the header points to the section's starting address, contains the section's size, etc.

section program counter (SPC): An element that keeps track of the current location within a section; each section has its own SPC.

sign extend: To fill 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 code or assembly language code that will be compiled or assembled to form an object file.

static variable: An element 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; the previous value is resumed when the function or program is reentered.

storage class: Any entry in the symbol table that indicates how a symbol is accessed.

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 will ultimately occupy continuous space in the TMS320C6000 memory map. Subsections are smaller sections within larger sections. Subsections give you tighter control of the memory map.

symbol: A string of alphanumeric characters that represents an address or a value.

symbolic debugging: The ability of a software tool to retain symbolic information so that it can be used by a debugging tool, such as a simulator or an emulator.

symbol table: A portion of a COFF object file that contains information about the symbols that are defined and used by the file.

T

tag: An optional *type* name that can be assigned to a structure, union, or enumeration.

target memory: Physical memory in a TMS320C6000 system into which executable object code is loaded.

.text: One of the default COFF sections. The .text section is an initialized section that contains executable code. You can use the .text directive to assemble code into the .text section.

U

unconfigured memory: Memory that is not defined as part of the memory map and cannot be loaded with code or data.

uninitialized section: A COFF section that reserves space in the memory map but that has no actual contents. These sections are built up 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: An element that is treated as a positive number, regardless of its actual sign.

W

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 16-bit addressable location in target memory.

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