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Digital UNIX

Assembly Language Programmer's Guide

Order Number: AA-PS31D-TE

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Product Version: Digital UNIX Version 4.0 or higher

This manual describes the assembly language supported by the Digital UNIX Alpha compiler system, its syntax rules, and how to write some assembly programs.

Digital Equipment Corporation
Maynard, Massachusetts

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New and Changed Features

Many minor literary and technical changes have been made throughout this manual for the Version 4.0 release of Digital UNIX. The major technical changes to the manual are as follows:

- Chapter 2 – Added information on support for relocation operands. (See Section 2.6.4.)
- Chapter 3 – Added information about the `sextb` and `sextw` instructions (see Section 3.2) and the `amask` and `implver` instructions (see Section 3.8).
- Chapter 5 – Added descriptions of the following directives: `.lit4`, `.lit8`, `.arch`, and `tune`.

Organization

This manual is organized as follows:

Chapter 1	Describes the format for the general registers, the special registers, and the floating-point registers. It also describes how addressing works and the exceptions you might encounter with assembly programs.
Chapter 2	Describes the lexical conventions that the assembler follows.
Chapter 3	Describes the main processor's instruction set, including notation, load and store instructions, computational instructions, and jump and branch instructions.
Chapter 4	Describes the floating-point instruction set.
Chapter 5	Describes the assembler directives.
Chapter 6	Describes calling conventions for all supported high-level languages. It also discusses memory allocation and register use.
Chapter 7	Provides an overview of the components of the object file and describes the headers and sections of the object file.
Chapter 8	Describes the purpose of the symbol table and the format of entries in the table. This chapter also lists the symbol table routines that are supplied.
Chapter 9	Describes the object file structures that relate to program execution and dynamic linking, and also describes how the process image is created from these files.
Appendix A	Summarizes all assembler instructions.
Appendix B	Describes issues relating to processing 32-bit data.
Appendix C	Describes instructions that generate more than one machine instruction.

About This Manual

This book describes the assembly language supported by the Digital UNIX® compiler system, its syntax rules, and how to write some assembly programs. For information about assembling and linking a program written in assembly language, see the `as`(1) and `ld`(1) reference pages.

The assembler converts assembly language statements into machine code. In most assembly languages, each instruction corresponds to a single machine instruction; however, in the assembly language for the Digital UNIX compiler system, some instructions correspond to multiple machine instructions.

The assembler's primary purpose is to produce object modules from the assembly instructions generated by some high-level language compilers. As a result, the assembler lacks many functions that are normally present in assemblers designed to produce object modules from source programs coded in assembly language. It also includes some functions that are not found in such assemblers because of special requirements associated with the high-level language compilers.

Digital has changed the name of its UNIX operating system from DEC OSF/1 to Digital UNIX. The new name reflects Digital's commitment to UNIX and its conformance to UNIX standards.

Audience

This manual assumes that you are an experienced assembly language programmer.

It is recommended that you use the assembler only when you need to perform programming tasks such as the following:

- Maximize the efficiency of a routine – for example, a low-level I/O driver – in a way that might not be possible in C, Fortran-77, Pascal, or another high-level language.
- Access machine functions unavailable from high-level languages or satisfy special constraints such as restricted register usage.
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- If known, the type of processor that is running the Digital UNIX software.

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Conventions

file	Italic (slanted) type indicates variable values and instruction operands.
[|] **{ | }**	In syntax definitions, brackets indicate items that are optional and braces indicate items that are required. Vertical bars separating items inside brackets or braces indicate that you choose one item from among those listed.
. . .	In syntax definitions, a horizontal ellipsis indicates that the preceding item can be repeated one or more times.

Appendix D Describes the PALcode (privileged architecture library code) instructions required to support an Alpha system.

Related Documents

The following manuals provide additional information on many of the topics addressed in this manual:

Programmer's Guide

The Alpha Architecture Reference Manual, 2nd Edition (Butterworth-Hinemann Press, ISBN:1-55558-145-5)

Calling Standard for Alpha Systems

The printed version of the Digital UNIX documentation set is color coded to help specific audiences quickly find the books that meet their needs. (You can order the printed documentation from Digital.) This color coding is reinforced with the use of an icon on the spines of books. The following list describes this convention:

Audience	Icon	Color Code
General users	G	Blue
System and network administrators	S	Red
Programmers	P	Purple
Device driver writers	D	Orange
Reference page users	R	Green

Some books in the documentation set help meet the needs of several audiences. For example, the information in some system books is also used by programmers. Keep this in mind when searching for information on specific topics.

The *Documentation Overview, Glossary, and Master Index* provides information on all of the books in the Digital UNIX documentation set.

Reader's Comments

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You can send your comments in the following ways:

- Fax: 603-881-0120 Attn: UEG Publications, ZK03-3/Y32

`cat`(1)	A cross-reference to a reference page includes the appropriate section number in parentheses. For example, `cat`(1) indicates that you can find information on the `cat` command in Section 1 of the reference pages.

and the assembler use the integer registers $28, $29, and $30 for specific purposes.

Note

If you need to use the registers reserved for the operating system and the assembler, you must specify their alias names in your program, not their regular names. The alias names for $28, $29, and $30 are $at, $gp, and $sp, respectively. To prevent you from using these registers unknowingly and thereby producing potentially unexpected results, the assembler issues warning messages if you specify their regular names in your program.

The $gp register (integer register $29) is available as a general register on some non-Alpha compiler systems when the -G 0 compilation option is specified. It is not available as a general register on Alpha systems under any circumstances.

Integer register $31 always contains the value 0. All other integer registers can be used interchangeably, except for integer register $30, which is assumed to be the stack pointer by certain PALcode. See Table 6-1 for a description of integer register assignments. See Appendix D and the *Alpha Architecture Handbook* for information on PALcode (Privileged Architecture Library code).

1.1.2 Floating-Point Registers

Alpha systems have 32 floating-point registers, each of which is 64 bits wide. Each register can hold one single-precision (32-bit) value or one double-precision (64-bit) value.

The floating-point registers have the names $f0 to $f31.

Floating-point register $f31 always contains the value 0.0. All other floating-point registers can be used interchangeably. See Table 6-2 for a description of floating-point register assignments.

1.2 Bit and Byte Ordering

A system's byte-ordering scheme, or endian scheme, affects memory organization and defines the relationship between address and byte position of data in memory:

- Big-endian systems store the sign bit in the lowest address byte.
- Little-endian systems store the sign bit in the highest address byte.

Architecture-Based Considerations 1

This chapter describes programming considerations that are determined by the Alpha system architecture. It addresses the following topics:

- Registers (Section 1.1)
- Bit and byte ordering (Section 1.2)
- Addressing (Section 1.3)
- Exceptions (Section 1.4)

1.1 Registers

This section discusses the registers that are available on Alpha systems and describes how memory organization affects them. Refer to Section 6.3 for information on register use and linkage.

Alpha systems have the following types of registers:

- Integer registers
- Floating-point registers

You must use integer registers where the assembly instructions expect integer registers and floating-point registers where the assembly instructions expect floating-point registers. If you confuse the two, the assembler issues an error message.

The assembler reserves all register names (see Section 6.3.1). All register names start with a dollar sign ($) and all alphabetic characters in register names are lowercase.

1.1.1 Integer Registers

Alpha systems have 32 integer registers, each of which is 64 bits wide. Integer registers are sometimes referred to as *general* registers in other system architectures.

The integer registers have the names $0 to $31.

By including the file regdef.h (use #include <alpha/regdef.h>) in your assembly language program, you can use the software names of all of the integer registers, except for $28, $29, and $30. The operating system

1.3 Addressing

This section describes the byte-addressing schemes for load and store instructions. (Section 2.8 describes the formats in which you can specify addresses.)

1.3.1 Aligned Data Operations

All Alpha systems use the following byte-addressing scheme for aligned data:

- Access to words requires alignment on byte boundaries that are evenly divisible by two.
- Access to longwords requires alignment on byte boundaries that are evenly divisible by four.
- Access to quadwords requires alignment on byte boundaries that are evenly divisible by eight.

Any attempt to address a data item that does not have the proper alignment causes an alignment exception.

The following instructions load or store aligned data:

- Load quadword (`ldq`)
- Store quadword (`stq`)
- Load longword (`ldl`)
- Store longword (`stl`)
- Load word (`ldw`)
- Store word (`stw`)
- Load word unsigned (`ldwu`)

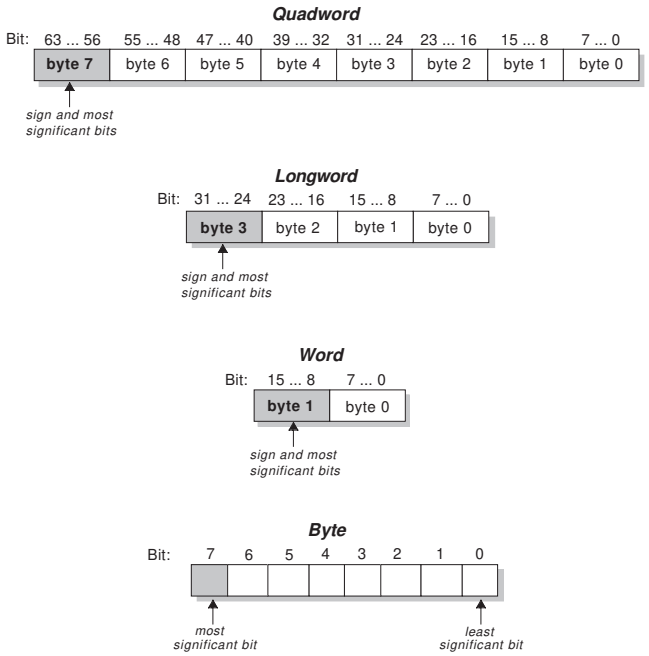
1.3.2 Unaligned Data Operations

The assembler's unaligned load and store instructions operate on arbitrary byte boundaries. They all generate multiple machine-code instructions. They do not raise alignment exceptions.

The following instructions load and store unaligned data:

- Unaligned load quadword (`uldq`)
- Unaligned store quadword (`ustq`)
- Unaligned load longword (`uldl`)
- Unaligned store longword (`ustl`)

Figure 1-1: Byte Ordering



ZK–0732U–R

Alpha systems use the little-endian scheme. Byte-ordering is as follows:

- The bytes of a quadword are numbered from 7 to 0. Byte 7 holds the sign and most significant bits.
- The bytes of a longword are numbered from 3 to 0. Byte 3 holds the sign and most significant bits.
- The bytes of a word are numbered from 1 to 0. Byte 1 holds the sign and most significant bits.

The bits of each byte are numbered from 7 to 0, using the format shown in Figure 1-1. (Bit numbering is a software convention; no assembler instructions depend on it.)

  - Comparison of predicates that have unordered operands and involve Less Than or Less Than or Equal.
  - Any operation on a signaling NaN. (See the introduction of Chapter 4 for a description of NaN symbols.)
- Divide-by-zero exceptions occur when a divisor is zero.
- Overflow exceptions occur when a rounded floating-point result exceeds the destination format's largest finite number.
- Underflow exceptions occur when a result has lost accuracy and also when a nonzero result is between $+-2^{min}$ (plus or minus 2 to the minimum expressible exponent).
- Inexact exceptions occur if the infinitely precise result differs from the rounded result.

For additional information on floating-point exceptions, see Section 4.1.3.

- Unaligned load word (`uldw`)
- Unaligned store word (`ustw`)
- Unaligned load word unsigned (`uldwu`)
- Load byte (`ldb`)
- Store byte (`stb`)
- Load byte unsigned (`ldbu`)

1.4 Exceptions

The Alpha system detects some exceptions directly, and other exceptions are signaled as a result of specific tests that are inserted by the assembler.

The following sections describe exceptions that you may encounter during the execution of assembly programs. Only those exceptions that occur most frequently are described.

1.4.1 Main Processor Exceptions

The following exceptions are the most common to the main processor:

- Address error exceptions occur when an address is invalid for the executing process or, in most instances, when a reference is made to a data item that is not properly aligned.
- Overflow exceptions occur when arithmetic operations compute signed values and the destination lacks the precision to store the result.
- Bus exceptions occur when an address is invalid for the executing process.
- Divide-by-zero exceptions occur when a divisor is zero.

1.4.2 Floating-Point Processor Exceptions

The following exceptions are the most common floating-point exceptions:

- Invalid operation exceptions include the following:
  - Magnitude subtraction of infinities, for example, (+∞) - (+∞).
  - Multiplication of 0 by ∞, with any signs.
  - Division of 0 by 0 or ∞ by ∞, with any signs.
  - Conversion of a binary floating-point number to an integer format, that is, only in those cases in which the conversion produces an overflow or an operand value of infinity or NaN. (The `cvttq` instruction converts floating-point numbers to integer formats.)

- . (period)
- _ (underscore)
- $ (dollar sign)

Identifiers can be up to 31 characters long, and the first character cannot be numeric (0-9).

If an undefined identifier is referenced, the assembler assumes that the identifier is an external symbol. The assembler treats the identifier like a name specified by a `.globl` directive (see Chapter 5).

If the identifier is defined to the assembler and the identifier has not been specified as global, the assembler assumes that the identifier is a local symbol.

2.4 Constants

The assembler supports the following constants:

- Scalar constants
- Floating-point constants
- String constants

2.4.1 Scalar Constants

The assembler interprets all scalar constants as twos complement numbers. Scalar constants can be any of the digits 0123456789abcdefABCDEF.

Scalar constants can be either decimal, hexadecimal, or octal constants:

- Decimal constants consist of a sequence of decimal digits (0-9) without a leading zero.
- Hexadecimal constants consist of the characters 0x (or 0X) followed by a sequence of hexadecimal digits (0-9abcdefABCDEF).
- Octal constants consist of a leading zero followed by a sequence of octal digits (0-7).

2.4.2 Floating-Point Constants

Floating-point constants can appear only in floating-point directives (see Chapter 5) and in the floating-point load immediate instructions (see Section 4.2). Floating-point constants have the following format:

Lexical Conventions 2

This chapter describes lexical conventions associated with the following items:

- Blank and tab characters (Section 2.1)
- Comments (Section 2.2)
- Identifiers (Section 2.3)
- Constants (Section 2.4)
- Physical lines (Section 2.5)
- Statements (Section 2.6)
- Expressions (Section 2.7)
- Address formats (Section 2.8)

2.1 Blank and Tab Characters

You can use blank and tab characters anywhere between operators, identifiers, and constants. Adjacent identifiers or constants that are not otherwise separated must be separated by a blank or tab.

These characters can also be used within character constants; however, they are not allowed within operators and identifiers.

2.2 Comments

The number sign character (#) introduces a comment. Comments that start with a number sign extend through the end of the line on which they appear. You can also use C language notation (`/*...*/`) to delimit comments.

Do not start a comment with a number sign in column one; the assembler uses `cpp` (the C language preprocessor) to preprocess assembler code and `cpp` interprets number signs in the first column as preprocessor directives.

2.3 Identifiers

An identifier consists of a case-sensitive sequence of alphanumeric characters (A-Z, a-z, 0-9) and the following special characters:

language. Table 2-1 shows the assembler's backslash conventions.

Table 2-1: Backslash Conventions

Convention	Meaning
\a	Alert (0x07)
\b	Backspace (0x08)
\f	Form feed (0x0c)
\n	Newline (0x0a)
\r	Carriage return (0x0d)
\t	Horizontal tab (0x09)
\v	Vertical feed (0x0b)
\\	Backslash (0x5c)
\"	Quotation mark (0x22)
\'	Single quote (0x27)
nnn	Character whose octal value is *nnn* (where *n* is 0-7)
\X*nn*	Character whose hexadecimal value is *nn* (where *n* is 0-9, a-f, or A-F)

Deviations from C conventions are as follows:

- The assembler does not recognize ''\?''.
- The assembler does not recognize the prefix ''L'' (wide character constant).
- The assembler limits hexadecimal constants to two characters.
- The assembler allows the leading ''x'' character in a hexadecimal constants to be either uppercase or lowercase; that is, both \x*nn* and \X*nn* are allowed.

For octal notation, the backslash conventions require three characters when the next character could be confused with the octal number.

For hexadecimal notation, the backslash conventions require two characters when the next character could be confused with the hexadecimal number. Insert a 0 (zero) as the first character of the single-character hexadecimal number when this condition occurs.


```
±d1[.d2][e|E±d3]
```

d1
is written as a decimal integer and denotes the integral part of the floating-point value.

d2
is written as a decimal integer and denotes the fractional part of the floating-point value.

d3
is written as a decimal integer and denotes a power of 10.

The ''+'' symbol (plus sign) is optional.

For example, the number .02173 can be represented as follows:

```
21.73E-3
```

The floating-point directives, such as `.float` and `.double`, may optionally use hexadecimal floating-point constants instead of decimal constants. A hexadecimal floating-point constant consists of the following elements:

```
[+|-]0x[1|0].<hex-digits>h0x<hex-digits>
```

The assembler places the first set of hexadecimal digits (excluding the 0 or 1 preceding the decimal point) in the mantissa field of the floating-point format without attempting to normalize it. It stores the second set of hexadecimal digits in the exponent field without biasing them. If the mantissa appears to be denormalized, it checks to determine whether the exponent is appropriate. Hexadecimal floating-point constants are useful for generating IEEE special symbols and for writing hardware diagnostics.

For example, either of the following directives generates the single-precision number 1.0:

```
.float 1.0e+0
.float 0x1.0h0x7f
```

The assembler uses normal (nearest) rounding mode to convert floating-point constants.

2.4.3 String Constants

All characters except the newline character are allowed in string constants. String constants begin and end with double quotation marks (").

The assembler observes most of the backslash conventions used by the C

2.6.2 Null Statements

A null statement is an empty statement that the assembler ignores. Null statements can have label definitions. For example, the following line has three null statements in it:

```
label: ; ;
```

2.6.3 Keyword Statements

A keyword statement contains a predefined keyword. The syntax for the rest of the statement depends on the keyword. Keywords are either assembler instructions (mnemonics) or directives.

Assembler instructions in the main instruction set and the floating-point instruction set are described in Chapter 3 and Chapter 4, respectively. Assembler directives are described in Chapter 5.

2.6.4 Relocation Operands

Relocation operands are generally useful in only two situations:

- In application programs in which the programmer needs precise control over scheduling
- In source code written for compiler development

Some macro instructions (for example, `ldgp`) require special coordination between the machine-code instructions and the relocation sequences given to the linker. By using the macro instructions, the assembler programmer relies on the assembler to generate the appropriate relocation sequences.

In some instances, the use of macro instructions may be undesirable. For example, a compiler that supports the generation of assembly language files may not want to defer instruction scheduling to the assembler. Such a compiler will want to schedule some or all of the machine-code instructions. To do this, the compiler must have a mechanism for emitting an object file's relocation sequences without using macro instructions. The mechanism for establishing these sequences is the relocation operand.

A relocation operand can be placed after the normal operand on an assembly language statement:

opcode operand relocation_operand

The syntax of the *relocation_operand* is as follows:

!*relocation_type***!** *sequence_number*

relocation_type
Any one of the following relocation types can be specified:

2.5 Multiple Lines Per Physical Line

You can include multiple statements on the same line by separating the statements with semicolons. Note, however, that the assembler does not recognize semicolons as separators when they follow comment symbols (`#` or `/*`).

2.6 Statements

The assembler supports the following types of statements:

- Null statements
- Keyword statements

Each keyword statement can include an optional label, an operation code (mnemonic or directive), and zero or more operands (with an optional comment following the last operand on the statement):

`[` ***label*:**`]` *opcode operand*`[`**;** *opcode operand*`]` **...** `]` `[`**#** *comment*`]`

Some keyword statements also support relocation operands (see Section 2.6.4).

2.6.1 Labels

Labels can consist of label definitions or numeric values.

- A label definition consists of an identifier followed by a colon. (See Section 2.3 for the rules governing identifiers.) Label definitions assign the current value and type of the location counter to the name. An error results when the name is already defined.

  Label definitions always end with a colon. You can put a label definition on a line by itself.
- A numeric label is a single numeric value (1-255). Unlike label definitions, the value of a numeric label can be applied to any number of statements in a program. To reference a numeric label, put an `f` (forward) or a `b` (backward) immediately after the referencing digit in an instruction, for example, `br 7f` (which is a forward branch to numeric label 7). The reference directs the assembler to look for the nearest numeric label that corresponds to the specified number in the lexically forward or backward direction.

- Example 2: Referencing an `ldgp` sequence that is scheduled inside a `lituse_base` relocation

```
# Assembly statements containing macro instructions:
beq   $2, L
stq   $31, sym
ldgp  $gp, 0($27)

# Assembly statements containing machine-code instructions that
# require relocation operandss:
ldq   $at, sym($gp)!literal!1
beq   $2, L             # crosses basic block boundary
ldah  $gp, 0($27)!gpdisp!2
stq   $31, sym($at)!lituse_base!1
lda   $gp, 0($gp)!gpdisp!2
```

  In this example, the programmer has elected to schedule the load of the address of `sym` before the conditional branch.

- Example 3: A routine call

```
# Assembly statements containing macro instructions:
jsr   sym1
ldgp  $gp, 0($ra)

.extern sym1

.text

# Assembly statements containing machine-code instructions that
# require relocation operandss:
ldq   $27, sym1($gp)!literal!1
jsr   $26, ($27), sym1!lituse_jsr!1
# as1 puts in an R_HINT for the jsr instruction
ldah  $gp, 0($ra)!gpdisp!2
lda   $gp, 0($gp)!gpdisp!2
```

  In this example, the code with relocation operands does not provide any significant gains over the other code. This example is only provided to show the different coding methods.

2.7 Expressions

An expression is a sequence of symbols that represents a value. Each expression and its result have data types. The assembler does arithmetic in twos complement integers with 64 bits of precision. Expressions follow precedence rules and consist of the following elements:

- Operators
- Identifiers
- Constants


```
literal
lituse_base
lituse_bytoff
lituse_jsr
gpdisp
gprelhigh
gprellow
```

The relocation types must be enclosed within a pair of exclamation points (!) and are not case sensitive. See Table 7-11 for descriptions of the different types of relocation operations.

sequence_number
: The sequence number is a numeric constant with a value range of 1 to 2147483647. The constant can be base 8, 10, or 16. Bases other than 10 require a prefix (see Section 2.4.1).

The following examples contain relocation operands in the source code:

- Example 1: Referencing multiple `lituse_base` relocations

```
# Equivalent C statement:
# sym1 += sym2  (Both external)

# Assembly statements containing macro instructions:
ldq   $1, sym1
ldq   $2, sym2
addq  $1, $2, $3
stq   $3, sym1

# Assembly statements containing machine-code instructions
# requiring relocation operandss:
ldq   $1, sym1($gp)!literal!1
ldq   $2, sym2($gp)!literal!2

ldq   $3, sym1($1)!lituse_base!1
ldq   $4, sym2($1)!lituse_base!2
addq  $3, $4, $3
stq   $3, sym1($1)!lituse_base!1
```

  The assembler stores the `sym1` and `sym2` address constants in the `.lita` section.

  In this example, the code with relocation operands provides better performance than the other code because it saves on register usage and on the length of machine-code instruction sequences.

Table 2-3: Operator Precedence

Precedence	Operators
Least binding, lowest precedence	Binary +, -
.	
.	Binary *, /, %, <<, >>, ^, &, |
.	
Most binding, highest precedence	Unary -, +, ~

Note

The assembler's precedence scheme differs from that of the C language.

2.7.3 Data Types

Each symbol you reference or define in an assembly program belongs to one of the type categories shown in Table 2-4.

Table 2-4: Data Types

Type	Description
undefined	Any symbol that is referenced but not defined becomes *global undefined*. (Declaring such a symbol in a `.globl` directive merely makes its status clearer.)
absolute	A constant defined in an assignment (=) expression.
text	Any symbol defined while the `.text` directive is in effect belongs to the text section. The text section contains the program's instructions, which are not modifiable during execution.
data	Any symbol defined while the `.data` directive is in effect belongs to the data section. The data section contains memory that the linker can initialize to nonzero values before your program begins to execute.
sdata	The type sdata is similar to the type data, except that defining a symbol while the `.sdata` (''small data'') directive is in effect causes the linker to place it within the small data section. This increases the chance that the linker will be able to optimize memory references to the item by using gp-relative addressing.

You can also use a single character string in place of an integer within an expression. For example, the following two pairs of statements are equivalent:

```
.byte "a" ; .word "a"+0x19
.byte 0x61 ; .word 0x7a
```

2.7.1 Expression Operators

The assembler supports the operators shown in Table 2-2.

Table 2-2: Expression Operators

Operator	Meaning
+	Addition
-	Subtraction
*	Multiplication
/	Division
%	Remainder
<<	Shift left
>>	Shift right (sign is not extended)
^	Bitwise EXCLUSIVE OR
&	Bitwise AND
|	Bitwise OR
-	Minus (unary)
+	Identity (unary)
~	Complement

2.7.2 Expression Operator Precedence Rules

For the order of operator evaluation within expressions, you can rely on the precedence rules or you can group expressions with parentheses. Unless parentheses enforce precedence, the assembler evaluates all operators of the same precedence strictly from left to right. Because parentheses also designate index registers, ambiguity can arise from parentheses in expressions. To resolve this ambiguity, put a unary + in front of parentheses in expressions.

The assembler has three precedence levels. The following table lists the precedence rules from lowest to highest:

- If the operator is a minus sign (-) and the first operand refers to a relocatable symbol in a `.text` section, `.data` section, or `.bss` section, the type propagation rules can vary:
  - The second operand can be absolute (if it was previously defined) and the result has the first operand's type.
  - The second operand can have the same type as the first operand and the result is absolute.
  - If the first operand is external undefined, the second operand must be absolute.
- The operators `*`, `/`, `%`, `<<`, `>>`, `~`, `^`, `&`, and `|` apply only to absolute symbols.

2.8 Address Formats

The assembler accepts addresses expressed in the formats described in Table 2-5.

Table 2-5: Address Formats

Format	Address Description
(*base-register*)	Specifies an indexed address, which assumes a zero offset. The base register's contents specify the address.
expression	Specifies an absolute address. The assembler generates the most locally efficient code for referencing the value at the specified address.
expression(*base-register*)	Specifies a based address. To get the address, the value of the expression is added to the contents of the base register. The assembler generates the most locally efficient code for referencing the value at the specified address.
relocatable-symbol	Specifies a relocatable address. The assembler generates the necessary instructions to address the item and generates relocation information for the linker.

Table 2-4: (continued)

Type	Description
rdata and rconst	Any symbol defined while the `.rdata` or `.rconst` directives are in effect belongs to this category. The only difference between the types rdata and rconst is that the former is allowed to have dynamic relocations and the latter is not. (The types rdata and rconst are also similar to the type data but, unlike data, cannot be modified during execution.)
bss and sbss	Any symbol defined in a `.comm` or `.lcomm` directive belongs to these sections, except that a `.data`, `.sdata`, `.rdata`, or `.rconst` directive can override a `.comm` directive. The `.bss` and `.sbss` sections consist of memory that the kernel loader initializes to zero before your program begins to execute. If a symbol's size is less than the number of bytes specified by the `-G` compilation option (which defaults to eight), it belongs to `.sbss` section (small bss section), and the linker places it within the small data section. This increases the chance that the linker will be able to optimize memory references to the item by using gp-relative addressing. Local symbols in the `.bss` or `.sbss` sections defined by `.lcomm` directives are allocated memory by the assembler, global symbols are allocated memory by the linker, and symbols defined by `.comm` directives are overlaid upon like-named symbols (in the fashion of Fortran COMMON blocks) by the linker.

Symbols in the undefined category are always global; that is, they are visible to the linker and can be shared with other modules of your program. Symbols in the absolute, text, data, sdata, rdata, rconst, bss, and sbss type categories are local unless declared in a `.globl` directive.

2.7.4 Type Propagation in Expressions

For any expression, the result's type depends on the types of the operands and the operator. The following type propagation rules are used in expressions:

- If an operand is undefined, the result is undefined.
- If both operands are absolute, the result is absolute.
- If the operator is a plus sign (+) and the first operand refers to an undefined external symbol or a relocatable symbol in a `.text` section, `.data` section, or `.bss` section, the result has the first operand's type and the other operand must be absolute.

Table 2-5: (continued)

Format	Address Description
relocatable-symbol±*expression*	Specifies a relocatable address. To get the address, the value of the expression, which has an absolute value, is added or subtracted from the relocatable symbol. The assembler generates the necessary instructions to address the item and generates relocation information for the linker. If the symbol name does not appear as a label anywhere in the assembly, the assembler assumes that the symbol is external.
relocatable-symbol(*index-register*)	Specifies an indexed relocatable address. To get the address, the index register is added to the relocatable symbol's address. The assembler generates the necessary instructions to address the item and generates relocation information for the linker. If the symbol name does not appear as a label anywhere in the assembly, the assembler assumes that the symbol is external.
relocatable-symbol±*expression*(*index-register*)	Specifies an indexed relocatable address. To get the address, the assembler adds or subtracts the relocatable symbol, the expression, and the contents of index register. The assembler generates the necessary instructions to address the item and generates relocation information for the link editor. If the symbol name does not appear as a label anywhere in the assembly, the assembler assumes that the symbol is external.

Operand Specifier	Description
no_operands	No operands are specified.
offset	An immediate value that is added to the contents of a base register to calculate an effective address.
palcode	A value that determines the operation performed by a PALcode instruction.
s_reg, s_reg1, s_reg2	Source registers whose contents are to be used in an operation.
val_expr	An expression whose value is used as an absolute value.
val_immed	An immediate value that is to be used in an operation.
jhint	An address operand that provides a hint of where a `jmp` or `jsr` instruction will transfer control.
rhint	An immediate operand that provides software with a hint about how a `ret` or `jsr_coroutine` instruction is used.

3.1 Load and Store Instructions

Load and store instructions load immediate values and move data between memory and general registers. This section describes the general-purpose load and store instructions supported by the assembler.

Table 3-1 lists the mnemonics and operands for instructions that perform load and store operations. The table is divided into groups of instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 3-1: Load and Store Formats

Instruction	Mnemonic	Operands

Main Instruction Set 3

The assembler's instruction set consists of a main instruction set and a floating-point instruction set. This chapter describes the main instruction set; Chapter 4 describes the floating-point instruction set. For details on the instruction set beyond the scope of this manual, refer to the *Alpha Architecture Reference Manual*.

The assembler's main instruction set contains the following classes of instructions:

- Load and store instructions (Section 3.1)
- Arithmetic instructions (Section 3.2)
- Logical and shift instructions (Section 3.3)
- Relational instructions (Section 3.4)
- Move instructions (Section 3.5)
- Control instructions (Section 3.6)
- Byte-manipulation instructions (Section 3.7)
- Special-purpose instructions (Section 3.8)

Tables in this chapter show the format of each instruction in the main instruction set. The tables list the instruction names and the forms of operands that can be used with each instruction. The specifiers used in the tables to identify operands have the following meanings:

Operand Specifier	Description
address	A symbolic expression whose effective value is used as an address.
b_reg	Base register. An integer register containing a base address to which is added an offset (or displacement) value to produce an effective address.
d_reg	Destination register. An integer register that receives a value as a result of an operation.
d_reg/s_reg	One integer register that is used as both a destination register and a source register.
label	A label that identifies a location in a program.

Instructions whose address operands contain symbolic labels imply an index register, which the assembler determines. Some assembler load instructions can produce multiple machine-code instructions (see Section C.4).

Note

Load instructions can generate many code sequences for which the linker must fix the address by resolving external data items.

Table 3-2 describes the operations performed by load instructions.

Table 3-2: Load Instruction Descriptions

Instruction	Description
Load Address (`lda`)	Loads the destination register with the effective address of the specified data item.
Load Byte (`ldb`)	Loads the least significant byte of the destination register with the contents of the byte specified by the effective address. Because the loaded byte is a signed value, its sign bit is replicated to fill the other bytes in the destination register. (The assembler uses temporary registers `AT` and `t9` for this instruction.)
Load Byte Unsigned (`ldbu`)	Loads the least significant byte of the destination register with the contents of the byte specified by the effective address. Because the loaded byte is an unsigned value, the other bytes of the destination register are cleared to zeros. (The assembler uses temporary registers `AT` and `t9` for this instruction – unless the setting of the `.arch` directive or the `-arch` flag on the `cc` or `as` command line causes the assembler to generate a single machine instruction in response to the `ldbu` command.)
Load Word (`ldw`)	Loads the two least significant bytes of the destination register with the contents of the word specified by the effective address. Because the loaded word is a signed value, its sign bit is replicated to fill the other bytes in the destination register. If the effective address is not evenly divisible by two, a data-alignment exception may be signaled. (The assembler uses temporary registers `AT` and `t9` for this instruction.)

Table 3-1: (continued)

Instruction	Mnemonic	Operands
Load Address	`lda`[a]	*d_reg, address*
Load Byte	`ldb`	
Load Byte Unsigned	`ldbu`	
Load Word	`ldw`	
Load Word Unsigned	`ldwu`	
Load Sign Extended Longword	`ldl`[a]	
Load Sign Extended Longword Locked	`ldl_l`[a]	
Load Quadword	`ldq`[a]	
Load Quadword Locked	`ldq_l`[a]	
Load Quadword Unaligned	`ldq_u`[b]	
Unaligned Load Word	`uldw`	
Unaligned Load Word Unsigned	`uldwu`	
Unaligned Load Word Unsigned	`uldl`	
Unaligned Load Longword	`uldq`	
Load Address High	`ldah`[a]	*d_reg, offset(b_reg)*
Load Global Pointer	`ldgp`	
Load Immediate Longword	`ldil`	*d_reg, val_expr*
Load Immediate Quadword	`ldiq`	
Store Byte	`stb`	*s_reg, address*
Store Word	`stw`	
Store Longword	`stl`[a]	
Store Longword Conditional	`stl_c`[a]	
Store Quadword	`stq`[a]	
Store Quadword Conditional	`stq_c`[a]	
Store Quadword Unaligned	`stq_u`[a]	
Unaligned Store Word	`ustw`	
Unaligned Store Longword	`ustl`	
Unaligned Store Quadword	`ustq`	

Table Notes:

a. In addition to the normal operands that can be specified with this instruction, relocation operands can also be specified (see Section 2.6.4).

Section 3.1.1 describes the operations performed by load instructions and Section 3.1.2 describes the operations performed by store instructions.

3.1.1 Load Instruction Descriptions

Load instructions move values (addresses, values of expressions, or contents of memory locations) into registers. For all load instructions, the effective address is the 64-bit twos-complement sum of the contents of the index register and the sign-extended offset.

Table 3-2: (continued)

Instruction	Description
Load Quadword (`ldq`)	Loads the destination register with the contents of the quadword specified by the effective address. All bytes of the register are replaced with the contents of the loaded quadword. If the effective address is not evenly divisible by eight, a data-alignment exception is signaled. If a `literal` relocation type is specified in the `ldq` instruction, one machine instruction is generated and the symbol and offset is stored in the `.lita` section. Other relocation types generate a sequence of instructions and the symbol and offset is stored in that sequence.
Load Quadword Locked (`ldq_l`)	Loads the destination register with the contents of the quadword specified by the effective address. All bytes of the register are replaced with the contents of the loaded quadword. If the effective address is not evenly divisible by eight, a data-alignment exception is signaled. If an `ldq_l` instruction executes without generating an exception, the processor records the target physical address in a per-processor locked-physical-address register and sets the per-processor lock flag. If the per-processor lock flag is still set when a `stq_c` instruction is executed, the store occurs; otherwise, it does not occur.
Load Quadword Unaligned (`ldq_u`)	Loads the destination register with the contents of the quadword specified by the effective address (with the three low-order bits cleared). The address does not have to be aligned on an 8-byte boundary; it can be any byte address.
Unaligned Load Word (`uldw`)	Loads the two least significant bytes of the destination register with the word at the specified address. The address does not have to be aligned on a 2-byte boundary; it can be any byte address. Because the loaded word is a signed value, its sign bit is replicated to fill the other bytes in the destination register. (The assembler uses temporary registers `AT`, `t9`, and `t10` for this instruction.)

Table 3-2: (continued)

Instruction	Description
Load Word Unsigned (`ldwu`)	Loads the two least significant bytes of the destination register with the contents of the word specified by the effective address. Because the loaded word is an unsigned value, the other bytes of the destination register are cleared to zeros. If the effective address is not evenly divisible by two, a data alignment exception may be signaled. (The assembler uses temporary registers `AT` and `t9` for this instruction – unless the setting of the `.arch` directive or the `-arch` flag on the `cc` or `as` command line causes the assembler to generate a single machine instruction in response to the `ldwu` command.)
Load Sign Extended Longword (`ldl`)	Loads the four least significant bytes of the destination register with the contents of the longword specified by the effective address. Because the loaded longword is a signed value, its sign bit is replicated to fill the other bytes in the destination register. If the effective address is not evenly divisible by four, a data-alignment exception is signaled.
Load Sign Extended Longword Locked (`ldl_l`)	Loads the four least significant bytes of the destination register with the contents of the longword specified by the effective address. Because the loaded longword is a signed value, its sign bit is replicated to fill the other bytes in the destination register. If the effective address is not evenly divisible by four, a data-alignment exception is signaled. If an `ldl_l` instruction executes without generating an exception, the processor records the target physical address in a per-processor locked-physical-address register and sets the per-processor lock flag. If the per-processor lock flag is still set when a `stl_c` instruction is executed, the store occurs; otherwise, it does not occur.

3.1.2 Store Instruction Descriptions

For all store instructions, the effective address is the 64-bit twos-complement sum of the contents of the index register and the sign-extended 16-bit offset.

Instructions whose address operands contain symbolic labels imply an index register, which the assembler determines. Some assembler store instructions can produce multiple machine-code instructions (see Section C.4).

Table 3-3 describes the operations performed by store instructions.

Table 3-3: Store Instruction Descriptions

Instruction	Description
Store Byte (`stb`)	Stores the least significant byte of the source register in the memory location specified by the effective address. (The assembler uses temporary registers `AT`, `t9`, and `t10` for this instruction – unless the setting of the `.arch` directive or the `-arch` flag on the `cc` or `as` command line causes the assembler to generate a single machine instruction in response to the `stb` command.)
Store Word (`stw`)	Stores the two least significant bytes of the source register in the memory location specified by the effective address. If the effective address is not evenly divisible by two, a data-alignment exception may be signaled. (The assembler uses temporary registers `AT`, `t9`, and `t10` for this instruction – unless the setting of the `.arch` directive or the `-arch` flag on the `cc` or `as` command line causes the assembler to generate a single machine instruction in response to the `stw` command.)
Store Longword (`stl`)	Stores the four least significant bytes of the source register in the memory location specified by the effective address. If the effective address is not evenly divisible by four, a data-alignment exception is signaled.
Store Longword Conditional (`stl_c`)	Stores the four least significant bytes of the source register in the memory location specified by the effective address, if the lock flag is set. The lock flag is returned in the source register and is then set to zero. If the effective address is not evenly divisible by four, a data-alignment exception is signaled.

Table 3-2: (continued)

Instruction	Description
Unaligned Load Word Unsigned (`uldwu`)	Loads the two least significant bytes of the destination register with the word at the specified address. The address does not have to be aligned on a 2-byte boundary; it can be any byte address. Because the loaded word is an unsigned value, the other bytes of the destination register are cleared to zeros. (The assembler uses temporary registers `AT`, `t9`, and `t10` for this instruction.)
Unaligned Load Longword (`uldl`)	Loads the four least significant bytes of the destination register with the longword at the specified address. The address does not have to be aligned on a 4-byte boundary; it can be any byte address in memory. (The assembler uses temporary registers `AT`, `t9`, and `t10` for this instruction.)
Unaligned Load Quadword (`uldq`)	Loads the destination register with the quadword at the specified address. The address does not have to be aligned on an 8-byte boundary; it can be any byte address in memory. (The assembler uses temporary registers `AT`, `t9`, and `t10` for this instruction.)
Load Address High (`ldah`)	Loads the destination register with the effective address of the specified data item. In computing the effective address, the signed constant offset is multiplied by 65536 before adding to the base register. The signed constant must be in the range –32768 to 32767.
Load Global Pointer (`ldgp`)	Loads the destination register with the global pointer value for the procedure. The sum of the base register and the sign-extended offset specifies the address of the `ldgp` instruction.
Load Immediate Longword (`ldil`)	Loads the destination register with the value of an expression that can be computed at assembly time. The value is converted to canonical longword form before being stored in the destination register; bit 31 is replicated in bits 32 though 63 of the destination register. (See Appendix B for additional information on canonical forms.)
Load Immediate Quadword (`ldiq`)	Loads the destination register with the value of an expression that can be computed at assembly time.

contained in that group.

Table 3-4: Arithmetic Instruction Formats

Instruction	Mnemonic	Operands
Clear	clr	*d_reg*
Absolute Value Longword	absl	{ *s_reg, d_reg* / *d_reg/s_reg* / *val_immed, d_reg* }
Absolute Value Quadword	absq	
Negate Longword (without overflow)	negl	
Negate Longword (with overflow)	neglv	
Negate Quadword (without overflow)	negq	
Negate Quadword (with overflow)	negqv	
Sign-Extension Byte	sextb	
Sign-Extension Longword	sextl	
Sign-Extension Word	sextw	
Add Longword (without overflow)	addl	{ *s_reg1, s_reg2, d_reg* / *d_reg/s_reg1, s_reg2* / *s_reg1, val_immed, d_reg* / *d_reg/s_reg1, val_immed* }
Add Longword (with overflow)	addlv	
Add Quadword (without overflow)	addq	
Add Quadword (with overflow)	addqv	
Scaled Longword Add by 4	s4addl	
Scaled Quadword Add by 4	s4addq	
Scaled Longword Add by 8	s8addl	
Scaled Quadword Add by 8	s8addq	
Multiply Longword (without overflow)	mull	
Multiply Longword (with overflow)	mullv	
Multiply Quadword (without overflow)	mulq	
Multiply Quadword (with overflow)	mulqv	
Subtract Longword (without overflow)	subl	
Subtract Longword (with overflow)	sublv	
Subtract Quadword (without overflow)	subq	
Subtract Quadword (with overflow)	subqv	
Scaled Longword Subtract by 4	s4subl	
Scaled Quadword Subtract by 4	s4subq	
Scaled Longword Subtract by 8	s8subl	
Scaled Quadword Subtract by 8	s8subq	
Unsigned Quadword Multiply High	umulh	
Divide Longword	divl	
Divide Longword Unsigned	divlu	
Divide Quadword	divq	
Divide Quadword Unsigned	divqu	
Longword Remainder	reml	
Longword Remainder Unsigned	remlu	
Quadword Remainder	remq	
Quadword Remainder Unsigned	remqu	

Table 3-5 describes the operations performed by arithmetic instructions.

Table 3-3: (continued)

Instruction	Description
Store Quadword (stq)	Stores the contents of the source register in the memory location specified by the effective address. If the effective address is not evenly divisible by eight, a data-alignment exception is signaled.
Store Quadword Conditional (stq_c)	Stores the contents of the source register in the memory location specified by the effective address, if the lock flag is set. The lock flag is returned in the source register and is then set to zero. If the effective address is not evenly divisible by eight, a data-alignment exception is signaled.
Store Quadword Unaligned (stq_u)	Stores the contents of the source register in the memory location specified by the effective address (with the three low-order bits cleared).
Unaligned Store Word (ustw)	Stores the two least significant bytes of the source register in the memory location specified by the effective address. The address does not have to be aligned on a 2-byte boundary; it can be any byte address. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for this instruction.)
Unaligned Store Longword (ustl)	Stores the four least significant bytes of the source register in the memory location specified by the effective address. The address does not have to be aligned on a 4-byte boundary; it can be any byte address. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for this instruction.)
Unaligned Store Quadword (ustq)	Stores the contents of the source register in a memory location specified by the effective address. The address does not have to be aligned on an 8-byte boundary; it can be any byte address. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for this instruction.)

3.2 Arithmetic Instructions

Arithmetic instructions perform arithmetic operations on values in registers. (Floating-point arithmetic instructions are described in Section 4.3.)

Table 3-4 lists the mnemonics and operands for instructions that perform arithmetic operations. The table is divided into groups of instructions. The operands specified within a particular group apply to all of the instructions

Table 3-5: Arithmetic Instruction Descriptions

Instruction	Description
Clear (clr)	Sets the contents of the destination register to zero.
Absolute Value Longword (absl)	Computes the absolute value of the contents of the source register and places the result in the destination register. If the value in the source register is -2147483648, an overflow exception is signaled.
Absolute Value Quadword (absq)	Computes the absolute value of the contents of the source register and places the result in the destination register. If the value in the source register is -9223372036854775808, an overflow exception is signaled.
Negate Longword (without overflow) (negl)	Negates the integer contents of the four least significant bytes in the source register and places the result in the destination register. An overflow occurs if the value in the source register is -2147483648, but the overflow exception is not signaled.
Negate Longword (with overflow) (neglv)	Negates the integer contents of the four least significant bytes in the source register and places the result in the destination register. If the value in the source register is -2147483648, an overflow exception is signaled.
Negate Quadword (without overflow) (negq)	Negates the integer contents of the source register and places the result in the destination register. An overflow occurs if the value in the source register is -2147483648, but the overflow exception is not signaled.
Negate Quadword (with overflow) (negqv)	Negates the integer contents of the source register and places the result in the destination register. An overflow exception is signaled if the value in the source register is -9223372036854775808.
Sign-Extension Byte (sextb)	Moves the least significant byte of the source register into the least significant byte of the destination register. Because the moved byte is a signed value, its sign bit is replicated to fill the other bytes in the destination register.
Sign-Extension Word (sextw)	Moves the two least significant bytes of the source register into the two least significant bytes of the destination register. Because the moved word is a signed value, its sign bit is replicated to fill the other bytes in the destination register.

Table 3-5: (continued)

Instruction	Description
Sign-Extension Longword (sextl)	Moves the four least significant bytes of the source register into the four least significant bytes of the destination register. Because the moved longword is a signed value, its sign bit is replicated to fill the other bytes in the destination register.
Add Longword (without overflow) (addl)	Computes the sum of two signed 32-bit values. This instruction adds the contents of *s_reg1* to the contents of *s_reg2* or the immediate value and then places the result in the destination register. Overflow exceptions never occur.
Add Longword (with overflow) (addlv)	Computes the sum of two signed 32-bit values. This instruction adds the contents of *s_reg1* to the contents of *s_reg2* or the immediate value and then places the result in the destination register. If the result cannot be represented as a signed 32-bit number, an overflow exception is signaled.
Add Quadword (without overflow) (addq)	Computes the sum of two signed 64-bit values. This instruction adds the contents of *s_reg1* to the contents of *s_reg2* or the immediate value and then places the result in the destination register. Overflow exceptions never occur.
Add Quadword (with overflow) (addqv)	Computes the sum of two signed 64-bit values. This instruction adds the contents of *s_reg1* to the contents of *s_reg2* or the immediate value and then places the result in the destination register. If the result cannot be represented as a signed 64-bit number, an overflow exception is signaled.
Scaled Longword Add by 4 (s4addl)	Computes the sum of two signed 32-bit values. This instruction scales (multiplies) the contents of *s_reg1* by four and then adds the contents of *s_reg2* or the immediate value. The result is stored in the destination register. Overflow exceptions never occur.
Scaled Quadword Add by 4 (s4addq)	Computes the sum of two signed 64-bit values. This instruction scales (multiplies) the contents of *s_reg1* by four and then adds the contents of *s_reg2* or the immediate value. The result is stored in the destination register. Overflow exceptions never occur.

Table 3-5: (continued)

Instruction	Description
Subtract Quadword (without overflow) (subq)	Computes the difference of two signed 64-bit values. This instruction subtracts the contents of *s_reg2* or an immediate value from the contents of *s_reg1* and then places the result in the destination register. Overflow exceptions never occur.
Subtract Quadword (with overflow) (subqv)	Computes the difference of two signed 64-bit values. This instruction subtracts the contents of *s_reg2* or an immediate value from the contents of *s_reg1* and then places the result in the destination register. If the true result's sign differs from the destination register's sign, an overflow exception is signaled.
Scaled Longword Subtract by 4 (s4subl)	Computes the difference of two signed 32-bit values. This instruction subtracts the contents of *s_reg2* or the immediate value from the scaled (by 4) contents of *s_reg1*. The result is stored in the destination register. Overflow exceptions never occur.
Scaled Quadword Subtract by 4 (s4subq)	Computes the difference of two signed 64-bit values. This instruction subtracts the contents of *s_reg2* or the immediate value from the scaled (by 4) contents of *s_reg1*. The result is stored in the destination register. Overflow exceptions never occur.
Scaled Longword Subtract by 8 (s8subl)	Computes the difference of two signed 32-bit values. This instruction subtracts the contents of *s_reg2* or the immediate value from the scaled (by 8) contents of *s_reg1*. The result is stored in the destination register. Overflow exceptions never occur.
Scaled Quadword Subtract by 8 (s8subq)	Computes the difference of two signed 64-bit values. This instruction subtracts the contents of *s_reg2* or the immediate value from the scaled (by 8) contents of *s_reg1*. The result is stored in the destination register. Overflow exceptions never occur.
Unsigned Quadword Multiply High (umulh)	Computes the product of two unsigned 64-bit values. This instruction multiplies the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the high-order 64 bits of the 128-bit product in the destination register.

Table 3-5: (continued)

Instruction	Description

Instruction	Description
Scaled Longword Add by 8 (s8addl)	Computes the sum of two signed 32-bit values. This instruction scales (multiplies) the contents of *s_reg1* by eight and then adds the contents of *s_reg2* or the immediate value. The result is stored in the destination register. Overflow exceptions never occur.
Scaled Quadword Add by 8 (s8addq)	Computes the sum of two signed 64-bit values. This instruction scales (multiplies) the contents of *s_reg1* by eight and then adds the contents of *s_reg2* or the immediate value. The result is stored in the destination register. Overflow exceptions never occur.
Multiply Longword (without overflow) (mull)	Computes the product of two signed 32-bit values. This instruction places either the 32-bit product of *s_reg1* and *s_reg2* or the immediate value in the destination register. Overflows are not reported.
Multiply Longword (with overflow) (mullv)	Computes the product of two signed 32-bit values. This instruction places either the 32-bit product of *s_reg1* and *s_reg2* or the immediate value in the destination register. If an overflow occurs, an overflow exception is signaled.
Multiply Quadword (without overflow) (mulq)	Computes the product of two signed 64-bit values. This instruction places either the 64-bit product of *s_reg1* and *s_reg2* or the immediate value in the destination register. Overflow is not reported.
Multiply Quadword (with overflow) (mulqv)	Computes the product of two signed 64-bit values. This instruction places either the 64-bit product of *s_reg1* and *s_reg2* or the immediate value in the destination register. If an overflow occurs, an overflow exception is signaled.
Subtract Longword (without overflow) (subl)	Computes the difference of two signed 32-bit values. This instruction subtracts either the contents of *s_reg2* or an immediate value from the contents of *s_reg1* and then places the result in the destination register. Overflow exceptions never happen.
Subtract Longword (with overflow) (sublv)	Computes the difference of two signed 32-bit values. This instruction subtracts either the contents of *s_reg2* or an immediate value from the contents of *s_reg1* and then places the result in the destination register. If the true result's sign differs from the destination register's sign, an overflow exception is signaled.

Table 3-5: (continued)

Instruction	Description
Longword Remainder (reml)	Computes the remainder of the division of two signed 32-bit values. The remainder reml(i,j) is defined as i-(j*divl(i,j)), where j != 0. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or by the immediate value and then places the remainder in the destination register. The reml instruction rounds toward zero, for example, divl(5,-3)=-1 and reml(5,-3)=2. For divide-by-zero, an error is signaled and a call_pal PAL_gentrap instruction may be issued. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for the reml instruction.)
Longword Remainder Unsigned (remlu)	Computes the remainder of the division of two unsigned 32-bit values. The remainder remlu(i,j) is defined as i-(j*divlu(i,j)), where j != 0. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the remainder in the destination register. For divide-by-zero, an error is signaled and a call_pal PAL_gentrap instruction may be issued. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for the remlu instruction.)
Quadword Remainder (remq)	Computes the remainder of the division of two signed 64-bit values. The remainder remq(i,j) is defined as i-(j*divq(i,j)) where j != 0. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the remainder in the destination register. The remq instruction rounds toward zero, for example, divq(5,-3)=-1 and remq(5,-3)=2. For divide-by-zero, an error is signaled and a call_pal PAL_gentrap instruction may be issued. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for the remq instruction.)

Table 3-5: (continued)

Instruction	Description
Divide Longword (divl)	Computes the quotient of two signed 32-bit values. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the quotient in the destination register. The divl instruction rounds toward zero. If the divisor is zero, an error is signaled. Overflow is signaled when dividing -2147483648 by -1. A call_pal PAL_gentrap instruction may be issued for divide-by-zero and overflow exceptions.
Divide Longword Unsigned (divlu)	Computes the quotient of two unsigned 32-bit values. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the quotient in the destination register. If the divisor is zero, an exception is signaled and a call_pal PAL_gentrap instruction may be issued. Overflow exceptions never occur. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for the divlu instruction.)
Divide Quadword (divq)	Computes the quotient of two signed 64-bit values. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the quotient in the destination register. The divq instruction rounds toward zero. If the divisor is zero, an error is signaled. Overflow is signaled when dividing -9223372036854775808 by -1. A call_pal PAL_gentrap instruction may be issued for divide-by-zero and overflow exceptions. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for the divq instruction.)
Divide Quadword Unsigned (divqu)	Computes the quotient of two unsigned 64-bit values. This instruction divides the contents of *s_reg1* by the contents of *s_reg2* or the immediate value and then places the quotient in the destination register. If the divisor is zero, an exception is signaled and a call_pal PAL_gentrap instruction may be issued. Overflow exceptions never occur. (The assembler uses temporary registers AT, t9, t10, t11, and t12 for the divqu instruction.)

Table 3-5: (continued)

Instruction	Description
Quadword Remainder Unsigned (`remqu`)	Computes the remainder of the division of two unsigned 64-bit values. The remainder `remqu(i,j)` is defined as `i-(j*divqu(i,j))` where `j != 0`. This instruction divides the contents of *`s_reg1`* by the contents of *`s_reg2`* or the immediate value and then places the remainder in the destination register. For divide-by-zero, an error is signaled and a `call_pal PAL_gentrap` instruction may be issued. (The assembler uses temporary registers `AT`, `t9`, `t10`, `t11`, and `t12` for the `remqu` instruction.)

3.3 Logical and Shift Instructions

Logical and shift instructions perform logical operations and shifts on values in registers.

Table 3-6 lists the mnemonics and operands for instructions that perform logical and shift operations. The table is divided into groups of instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 3-6: Logical and Shift Instruction Formats

Instruction	Mnemonic	Operands
Logical Complement – NOT	`not`	*s_reg, d_reg* *d_reg/s_reg* *val_immed, d_reg*
Logical Product – AND	`and`	*s_reg1, s_reg2, d_reg* *d_reg/s_reg1, s_reg2* *s_reg1, val_immed, d_reg* *d_reg/s_reg1, val_immed*
Logical Sum – OR	`bis`	
Logical Sum – OR	`or`	
Logical Difference – XOR	`xor`	
Logical Product with Complement – ANDNOT	`bic`	
Logical Product with Complement – ANDNOT	`andnot`	
Logical Sum with Complement – ORNOT	`ornot`	
Logical Equivalence – XORNOT	`eqv`	
Logical Equivalence – XORNOT	`xornot`	
Shift Left Logical	`sll`	
Shift Right Logical	`srl`	
Shift Right Arithmetic	`sra`	

Table 3-7 describes the operations performed by logical and shift instructions.

Table 3-7: Logical and Shift Instruction Descriptions

Instruction	Description
Logical Complement – NOT (`not`)	Computes the Logical NOT of a value. This instruction performs a complement operation on the contents of *`s_reg1`* and places the result in the destination register.
Logical Product – AND (`and`)	Computes the Logical AND of two values. This instruction performs an AND operation between the contents of *`s_reg1`* and either the contents of *`s_reg2`* or the immediate value and then places the result in the destination register.

Table 3-7: (continued)

Instruction	Description
Shift Left Logical (`sll`)	Shifts the contents of a register left (toward the sign bit) and inserts zeros in the vacated bit positions. Register *s_reg1* contains the value to be shifted, and either the contents of *s_reg2* or the immediate value specifies the shift count. If *s_reg2* or the immediate value is greater than 63 or less than zero, *s_reg1* shifts by the result of the following AND operation: *s_reg2* AND 63.
Shift Right Logical (`srl`)	Shifts the contents of a register to the right (toward the least significant bit) and inserts zeros in the vacated bit positions. Register *s_reg1* contains the value to be shifted, and either the contents of *s_reg2* or the immediate value specifies the shift count. If *s_reg2* or the immediate value is greater than 63 or less than zero, *s_reg1* shifts by the result of the result of the following AND operation: *s_reg2* AND 63.
Shift Right Arithmetic (`sra`)	Shifts the contents of a register to the right (toward the least significant bit) and inserts the sign bit in the vacated bit position. Register *s_reg1* contains the value to be shifted, and either the contents of *s_reg2* or the immediate value specifies the shift count. If *s_reg2* or the immediate value is greater than 63 or less than zero, *s_reg1* shifts by the result of the following AND operation: *s_reg2* AND 63.

3.4 Relational Instructions

Relational instructions compare values in registers.

Table 3-8 lists the mnemonics and operands for instructions that perform relational operations. Each of the instructions listed in the table can take an operand in any of the forms shown.

Table 3-7: (continued)

Instruction	Description
Logical Sum – OR (`bis`)	Computes the Logical OR of two values. This instruction performs an OR operation between the contents of *s_reg1* and either the contents of *s_reg2* or the immediate value and then places the result in the destination register.
Logical Sum – OR (`or`)	Synonym for `bis`.
Logical Difference – XOR (`xor`)	Computes the XOR of two values. This instruction performs an XOR operation between the contents of *s_reg1* and either the contents of *s_reg2* or the immediate value and then places the result in the destination register.
Logical Product with Complement – ANDNOT (`bic`)	Computes the Logical AND of two values. This instruction performs an AND operation between the contents of *s_reg1* and the ones complement of either the contents of *s_reg2* or the immediate value and then places the result in the destination register.
Logical Product with Complement – ANDNOT (`andnot`)	Synonym for `bic`.
Logical Sum with Complement – ORNOT (`ornot`)	Computes the logical OR of two values. This instruction performs an OR operation between the contents of *s_reg1* and the ones complement of either the contents of *s_reg2* or the immediate value and then places the result in the destination register.
Logical Equivalence – XORNOT (`eqv`)	Computes the logical XOR of two values. This instruction performs an XOR operation between the contents of *s_reg1* and the ones complement of either the contents of *s_reg2* or the immediate value and then places the result in the destination register.
Logical Equivalence – XORNOT (`xornot`)	Synonym for `eqv`.

Table 3-9: (continued)

Instruction	Description
Compare Unsigned Quadword Less Than or Equal (`cmpule`)	Compares two unsigned 64-bit values. If the value in *s_reg1* is less than or equal to either the value in *s_reg2* or the immediate value, this instruction sets the destination register to one; otherwise, it sets the destination register to zero.

3.5 Move Instructions

Move instructions move data between registers.

Table 3-10 lists the mnemonics and operands for instructions that perform move operations. The table is divided into groups of instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 3-10: Move Instruction Formats

Instruction	Mnemonic	Operands
Move	`mov`	*s_reg, d_reg* *val_immed, d_reg*

Move if Equal to Zero
Move if Not Equal to Zero
Move if Less Than Zero
Move if Less Than or Equal to Zero
Move if Greater Than Zero
Move if Greater Than or Equal to Zero
Move if Low Bit Clear
Move if Low Bit Set
	`cmoveq`
	`cmovne`
	`cmovlt`
	`cmovle`
	`cmovgt`
	`cmovge`
	`cmovlbc`
	`cmovlbs`
		s_reg1, s_reg2, d_reg
		d_reg/s_reg1, s_reg2
		s_reg1, val_immed, d_reg
		d_reg/s_reg1, val_immed

Table 3-11 describes the operations performed by move instructions.

Table 3-8: Relational Instruction Formats

Instruction	Mnemonic	Operands

Compare Signed Quadword Equal
Compare Signed Quadword Less Than
Compare Signed Quadword Less Than or Equal
Compare Unsigned Quadword Less Than
Compare Unsigned Quadword Less Than or Equal
	`cmpeq`
	`cmplt`
	`cmple`
	`cmpult`
	`cmpule`
		s_reg1, s_reg2, d_reg
		d_reg/s_reg1, s_reg2
		s_reg1, val_immed, d_reg
		d_reg/s_reg1, val_immed

Table 3-9 describes the operations performed by relational instructions.

Table 3-9: Relational Instruction Descriptions

Instruction	Description
Compare Signed Quadword Equal (`cmpeq`)	Compares two 64-bit values. If the value in *s_reg1* equals the value in *s_reg2* or the immediate value, this instruction sets the destination register to one; otherwise, it sets the destination register to zero.
Compare Signed Quadword Less Than (`cmplt`)	Compares two signed 64-bit values. If the value in *s_reg1* is less than the value in *s_reg2* or the immediate value, this instruction sets the destination register to one; otherwise, it sets the destination register to zero.
Compare Signed Quadword Less Than or Equal (`cmple`)	Compares two signed 64-bit values. If the value in *s_reg1* is less than or equal to the value in *s_reg2* or the immediate value, this instruction sets the destination register to one; otherwise, it sets the destination register to zero.
Compare Unsigned Quadword Less Than (`cmpult`)	Compares two unsigned 64-bit values. If the value in *s_reg1* is less than either the value in *s_reg2* or the immediate value, this instruction sets the destination register to one; otherwise, it sets the destination register to zero.

Table 3-11: Move Instruction Descriptions

Instruction	Description
Move (`mov`)	Moves the contents of the source register or the immediate value to the destination register.
Move if Equal to Zero (`cmoveq`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the contents of *`s_reg1`* is equal to zero.
Move if Not Equal to Zero (`cmovne`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the contents of *`s_reg1`* is not equal to zero.
Move if Less Than Zero (`cmovlt`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the contents of *`s_reg1`* is less than zero.
Move if Less Than or Equal to Zero (`cmovle`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the contents of *`s_reg1`* is less than or equal to zero.
Move if Greater Than Zero (`cmovgt`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the contents of *`s_reg1`* is greater than zero.
Move if Greater Than or Equal to Zero (`cmovge`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the contents of *`s_reg1`* is greater than or equal to zero.
Move if Low Bit Clear (`cmovlbc`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the low-order bit of *`s_reg1`* is equal to zero.
Move if Low Bit Set (`cmovlbs`)	Moves the contents of *`s_reg2`* or the immediate value to the destination register if the low-order bit of *`s_reg1`* is not equal to zero.

3.6 Control Instructions

Control instructions change the control flow of an assembly program. They affect the sequence in which instructions are executed by transferring control from one location in a program to another.

Table 3-12 lists the mnemonics and operands for instructions that perform control operations. The table is divided into groups of instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 3-12: Control Instruction Formats

Instruction	Mnemonic	Operands

Branch if Equal to Zero
Branch if Not Equal to Zero
Branch if Less Than Zero
Branch if Less Than or Equal to Zero
Branch if Greater Than Zero
Branch if Greater Than or Equal to Zero
Branch if Low Bit is Clear
Branch if Low Bit is Set
	`beq`
	`bne`
	`blt`
	`ble`
	`bgt`
	`bge`
	`blbc`
	`blbs`
		`s_reg, label`

Branch Branch to Subroutine	`br` `bsr`	*d_reg, label* *label*
Jump Jump to Subroutine	`jmp`[a] `jsr`[a]	*d_reg, (s_reg), jhint* *d_reg, (s_reg)* *(s_reg), jhint* *(s_reg)* *d_reg, address* *address*
Return from Subroutine Jump to Subroutine Return	`ret` `jsr_coroutine`[a]	*d_reg, (s_reg), rhint* *d_reg, (s_reg)* *d_reg, rhint* *d_reg* *(s_reg), rhint* *(s_reg)* *rhint* *no_operands*

Table Notes:

a. In addition to the normal operands that can be specified with this instruction, relocation operands can also be specified (see Section 2.6.4).

Table 3-13 describes the operations performed by control instructions. For all branch instructions described in the table, the branch destinations must be

Table 3-13: (continued)

Instruction	Description
Jump to Subroutine (jsr)	Unconditionally jumps to a specified location and stores the return address in the destination register. If a destination register is not specified, register $26 (ra) is used. A symbolic address or the source register specifies the target location. The instruction jsr *procname* transfers to *procname* and saves the return address in register $26.
Return from Subroutine (ret)	Unconditionally returns from a subroutine. If a destination register is specified, the address of the instruction following the ret instruction is stored in the specified register. The source register contains the return address. If the source register is not specified, register $26 (ra) is used. If a hint is not specified, a hint value of one is used.
Jump to Subroutine Return (jsr_coroutine)	Unconditionally returns from a subroutine and stores the return address in the destination register. If a destination register is not specified, register $26 (ra) is used. The source register contains the target address. If the source register is not specified, register $26 (ra) is used.

All jump instructions (jmp, jsr, ret, jsr_coroutine) perform identical operations. They differ only in hints to possible branch-prediction logic. See the *Alpha Architecture Reference Manual* for information about branch-prediction logic.

3.7 Byte-Manipulation Instructions

Byte-manipulation instructions perform byte operations on values in registers.

Table 3-14 lists the mnemonics and operands for instructions that perform byte-manipulation operations. Each of the instructions listed in the table can take an operand in any of the forms shown.

defined in the source being assembled, not in an external source file.

Table 3-13: Control Instruction Descriptions

Instruction	Description
Branch if Equal to Zero (beq)	Branches to the specified label if the contents of the source register is equal to zero.
Branch if Not Equal to Zero (bne)	Branches to the specified label if the contents of the source register is not equal to zero.
Branch if Less Than Zero (blt)	Branches to the specified label if the contents of the source register is less than zero. The comparison treats the source register as a signed 64-bit value.
Branch if Less Than or Equal to Zero (ble)	Branches to the specified label if the contents of the source register is less than or equal to zero. The comparison treats the source register as a signed 64-bit value.
Branch if Greater Than Zero (bgt)	Branches to the specified label if the contents of the source register is greater than zero. The comparison treats the source register as a signed 64-bit value.
Branch if Greater Than or Equal to Zero (bge)	Branches to the specified label if the contents of the source register is greater than or equal to zero. The comparison treats the source register as a signed 64-bit value.
Branch if Low Bit is Clear (blbc)	Branches to the specified label if the low-order bit of the source register is equal to zero.
Branch if Low Bit is Set (blbs)	Branches to the specified label if the low-order bit of the source register is not equal to zero.
Branch (br)	Branches unconditionally to the specified label. If a destination register is specified, the address of the instruction following the br instruction is stored in that register.
Branch to Subroutine (bsr)	Branches unconditionally to the specified label and stores the return address in the destination register. If a destination register is not specified, register $26 (ra) is used.
Jump (jmp)	Unconditionally jumps to a specified location. A symbolic address or the source register specifies the target location. If a destination register is specified, the address of the instruction following the jmp instruction is stored in the specified register.

Table 3-14: Byte-Manipulation Instruction Formats

Instruction	Mnemonic	Operands
Compare Byte	`cmpbge`	*s_reg1, s_reg2, d_reg* *d_reg/s_reg1, s_reg2* *s_reg1, val_immed, d_reg* *d_reg/s_reg1, val_immed*
Extract Byte Low	`extbl`	
Extract Word Low	`extwl`	
Extract Longword Low	`extll`	
Extract Quadword Low	`extql`	
Extract Word High	`extwh`	
Extract Longword High	`extlh`	
Extract Quadword High	`extqh`	
Insert Byte Low	`insbl`	
Insert Word Low	`inswl`	
Insert Longword Low	`insll`	
Insert Quadword Low	`insql`	
Insert Word High	`inswh`	
Insert Longword High	`inslh`	
Insert Quadword High	`insqh`	
Mask Byte Low	`mskbl`	
Mask Word Low	`mskwl`	
Mask Longword Low	`mskll`	
Mask Quadword Low	`mskql`	
Mask Word High	`mskwh`	
Mask Longword High	`msklh`	
Mask Quadword High	`mskqh`	
Zero Bytes	`zap`	
Zero Bytes NOT	`zapnot`	

Table 3-15 describes the operations performed by byte-manipulation instructions.

Table 3-15: Byte-Manipulation Instruction Descriptions

Instruction	Description
Compare Byte (`cmpbge`)	Performs eight parallel unsigned byte comparisons between corresponding bytes of register *s_reg1* and *s_reg2* or the immediate value. A bit is set in the destination register if a byte in *s_reg1* is greater than or equal to the corresponding byte in *s_reg2* or the immediate value. The results of the comparisons are stored in the eight low-order bits of the destination register; bit 0 of the destination register corresponds to byte 0 and so forth. The 56 high-order bits of the destination register are cleared.
Extract Byte Low (`extbl`)	Shifts the register *s_reg1* right by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts the low-order byte into the destination register. The seven high-order bytes of the destination register are cleared to zeros. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Extract Word Low (`extwl`)	Shifts the register *s_reg1* right by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts the two low-order bytes and stores them in the destination register. The six high-order bytes of the destination register are cleared to zeros. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Extract Longword Low (`extll`)	Shifts the register *s_reg1* right by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts the four low-order bytes and stores them in the destination register. The four high-order bytes of the destination register are cleared to zeros. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Extract Quadword Low (`extql`)	Shifts the register *s_reg1* right by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts all eight bytes and stores them in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.

Table 3-15: (continued)

Instruction	Description
Extract Word High (extwh)	Shifts the register *s_reg1* left by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts the two low-order bytes and stores them in the destination register. The six high-order bytes of the destination register are cleared to zeros. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Extract Longword High (extlh)	Shifts the register *s_reg1* left by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts the four low-order bytes and stores them in the destination register. The four high-order bytes of the destination register are cleared to zeros. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Extract Quadword High (extqh)	Shifts the register *s_reg1* left by 0-7 bytes, inserts zeros into the vacated bit positions, and then extracts all eight bytes and stores them in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Byte Low (insbl)	Shifts the register *s_reg1* left by 0-7 bytes, inserts the byte into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Word Low (inswl)	Shifts the register *s_reg1* left by 0-7 bytes, inserts the word into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Longword Low (insll)	Shifts the register *s_reg1* left by 0-7 bytes, inserts the longword into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Quadword Low (insql)	Shifts the register *s_reg1* left by 0-7 bytes, inserts the quadword into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.

Table 3-15: (continued)

Instruction	Description
Insert Quadword Low (insql)	Shifts the register *s_reg1* left by 0-7 bytes, inserts the quadword into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Word High (inswh)	Shifts the register *s_reg1* right by 0-7 bytes, inserts the word into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Longword High (inslh)	Shifts the register *s_reg1* right by 0-7 bytes, inserts the longword into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Insert Quadword High (insqh)	Shifts the register *s_reg1* right by 0-7 bytes, inserts the quadword into a field of zeros, and then places the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the shift count.
Mask Byte Low (mskbl)	Sets a byte in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the byte.
Mask Word Low (mskwl)	Sets a word in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the word.
Mask Longword Low (mskll)	Sets a longword in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the longword.
Mask Quadword Low (mskql)	Sets a quadword in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the quadword.
Mask Word High (mskwh)	Sets a word in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the word.

Table 3-16: Special-Purpose Instruction Formats

Instruction	Mnemonic	Operands
Call Privileged Architecture Library	`call_pal`	*palcode*
Architecture Mask	`amask`	{ *s_reg, d_reg* } { *val_immed, d_reg* }
Prefetch Data	`fetch`	*offset* (*b_reg*)
Prefetch Data, Modify Intent	`fetch_m`	
Read Process Cycle Counter	`rpcc`	*d_reg*
Implementation Version	`implver`	
No Operation	`nop`	*no_operands*
Universal No Operation	`unop`	
Trap Barrier	`trapb`	
Exception Barrier	`excb`	
Memory Barrier	`mb`	
Write Memory Barrier	`wmb`	

Table 3-17 describes the operations performed by special-purpose instructions.

Table 3-17: Special-Purpose Instruction Descriptions

Instruction	Description
Call Privileged Architecture Library (`call_pal`)	Unconditionally transfers control to the exception handler. The *palcode* operand is interpreted by software conventions.
Architecture Mask (`amask`)	The value of the contents of `s_reg` or the immediate value represent a mask of architectural extensions that are being requested. Bits are cleared if they correspond to architectural extensions that are present, and the result is placed in the destination register.
Prefetch Data (`fetch`)	Indicates that the 512-byte block of data specified by the effective address should be moved to a faster-access part of the memory hierarchy.

Table 3-15: (continued)

Instruction	Description
Mask Longword High (`msklh`)	Sets a longword in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the longword.
Mask Quadword High (`mskqh`)	Sets a quadword in register *s_reg1* to zero and stores the result in the destination register. Bits 0-2 of register *s_reg2* or the immediate value specify the offset of the quadword.
Zero Bytes (`zap`)	Sets selected bytes of register *s_reg1* to zero and places the result in the destination register. Bits 0-7 of register *s_reg2* or an immediate value specify the bytes to be cleared to zeros. Each bit corresponds to one byte in register *s_reg1*; for example, bit 0 corresponds to byte 0. A bit with a value of one indicates its corresponding byte should be cleared to zeros.
Zero Bytes NOT (`zapnot`)	Sets selected bytes of register *s_reg1* to zero and places the result in the destination register. Bits 0-7 of register *s_reg2* or an immediate value specify the bytes to be cleared to zeros. Each bit corresponds to one byte in register *s_reg1*; for example, bit 0 corresponds to byte 0. A bit with a value of zero indicates its corresponding byte should be cleared to zeros.

3.8 Special-Purpose Instructions

Special-purpose instructions perform miscellaneous tasks.

Table 3-16 lists the mnemonics and operands for instructions that perform special operations. The table is divided into groups of instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 3-17: (continued)

Instruction	Description
Prefetch Data, Modify Intent (`fetch_m`)	Indicates that the 512-byte block of data specified by the effective address should be moved to a faster-access part of the memory hierarchy. In addition, this instruction is a hint that part or all of the data may be modified.
Read Process Cycle Counter (`rpcc`)	Returns the contents of the process cycle counter in the destination register.
Implementation Version (`implver`)	A small integer is placed in the destination register. This integer specifies the major implementation version of the processor on which it is executed. This information can be used to make code-scheduling or tuning decisions. The returned small integer can have the values 0 or 1. 1 indicates an EV5 Alpha chip (21164). 0 indicates EV4, EV45, LCA, and LCA-45 Alpha chips (that is, 21064, 21064A, 21066, 21068, and 21066A, respectively).
No Operation (`nop`)	Has no effect on the machine state.
Universal No Operation (`unop`)	Has no effect on the machine state.
Trap Barrier (`trapb`)	Guarantees that all previous arithmetic instructions are completed, without incurring any arithmetic traps, before any instructions after the `trapb` instruction are issued.
Exception Barrier (`excb`)	Guarantees that all previous instructions complete any exception-related behavior or rounding-mode behavior before any instructions after the `excb` instruction are issued.
Memory Barrier (`mb`)	Used to serialize access to memory. See the *Alpha Architecture Reference Manual* for addition information on memory barriers.
Write Memory Barrier (`wmb`)	Guarantees that all previous store instructions access memory before any store instructions issued after the `wmb` instruction.

The following terms are used to discuss floating-point operations:

Term	Meaning
Infinite	A value of +∞ or –∞.
Infinity	A symbolic entity that represents values with magnitudes greater than the largest magnitude for a particular format.
Ordered	The usual result from a comparison, namely: less than (<), equal (=), or greater than (>).
NaN	Symbolic entities that represent values not otherwise available in floating-point formats. (NaN is an acronym for not-a-number.)
Unordered	The condition that results from a floating-point comparison when one or both operands are NaNs.

There are two kinds of NaNs:

- Quiet NaNs represent unknown or uninitialized values.
- Signaling NaNs represent symbolic values and values that are too big or too precise for the format. Signaling NaNs raise an invalid-operation exception whenever an operation is attempted on them.

4.1 Background Information on Floating-Point Operations

Topics addressed in the following sections include:

- Floating-point data types (Section 4.1.1)
- The floating-point control register (Section 4.1.2)
- Floating-point exceptions (Section 4.1.3)
- Floating-point rounding modes (Section 4.1.4)
- Floating-point instruction qualifiers (Section 4.1.5)

4.1.1 Floating-Point Data Types

Floating-point instructions operate on the following data types:

- D_floating (VAX double precision, limited support)
- F_floating (VAX single precision)
- G_floating (VAX double precision)
- S_floating (IEEE single precision)

Floating-Point Instruction Set 4

This chapter describes the assembler's floating-point instructions. See Chapter 3 for a description of the integer instructions. For details on the instruction set beyond the scope of this manual, refer to the *Alpha Architecture Reference Manual*.

The assembler's floating-point instruction set contains the following classes of instructions:

- Load and store instructions (Section 4.2)
- Arithmetic instructions. (Section 4.3)
- Relational instructions (Section 4.4)
- Move instructions (Section 4.5)
- Control instructions (Section 4.6)
- Special-purpose instructions (Section 4.7)

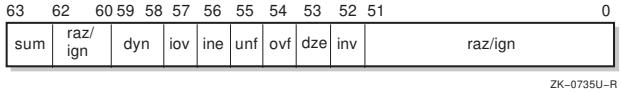
A particular floating-point instruction may be implemented in hardware, software, or a combination of hardware and software.

Tables in this chapter show the format for each instruction in the floating-point instruction set. The tables list the instruction names and the forms of operands that can be used with each instruction. The specifiers used in the tables to identify operands have the following meanings:

Operand Specifier	Description
`address`	A symbolic expression whose effective value is used as an address.
`d_reg`	Destination register. A floating-point register that receives a value as a result of an operation.
`2d_reg/s_reg`	One floating-point register that is used as both a destination register and a source register.
`label`	A label that identifies a location in a program.
`s_reg,s_reg1,s_reg2`	Source registers. Floating-point registers whose contents are to be used in an operation.
`val_expr`	An expression whose value is a floating-point constant.

Figure 4-2 shows the format of the floating-point control register.

Figure 4-2: Floating-Point Control Register



The fields of the floating-point control register have the following meaning:

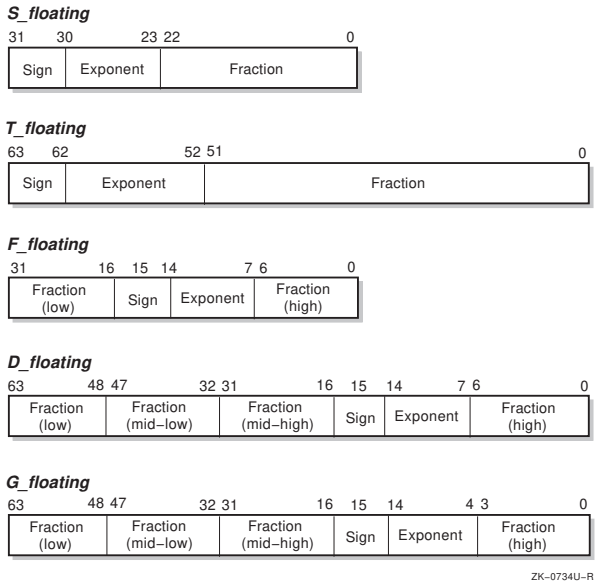
Bits	Name	Description
63	sum	Summary – records the bitwise OR of the FPCR exception bits (bits 57 to 52).
62-60	raz/ign	Read-As-Zero – ignored when written.
59-58	dyn	Dynamic Rounding Mode – indicates the current rounding mode to be used by an IEEE floating-point instruction that specifies dynamic mode (d qualifier). The bit assignments for this field are as follows: 00 – Chopped rounding mode 01 – Minus infinity 10 – Normal rounding 11 – Plus infinity
57	iov	Integer overflow.
56	ine	Inexact result.
55	unf	Underflow.
54	ovf	Overflow.
53	dze	Division by zero.
52	inv	Invalid operation.
51-0	raz/ign	Read-As-Zero – ignored when written.

The floating-point exceptions associated with bits 57 to 52 are described in Section 4.1.3.

- T_floating (IEEE double precision)
- Longword integer and quadword integer

Figure 4-1 shows the memory formats for the single- and double-precision floating-point data types.

Figure 4-1: Floating-Point Data Formats



4.1.2 Floating-Point Control Register

The floating-point control register (FPCR) contains status and control information. It controls the arithmetic rounding mode of instructions that specify dynamic rounding (d qualifier – see Section 4.1.5 for information on instruction qualifiers) and gives a summary for each exception type of the exception conditions detected by the floating-point instructions. It also contains an overall summary bit indicating whether an exception occurred.

larger representable number.

- MAX – The largest noninfinite representable floating-point number.
- MIN – The smallest nonzero representable normalized floating-point number.

For VAX floating-point operations, two rounding modes are provided and are specified in each instruction:

- Normal rounding (biased)
  - Maps the true result to the nearest of two representable results, with true results exactly halfway between mapped to the larger in absolute value. (Sometimes referred to as biased rounding away from zero.)
  - Maps true results ≥ MAX + 1/2 LSB in magnitude to an overflow
  - Maps true results < MIN - 1/2 LSB in magnitude to an underflow
- Chopped rounding
  - Maps the true result to the smaller in magnitude of two surrounding representable results
  - Maps true results ≥ MAX + 1 LSB in magnitude to an overflow
  - Maps true results < MIN in magnitude to an underflow

For IEEE floating-point operations, four rounding modes are provided:

- Normal rounding (unbiased round to nearest)
  - Maps the true result to the nearest of two representable results, with true results exactly halfway between mapped to the one whose fraction ends in 0. (Sometimes referred to as unbiased rounding to even.)
  - Maps true results ≥ MAX + 1/2 LSB in magnitude to an overflow
  - Maps true results < MIN - 1/2 LSB in magnitude to an underflow
- Rounding toward minus infinity
  - Maps the true results to the smaller of two surrounding representable results
  - Maps true results > MAX in magnitude to an overflow
  - Maps positive true results < +MIN to an underflow
  - Maps negative true results ≥ -MIN + 1 LSB to an underflow
- Chopped rounding (round toward zero)
  - Maps the true result to the smaller in magnitude of two surrounding representable results
  - Maps true results ≥ MAX + 1 LSB in magnitude to an overflow

4.1.3 Floating-Point Exceptions

Six exception conditions can result from the use of floating-point instructions. All of the exceptions are signaled by an arithmetic exception trap. The exceptions are as follows:

- Invalid Operation – An invalid-operation exception is signaled if any operand of a floating-point instruction, other than `cmpt`*xx*, is nonfinite. (The `cmpt`*xx* instruction operates normally with plus and minus infinity.) This trap is always enabled. If this trap occurs, an unpredictable value is stored in the destination register.
- Division by Zero – A division-by-zero exception is taken if the numerator does not cause an invalid-operation trap and the denominator is zero. This trap is always enabled. If this trap occurs, an unpredictable value is stored in the destination register.
- Overflow – An overflow exception is signaled if the rounded result exceeds the largest finite number of the destination format. This trap is always enabled. If this trap occurs, an unpredictable value is stored in the destination register.
- Underflow – An underflow exception occurs if the rounded result is smaller than the smallest finite number of the destination format. This trap can be disabled. If this trap occurs, a true zero is always stored in the destination register.
- Inexact Result – An inexact-result exception occurs if the infinitely precise result differs from the rounded result. This trap can be disabled. If this trap occurs, the normal rounded result is still stored in the destination register.
- Integer Overflow – An integer-overflow exception occurs if the conversion from a floating-point or integer format to an integer format results in a value that is outside of the range of values representable by the destination format. This trap can be disabled. If this trap occurs, the true result is truncated to the number of bits in the destination format and stored in the destination register.

4.1.4 Floating-Point Rounding Modes

If a true result can be exactly represented in a floating-point format, all rounding modes map the true result to that value.

The following abbreviations are used in the descriptions of rounding modes provided in this section:

- LSB (least significant bit) – For a positive representable number, A, whose fraction is not all ones: A + 1 LSB is the next-larger representable number, and A + 1/2 LSB is exactly halfway between A and the next

Trapping Mode	Qualifier
VAX Trap Mode	
Imprecise, underflow disabled	(no modifier)
Imprecise, underflow enabled	u
Software, underflow disabled	s
Software, underflow enabled	su
VAX Convert-to-Integer Trap Mode	
Imprecise, integer overflow disabled	(no modifier)
Imprecise, integer overflow enabled	v
Software, integer overflow disabled	s
Software, integer overflow enabled	sv
IEEE Trap Mode	
Imprecise, underflow disabled, inexact disabled	(no modifier)
Imprecise, underflow enabled, inexact disabled	u
Software, underflow enabled, inexact disabled	su
Software, underflow enabled, inexact enabled	sui
IEEE Convert-to-integer Trap Mode	
Imprecise, integer overflow disabled, inexact disabled	(no modifier)
Imprecise, integer overflow enabled, inexact disabled	v
Software, integer overflow enabled, inexact disabled	sv
Software, integer overflow enabled, inexact enabled	svi

Table 4-1 lists the qualifier combinations that are supported by one or more of the individual instructions. The values in the Number column are referenced in subsequent sections to identify the combination of qualifiers accepted by the various instructions.

  - Maps nonzero true results < MIN in magnitude to an underflow
- Rounding toward plus infinity
  - Maps the true results to the larger of two surrounding representable results
  - Maps true results > MAX in magnitude to an overflow
  - Maps positive results ≤ +MIN - 1 LSB to an underflow
  - Maps negative true results > -MIN to an underflow

The first three of the IEEE rounding modes can be specified in the instruction. The last mode, rounding toward plus infinity, can be obtained by setting the floating-point control register (FPCR) to select it and then specifying dynamic rounding mode in the instruction.

Dynamic rounding mode uses the IEEE rounding mode selected by the FPCR and is described in Section 4.1.2. Dynamic rounding can be used with any of the IEEE rounding modes.

Alpha IEEE arithmetic does rounding before detecting overflow or underflow.

4.1.5 Floating-Point Instruction Qualifiers

Many of the floating-point instructions accept a qualifier that specifies rounding and trapping modes.

The following table lists the rounding mode qualifiers. See Section 4.1.4 for a detailed description of the rounding modes.

Rounding Mode	Qualifier
VAX Rounding Mode	
Normal rounding	(no modifier)
Chopped	c
IEEE Rounding Mode	
Normal rounding	(no modifier)
Plus infinity	d (ensure that the dyn field of the FPCR is 11)
Minus infinity	m
Chopped	c

The following table lists the trapping mode qualifiers. See Section 4.1.3 for a detailed description of the exceptions.

Table Notes:

a. In addition to the normal operands that can be specified with this instruction, relocation operands can also be specified (see Section 2.6.4).

Table 4-3 describes the operations performed by floating-point load and store instructions.

The load and store instructions are grouped by function. Refer to Table 4-2 for the instruction names.

Table 4-3: Load and Store Instruction Descriptions

Instruction	Description
Load Instructions (`ldf`, `ldg`, `lds`, `ldt`, `ldif`, `ldid`, `ldig`, `ldis`, `ldit`)	Load eight bytes (G_, D_, and T_floating formats) or four bytes (F_ and S_floating formats) from the specified effective address into the destination register. The address must be quadword aligned for 8-byte load instructions and longword aligned for 4-byte load instructions.
Store Instructions (`stf`, `stg`, `sts`, `stt`)	Store eight bytes (G_, D_, and T_floating formats) or four bytes (F_ and S_floating formats) from the source floating-point register into the specified effective address. The address must be quadword aligned for 8-byte store instructions and longword aligned for 4-byte store instructions.

4.3 Floating-Point Arithmetic Instructions

Floating-point arithmetic instructions perform arithmetic and logical operations on values in floating-point registers.

Table 4-4 lists the mnemonics and operands for instructions that perform floating-point arithmetic and logical operations. The table is divided into groups of functionally related instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

The Qualifiers column in Table 4-4 refers to one or more trap or rounding modes as specified in Table 4-1.

Table 4-1: Qualifier Combinations for Floating-Point Instructions

Number	Qualifiers
1	`c`, `u`, `uc`, `s`, `sc`, `su`, `suc`
2	`c`, `m`, `d`, `u`, `uc`, `um`, `ud`, `su`, `suc`, `sum`, `sud`, `sui`, `suic`, `suim`, `suid`
3	`s`
4	`su`
5	`sv`, `v`
6	`c`, `v`, `vc`, `s`, `sc`, `sv`, `svc`
7	`c`, `v`, `vc`, `sv`, `svc`, `svi`, `svic`, `d`, `vd`, `svd`, `svid`
8	`c`
9	`c`, `m`, `d`, `sui`, `suic`, `suim`, `suid`

4.2 Floating-Point Load and Store Instructions

Floating-point load and store instructions load values and move data between memory and floating-point registers.

Table 4-2 lists the mnemonics and operands for instructions that perform floating-point load and store operations. The table is divided into groups of functionally related instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 4-2: Load and Store Instruction Formats

Instruction	Mnemonic	Operands
Load F_floating	`ldf`[a]	*d_reg*, *address*
Load G_floating (Load D_floating)	`ldg`[a]	
Load S_floating (Load Longword)	`lds`[a]	
Load T_floating (Load Quadword)	`ldt`[a]	
Load Immediate F_floating	`ldif`	*d_reg*, *val_expr*
Load Immediate D_floating	`ldid`	
Load Immediate G_floating	`ldig`	
Load Immediate S_floating (Load Longword)	`ldis`	
Load Immediate T_floating (Load Quadword)	`ldit`	
Store F_floating	`stf`[a]	*s_reg*, *address*
Store G_floating (Store D_floating)	`stg`[a]	
Store S_floating (Store Longword)	`sts`[a]	
Store T_floating (Store Quadword)	`stt`[a]	

Table 4-4: (continued)

Instruction	Mnemonic	Qualifiers	Operands
Convert Quadword to Longword	cvtql	5	{*s_reg, d_reg* / *d_reg/s_reg*}
Convert Longword to Quadword	cvtlq	–	
Convert G_floating to Quadword	cvtgq	6	
Convert T_floating to Quadword	cvttq	7	
Convert Quadword to F_floating	cvtqf	8	
Convert Quadword to G_floating	cvtqg	8	
Convert Quadword to S_floating	cvtqs	9	
Convert Quadword to T_floating	cvtqt	9	
Convert D_floating to G_floating	cvtdg	1	
Convert G_floating to D_floating	cvtgd	1	
Convert G_floating to F_floating	cvtgf	1	
Convert T_floating to S_floating	cvtts	2	
Convert S_floating to T_floating	cvtst	3	

Table 4-5 describes the operations performed by floating-point load and store instructions. The arithmetic instructions are grouped by function. Refer to Table 4-4 for the instruction names.

Table 4-5: Arithmetic Instruction Descriptions

Instruction	Description
Clear Instruction (fclr)	Clear the destination register.
Absolute Value Instruction (fabs)	Compute the absolute value of the contents of the source register and put the floating-point result in the destination register.

Table 4-4: Arithmetic Instruction Formats

Instruction	Mnemonic	Qualifiers	Operands
Floating Clear	fclr	–	*d_reg*
Floating Absolute Value	fabs	–	{*s_reg, d_reg* / *d_reg/s_reg*}
Floating Negate	fneg	–	
Negate F_floating	negf	3	
Negate G_floating	negg	3	
Negate S_floating	negs	4	
Negate T_floating	negt	4	
Add F_floating	addf	1	{*s_reg1, s_reg2, d_reg* / *d_reg/s_reg1, s_reg2*}
Add G_floating	addg	1	
Add S_floating	adds	2	
Add T_floating	addt	2	
Divide F_floating	divf	1	
Divide G_floating	divg	1	
Divide S_floating	divs	2	
Divide T_floating	divt	2	
Multiply F_floating	mulf	1	
Multiply G_floating	mulg	1	
Multiply S_floating	muls	2	
Multiply T_floating	mult	2	
Subtract F_floating	subf	1	
Subtract G_floating	subg	1	
Subtract S_floating	subs	2	
Subtract T_floating	subt	2	

Table 4-5: (continued)

Instruction	Description
Conversion Between Floating-Point Formats Instructions (cvtdg, cvtgd, cvtgf, cvtts, cvtst)	Convert the contents of *s_reg* to the specified precision, round according to the rounding mode, and put the result in *d_reg*. If an overflow occurs, an unpredictable value is stored in *d_reg* and a floating-point trap occurs.

4.4 Floating-Point Relational Instructions

Floating-point relational instructions compare two floating-point values.

Table 4-6 lists the mnemonics and operands for instructions that perform floating-point relational operations. Each of the instructions can take an operand in any of the forms shown.

The Qualifiers column in Table 4-6 refers to one or more trap or rounding modes as specified in Table 4-1.

Table 4-6: Relational Instruction Formats

Instruction	Mnemonic	Qualifiers	Operands
Compare G_floating Equal	cmpgeq	3	{ *s_reg1, s_reg2, d_reg* / *d_reg/s_reg1, s_reg2* }
Compare G_floating Less Than	cmpglt	3	
Compare G_floating Less Than or Equal	cmpgle	3	
Compare T_floating Equal	cmpteq	4	
Compare T_floating Less Than	cmptlt	4	
Compare T_floating Less Than or Equal	cmptle	4	
Compare T_floating Unordered	cmptun	4	

Table 4-7 describes the relational instructions supported by the assembler. The relational instructions are grouped by function. Refer to Table 4-6 for the instruction names.

Table 4-5: (continued)

Instruction	Description
Negate Instructions (fneg, negf, negg, negs, negt)	Compute the negative value of the contents of *s_reg* or *d_reg* and put the specified precision floating-point result in *d_reg*.
Add Instructions (addf, addg, adds, addt)	Add the contents of *s_reg* or *d_reg* to the contents of *s_reg2* and put the result in *d_reg*. When the sum of two operands is exactly zero, the sum has a positive sign for all rounding modes except round toward $-\infty$. For that rounding mode, the sum has a negative sign.
Divide Instructions (divf, divg, divs, divt)	Compute the quotient of two values. These instructions divide the contents of *s_reg1* or *d_reg* by the contents of *s_reg2* and put the result in *d_reg*. If the divisor is a zero, an error is signaled if the divide-by-zero exception is enabled.
Multiply Instructions (mulf, mulg, muls, mult)	Multiply the contents of *s_reg1* or *d_reg* with the contents of *s_reg2* and put the result in *d_reg*.
Subtract Instructions (subf, subg, subs, subt)	Subtract the contents of *s_reg2* from the contents of *s_reg1* or *d_reg* and put the result in *d_reg*. When the difference of two operands is exactly zero, the difference has a positive sign for all rounding modes except round toward $-\infty$. For that rounding mode, the sum has a negative sign.
Conversion Between Integer Formats Instructions (cvtql, cvtlq)	Convert the integer contents of *s_reg* to the specified integer format and put the result in *d_reg*. If an integer overflow occurs, the truncated result is stored in *d_reg* and, if enabled, an arithmetic trap occurs.
Conversion from Floating-Point to Integer Format Instructions (cvtgq, cvttq)	Convert the floating-point contents of *s_reg* to the specified integer format and put the result in *d_reg*. If an integer overflow occurs, the truncated result is stored in *d_reg* and, if enabled, an arithmetic trap occurs.
Conversion from Integer to Floating-Point Format Instructions (cvtqf, cvtqg, cvtqs, cvtqt)	Convert the integer contents of *s_reg* to the specified floating-point format and put the result in *d_reg*.

Table 4-8: (continued)

Instruction	Mnemonic	Operands
Copy Sign	cpys	{ *s_reg1, s_reg2, d_reg* / *d_reg/s_reg1, s_reg2* }
Copy Sign Negate	cpysn	
Copy Sign and Exponent	cpyse	
Move if Equal to Zero	fcmoveq	
Move if Not Equal to Zero	fcmovne	
Move if Less Than Zero	fcmovlt	
Move if Less Than or Equal to Zero	fcmovle	
Move if Greater Than Zero	fcmovgt	
Move if Greater Than or Equal to Zero	fcmovge	

Table 4-9 describes the operations performed by move instructions. The move instructions are grouped by function. Refer to Table 4-8 for the instruction names.

Table 4-9: Move Instruction Descriptions

Instruction	Description
Move Instruction (fmov)	Move the contents of *s_reg* to *d_reg*.
Copy Sign Instruction (cpys)	Fetch the sign bit of *s_reg1* or *d_reg*, combine it with the exponent and fraction of *s_reg2*, and copy the result to *d_reg*.
Copy Sign Negate Instruction (cpysn)	Fetch the sign bit of *s_reg1* or *d_reg*, complement it, combine it with the exponent and fraction of *s_reg2*, and copy the result to *d_reg*.
Copy Sign and Exponent Instruction (cpyse)	Fetch the sign and exponent of *s_reg1* or *d_reg*, combine them with the fraction of *s_reg2*, and copy the result to *d_reg*.
Move If Instructions (fcmoveq, fcmovne, fcmovlt, fcmovle, fcmovgt, fcmovge)	Compare the contents of *s_reg1* or *d_reg* against zero. If the specified condition is true, the contents of *s_reg2* is copied to *d_reg*; otherwise, *d_reg* is unchanged.

Table 4-7: Relational Instruction Descriptions

Instruction	Description
Compare Equal Instructions (cmpgeq, cmpteq)	Compare the contents of *s_reg1* with the contents of *s_reg2*. If *s_reg1* equals *s_reg2*, a nonzero value is written to the destination register; otherwise, a true zero value is written to the destination. Exceptions are not signaled for unordered values.
Compare Less Than Instructions (cmpglt, cmptlt)	Compare the contents of *s_reg1* with the contents of *s_reg2*. If *s_reg1* is less than *s_reg2*, a nonzero value is written to the destination register; otherwise, a true zero value is written to the destination. Exceptions are not signaled for unordered values.
Compare Less Than or Equal Instructions (cmpgle, cmptle)	Compare the contents of *s_reg1* with the contents of *s_reg2*. If *s_reg1* is less than or equal to *s_reg2*, a nonzero value is written to the destination register; otherwise, a true zero value is written to the destination. Exceptions are not signaled for unordered values.
Compare Unordered Instruction (cmptun)	Compare the contents of *s_reg1* with the contents of *s_reg2*. If either *s_reg1* or *s_reg2* is unordered, a nonzero value is written to the destination register; otherwise, a true zero value is written to the destination. Exceptions are not signaled for unordered values.

4.5 Floating-Point Move Instructions

Floating-point move instructions move data between floating-point registers.

Table 4-8 lists the mnemonics and operands for instructions that perform floating-point move operations. The table is divided into groups of functionally related instructions. The operands specified within a particular group apply to all of the instructions contained in that group.

Table 4-8: Move Instruction Formats

Instruction	Mnemonic	Operands
Floating Move	fmov	*s_reg,d_reg*

4.6 Floating-Point Control Instructions

Floating-point control instructions test floating-point registers and conditionally branch.

Table 4-10 lists the mnemonics and operands for instructions that perform floating-point control operations. The specified operands apply to all of the instructions listed in the table.

Table 4-10: Control Instruction Formats

Instruction	Mnemonic	Operands
Branch Equal to Zero	`fbeq`	*`s_reg,label`*
Branch Not Equal to Zero	`fbne`	
Branch Less Than Zero	`fblt`	
Branch Less Than or Equal to Zero	`fble`	
Branch Greater Than Zero	`fbgt`	
Branch Greater Than or Equal to Zero	`fbge`	

Table 4-11 describes the operations performed by control instructions. The control instructions are grouped by function. Refer to Table 4-10 for instruction names.

Table 4-11: Control Instruction Descriptions

Instruction	Description
Branch Instructions (`fbeq`, `fbne`, `fblt`, `fble`, `fbgt`, `fbge`)	The contents of the source register are compared with zero. If the specified relationship is true, a branch is made to the specified label.

4.7 Floating-Point Special-Purpose Instructions

Floating-point special-purpose instructions perform miscellaneous tasks.

Table 4-12 lists the mnemonics and operands for instructions that perform floating-point special-purpose operations.

Table 4-12: Special-Purpose Instruction Formats

Instruction	Mnemonic	Operands
Move from FP Control Register	`mf_fpcr`	*`d_reg`*
Move to FP Control Register	`mt_fpcr`	*`s_reg`*
No Operation	`fnop`	(none)

Table 4-13 describes the operations performed by floating-point special-purpose instructions.

Table 4-13: Control Register Instruction Descriptions

Instruction	Description
Move to FPCR Instruction (`mf_fpcr`)	Copy the value in the specified source register to the floating-point control register (FPCR).
Move from FPCR Instruction (`mt_fpcr`)	Copy the value in floating-point control register (FPCR) to the specified destination register.
No Operation Instruction (`fnop`)	This instruction has no effect on the machine state.

Table 5-1: (continued)

Category	Directives
Data Storage Directives	.ascii .asciiz .byte .comm .double .d_floating .extended .float .f_floating .gprel32 .g_floating .lcomm .lit4 .lit8 .long .quad .s_floating .t_floating .word .x_floating
Repeat Block Directives	.endr .repeat
Assembler Option Directive	.set
Procedure Attribute Directives	.edata .eflag .end .fmask .frame .mask .prologue .save_ra
Version Control Directive	.verstamp
Scheduling and Architecture Subset Directives	.arch .tune

Assembler Directives 5

Assembler directives are instructions to the assembler to perform various bookkeeping tasks, storage reservation, and other control functions. To distinquish them from other instructions, directive names begin with a period. Table 5-1 lists the assembler directives by category.

Table 5-1: Summary of Assembler Directives

Category	Directives
Compiler-Use-Only Directives	.bgnb .endb .file .gjsrlive .gjsrsaved .lab .livereg .loc .option .ugen .vreg
Location Control Directives	.align .data .rdata .sdata .space .text
Symbol Declaration Directives	.extern .globl .struct symbolic equate .weakext
Routine Entry Point Definition Directives	.aent .ent

.ascii *string* [, *string*] ...
Assembles each *string* from the list into successive locations. The `.ascii` directive does not pad the string with null characters. You must put quotation marks (") around each string. You can optionally use the backslash escape characters. For a list of the backslash characters, see Section 2.4.3.

.asciiz *string* [, *string*] ...
Assembles each *string* in the list into successive locations and adds a null character. You can optionally use the backslash escape characters. For a list of the backslash characters, see Section 2.4.3.

.bgnb *symno*
For use only by compilers. Sets the beginning of a language block. The `.bgnb` and `.endb` directives delimit the scope of a variable set. The scope can be an entire procedure, or it can be a nested scope (for example, a ''{}'' block in the C language). The symbol number *symno* refers to a dense number in a `.T` file (symbol table). For an explanation of `.T` files, see Chapter 8.

.byte *expression1* [,*expression2*] [*expressionN*]
Truncates the values of the expressions specified in the comma-separated list to 8-bit values, and assembles the values in successive locations. The values of the expressions must be absolute.

The operands for the `.byte` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is an 8-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

.comm *name, expression*
Unless defined elsewhere, *name* becomes a global common symbol at the head of a block of at least *expression* bytes of storage. The linker overlays like-named common blocks, using the expression value of the largest block as the byte size of the overlay.

.data
Directs the assembler to add all subsequent data to the `.data` section.

.d_floating *expression1* [,*expression2*] [*expressionN*]
Initializes memory to double-precision (64-bit) VAX D_floating numbers. The values of the expressions must be absolute.

The operands for the `.d_floating` directive can optionally have the following form:

The following list contains descriptions of the assembly directives (in alphabetical order):

.aent *name* [,*symno*]
Sets an alternate entry point for the current procedure. Use this information when you want to generate information for the debugger. This directive must appear between a pair of `.ent` and `.end` directives. (The optional *symno* is for compiler use only. It refers to a dense number in a `.T` file (symbol table).)

.alias *reg1, reg2*
Indicates that memory referenced through the two registers will overlap. The compiler uses this form to improve instruction scheduling.

.align *expression*
Sets low-order bits in the location counter to zero. The value of *expression* establishes the number of bits to be set to zero. The maximum value for *expression* is four (which produces octaword alignment).

If the `.align` directive advances the location counter, the assembler fills the skipped bytes with zeros in data sections and `nop` instructions in text sections.

Normally, the `.word`, `.long`, `.quad`, `.float`, `.double`, `.extended`, `.d_floating`, `.f_floating`, `.g_floating`, `.s_floating`, `.t_floating`, and `.x_floating` directives automatically align their data appropriately. For example, `.word` does an implicit `.align 1`, and `.double` does an implicit `.align 3`.

You can disable the automatic alignment feature with `.align 0`. The assembler reinstates automatic alignment at the next `.text`, `.data`, `.rdata`, or `.sdata` directive that it encounters.

Labels immediately preceding an automatic or explicit alignment are also realigned. For example,

```
foo: .align 3
     .word 0
```

is the same as

```
     .align 3
foo: .word 0
```

.arch *model*
Specifies the version of the Alpha architecture that the Assembler is to generate instructions for. The valid values for *model* are identical to those you can specify with the `-arch` flag on the `cc` command line. See `cc`(1) for details.

directive sets the end of a procedure.

The *lex-level* operand indicates the number of procedures that statically surround the current procedure. This operand is only informational. It does not affect the assembly process; the assembler ignores it.

.err
For use only by compilers. Signals an error. Any compiler front-end that detects an error condition puts this directive in the input stream. When the assembler encounters a `.err` directive, it quietly ceases to assemble the source file. This prevents the assembler from continuing to process a program that is incorrect.

.extended *expression1* [,*expression2*] [*expressionN*]
Synonym for `.x_floating`.

.extern *name* [*number*]
Indicates that the specified symbol is global and external; that is, the symbol is defined in another object module and cannot be defined until link time. The *name* operand is a global undefined symbol and *number* is the expected size of the external object.

.f_floating *expression1* [,*expression2*] [*expressionN*]
Initializes memory to single-precision (32-bit) VAX F_floating numbers. The values of the expressions must be absolute.

The operands for the `.f_floating` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 32-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.f_floating` directive automatically aligns its data and preceding labels on a longword boundary. You can disable this feature by using the `.align 0` directive.

.file *file_number file_name_string*
For use only by compilers. Specifies the source file from which the assembly instructions that follow originated. This directive causes the assembler to stop generating line numbers that are used by the debugger. A subsequent `.loc` directive causes the assembler to resume generating line numbers.

.float *expression1* [,*expression2*] [*expressionN*]
Synonym for `.s_floating`.

expressionVal [: *expressionRep*]

The *expressionVal* is a 64-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.d_floating` directive automatically aligns its data and any preceding labels on a double-word boundary. You can disable this feature with the `.align 0` directive .

.double *expression1* [,*expression2*] [*expressionN*]
Synonym for `.t_floating`.

.edata 0
.edata 1 *lang-handler relocatable-expression*
.edata 2 *lang-handler constant-expression*
Marks data related to exception handling.

If *flag* is zero, the assembler adds all subsequent data to the `.xdata` section.

If *flag* is 1 or 2, the assembler creates a function table entry for the next `.ent` directive. The function table entry contains the language-specific handler (*lang-handler*) and data (*relocatable-expression* or *constant-expression*).

.eflag *flags*
Encodes exception-related flags to be stored in the `PDSC_RPD_FLAGS` field of the procedure's run-time procedure descriptor. Refer to the *Calling Standard for Alpha Systems* for a description of the individual flags.

.end [*proc_name*]
Sets the end of a procedure. The `.ent` directive sets the beginning of a procedure. Use the `.ent` and `.end` directives when you want to generate information for the debugger.

.endb *symno*
Sets the end of a language block. (See the description of the `.bgnb` directive for details. The `.bgnb` directive sets the beginning of a language block.)

.endr
Signals the end of a repeat block. The `.repeat` directive starts a repeat block.

.ent *proc_name* [*lex-level*]
Sets the beginning of the procedure *proc_name*. Use this directive when you want to generate information for the debugger. The `.end`

.gjsrsaved
For use only by compilers. Sets the masks that define the registers whose values are preserved during a procedure call. See Table 6-1 and Table 6-2 for the default for integer and floating-point saved registers.

.globl *name*
Identifies *name* as an external symbol. If the name is otherwise defined (for example, by its appearance as a label), the assembler exports the symbol; otherwise, it imports the symbol. In general, the assembler imports undefined symbols; that is, it gives them the UNIX storage class ''global undefined'' and requires the linker to resolve them.

.gprel32 *address1*[, *address2*] [,*addressN*]
Truncates the signed displacement between the global pointer value and the addresses specified in the comma-separated list to 32-bit values, and assembles the values in successive locations.

The operands for the `.gprel32` directive can optionally have the following form:

addressVal [: *addressRep*]

The *addressVal* is the address value. The optional *addressRep* is a non-negative expression that specifies how many times to replicate the value of *addressVal*. The expression value (*addressVal*) and repetition count (*addressRep*) must be absolute.

The `.gprel32` directive automatically aligns its data and preceding labels on a longword boundary. You can disable this feature with the `.align 0` directive.

.gretlive
For use by compilers. Sets the default masks for live registers before a procedure's return (a `ret` instruction).

.lab *label_name*
For use only by compilers. Associates a named label with the current location in the program text.

.lcomm *name*, *expression*
Gives the named symbol (*name*) a data type of `bss`. The assembler allocates the named symbol to the `bss` area, and the expression defines the named symbol's length. If a `.globl` directive also specifies the name, the assembler allocates the named symbol to external `bss`.

The assembler puts `bss` symbols in one of two `bss` areas. If the defined size is less than or equal to the size specified by the assembler or compiler's `-G` command line option, the assembler puts the symbols in the `sbss` area.

.fmask *mask offset*
Sets a mask with a bit turned on for each floating-point register that the current routine saved. The least-significant bit corresponds to register `$f0`. The *offset* is the distance in bytes from the virtual frame pointer to where the floating-point registers are saved.

You must use `.ent` before `.fmask`, and you can use only one `.fmask` for each `.ent`. Space should be allocated for those registers specified in the `.fmask`.

.frame *frame-register frame-size return_pc-register* [*local_offset*]
Describes a stack frame. The first register is the frame register, *frame-size* is the size of the stack frame, that is, the number of bytes between the frame register and the virtual frame pointer. The second register specifies the register that contains the return address. The *local_offset* parameter, which is for use only by compilers, specifies the number of bytes between the virtual frame pointer and the local variables.

You must use `.ent` before `.frame`, and you can use only one `.frame` for each `.ent`. No stack traces can be done in the debugger without the `.frame` directive.

.g_floating *expression1* [,*expression2*] [*expressionN*]
Initializes memory to double-precision (64-bit) VAX G_floating numbers. The values of the expressions must be absolute.

The operands for the `.g_floating` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 64-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.g_floating` directive automatically aligns its data and any preceding labels on a quadword boundary. You can disable this feature with the `.align 0` directive.

.gjsrlive
For use only by compilers. Sets the default masks for live registers before a procedure call (a `bsr` or `jsr` instruction).

list to 32-bit values, and assembles the values in successive locations. The values of the expression can be relocatable.

The operands for the `.long` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 32-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.long` directive automatically aligns its data and preceding labels on a longword boundary. You can disable this feature with the `.align 0` directive.

.mask *mask, offset*
Sets a mask with a bit turned on for each general-purpose register that the current routine saved. The least significant bit corresponds to register `$0`. The *offset* is the distance in bytes from the virtual frame pointer to where the registers are saved.

You must use `.ent` before `.mask`, and you can use only one `.mask` for each `.ent`. Space should be allocated for those registers specified in the `.mask`.

.noalias *reg1, reg2*
Informs the assembler that *reg1* and *reg2* will never point to the same memory location when they are used as indexed registers. The assembler uses this as a hint to make more liberal assumptions about resource dependency in the program.

.option *options*
For use only by compilers. Informs the assembler that certain options were in effect during compilation. For example, these options can limit the assembler's freedom to perform branch optimizations.

.prologue *flag*
Marks the end of the prologue section of a procedure.

A *flag* of zero indicates that the procedure does not use `$gp`; the caller does not need to set up `$pv` prior to calling the procedure or restore `$gp` on return from the procedure.

A *flag* of one indicates that the procedure does use `$gp`; the caller must set up `$pv` prior to calling the procedure and restore `$gp` on return from the procedure.

If *flag* is not specified, the behavior is as if a value of one was specified.

.lit4
Allows 4-byte constants to be generated and placed in the `lit4` section. This directive is only valid for `.long` (with non-relocatable expressions), `.f_floating`, `.float`, and `.s_floating`.

.lit8
Allows 8-byte constants to be generated and placed in the `lit4` section. This directive is only valid for `.quad` (with non-relocatable expressions), `.d_floating`, `.g_floating`, `.double`, and `.t_floating`.

.livereg *int_bitmask fp_bitmask*
For use only by compilers. Affects the next jump instruction even if it is not the successive instruction. By default, external `br` instructions and `jmp` instructions are treated as external calls; that is; all registers are assumed to be live. The `.livereg` directive cannot appear before an external `br` instruction because it will affect the next `ret`, `jsr`, `bsr`, `jmp`, or `call_pal callsys` instruction instead of the `br` instruction. The directive cannot be used before a `call_pal bpt` instruction. For `call_pal bpt` instructions, the assembler also assumes that all registers are live.

To avoid unsafe optimizations by the reorganizer, `.livereg` notes to the assembler those registers that are live before a jump. The directive `.livereg` takes two arguments, *int_bitmask* and *fp_bitmask*, which are 32-bit bitmasks with a bit turned on for each register that is live before a jump. The most significant bit corresponds to register `$0` (which is opposite to that used in other assembly directives, for example, `.mask` and `.fmask`). The first bitmap indicates live integer registers and the second indicates live floating-point registers.

When present, this directive causes the assembler to be more conservative and to preserve the indicated register contents. If omitted, the assembler assumes the default masks. The `.livereg` directive can be coded before any of the following instructions: `bsr`, `jsr`, `ret`, `jmp`, and `call_pal callsys`.

.loc *file_number line_number*
For use only by compilers. Specifies the source file and the line within it that corresponds to the assembly instructions that follow. The assembler ignores the file number when this directive appears in the assembly source file. Then, the assembler assumes that the directive refers to the most recent `.file` directive. When a `.loc` directive appears in the binary assembly language `.G` file, the file number is a dense number pointing at a file symbol in the symbol table `.T` file. For more information about `.G` and `.T` files, see Chapter 8.

.long *expression1* [,*expression2*] [*expressionN*]
Truncates the values of the expressions specified in the comma-separated

violates the hardware pipeline constraints, the assembler issues a warning message.

- The `macro` option permits the assembler to generate multiple machine-language instructions from a single assembler instruction.

  The `nomacro` option causes the assembler to print a warning whenever an assembler operation generates more than one machine-language instruction. You must select the `noreorder` option before using the `nomacro` option; otherwise, an error results.

- The `at` option permits the assembler to use the `$at` register for macros, but generates warnings if the source program uses `$at`.

  When you use the `noat` option and an assembler operation requires the `$at` register, the assembler issues a warning message; however, the `noat` option does permit source programs to use `$at` without warnings being issued.

- The `nomove` options instructs the assembler to mark each subsequent instruction so that it cannot be moved during reorganization. The assembler can still move instructions from below the `nomove` region to above the region or vice versa. The `nomove` option has part of the effect of the ''volatile'' C declaration; it prevents otherwise independent loads or stores from occurring in a different order than intended.

  The `move` option cancels the effect of `nomove`.

- The `volatile` option instructs the assembler that subsequent load and store instructions may not be moved in relation to each other or removed by redundant load removal or other optimization. The `volatile` option is less restrictive than `noreorder`; it allows the assembler to move other instructions (that is, instructions other than load and store instructions) without restrictions.

  The `novolatile` option cancels the effect of the `volatile` option.

.s_floating *expression1* [,*expression2*] [*expressionN*]
Initializes memory to single-precision (32-bit) IEEE floating-point numbers. The values of the expressions must be absolute.

The operands for the `.s_floating` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 32-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count

.quad *expression1* [,*expression2*] [*expressionN*]
Truncates the values of the expressions specified in the comma-separated list to 64-bit values, and assembles the values in successive locations. The values of the expressions can be relocatable.

The operands for the `.quad` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 64-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.quad` directive automatically aligns its data and preceding labels on a quadword boundary. You can disable this feature with the `.align 0` directive.

.rdata
Instructs the assembler to add subsequent data into the `.rdata` section.

.repeat *expression*
Repeats all instructions or data between the `.repeat` and `.endr` directives. The *expression* defines how many times the enclosing text and data repeats. With the `.repeat` directive, you cannot use labels, branch instructions, or values that require relocation in the block. Also note that nesting `.repeat` directives is not allowed.

.save_ra *saved_ra_register*
Specifies that *saved_ra_register* is the register in which the return address is saved during the execution of the procedure. If `.save_ra` is not used, the saved return address register is assumed to be the same as the *return_pc_register* argument of the `frame` directive. The `.save_ra` directive is valid only for register frame procedures.

.sdata
Instructs the assembler to add subsequent data to the `.sdata` section.

.set *option*
Instructs the assembler to enable or disable certain options. The assembler has the following default options: `reorder`, `macro`, `move`, `novolatile`, and `at`. Only one option can be specified by a single `.set` directive. The effects of the options are as follows:

- The `reorder` option permits the assembler to reorder machine-language instructions to improve performance.

  The `noreorder` option prevents the assembler from reordering machine-language instructions. If a machine-language instruction

directive, the generated code will run correctly on all implementations of the Alpha architecture. The valid values for `option` are identical to those you can specify with the `-arch` flag on the `cc` command line. See `cc`(1) for details.

.ugen
For use only by compilers. Informs the assembler that the source was generated by the code generator.

.verstamp *major minor*
Specifies the major and minor version numbers; for example, version 0.15 would be `.verstamp 0 15`.

.vreg *register offset symno*
For use only by compilers. Describes a register variable by giving the offset from the virtual frame pointer and the symbol number *symno* (the dense number) of the surrounding procedure.

.weakext *name1* [,*name2*]
Sets *name1* to be a weak symbol during linking. If *name2* is specified, *name1* is created as a weak symbol with the same value as *name2*. Weak symbols can be silently redefined at link time.

.word *expression1* [,*expression2*] [*expressionN*]
Truncates the values of the expressions specified in the comma-separated list to 16-bit values, and assembles the values in successive locations. The values of the expressions must be absolute.

The operands for the `.word` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 16-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.word` directive automatically aligns its data and preceding labels on a word boundary. You can disable this feature with the `.align 0` directive.

.x_floating *expression1* [,*expression2*] [*expressionN*]
Initializes memory to quad-precision (128-bit) IEEE floating-point numbers. The values of the expressions must be absolute.

The operands for the `.x_floating` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 128-bit value. The optional

(*expressionRep*) must be absolute.

The `.s_floating` directive automatically aligns its data and preceding labels on a longword boundary. You can disable this feature with the `.align 0` directive.

.space *expression*
Advances the location counter by the number of bytes specified by the value of *expression*. The assembler fills the space with zeros.

.struct *expression*
Permits you to lay out a structure using labels plus directives such as `.word` or `.byte`. It ends at the next segment directive (`.data`, `.text`, and so forth). It does not emit any code or data, but defines the labels within it to have values that are the sum of *expression* plus their offsets from the `.struct` itself.

symbolic equate
Takes one of the following forms: *name = expression* or *name = register*. You must define the name only once in the assembly, and you cannot redefine the name. The expression must be computable when you assemble the program, and the expression must involve only operators, constants, or equated symbols. You can use the name as a constant in any later statement.

.text
Instructs the assembler to add subsequent code to the `.text` section. (This is the default.)

.t_floating *expression1* [,*expression2*] [*expressionN*]
Initializes memory to double-precision (64-bit) IEEE floating-point numbers. The values of the expressions must be absolute.

The operands for the `.t_floating` directive can optionally have the following form:

expressionVal [: *expressionRep*]

The *expressionVal* is a 64-bit value. The optional *expressionRep* is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.t_floating` directive automatically aligns its data and any preceding labels on a quadword boundary. You can disable this feature with the `.align 0` directive.

.tune *option*
Selects processor-specific instruction tuning for various implementations of the Alpha architecture. Regardless of the setting of the `.arch`

expressionRep is a non-negative expression that specifies how many times to replicate the value of *expressionVal*. The expression value (*expressionVal*) and repetition count (*expressionRep*) must be absolute.

The `.x_floating` directive automatically aligns its data and preceding labels on an octaword boundary. You can disable this feature with the `.align 0` directive.

- The C compiler and the debugger observe certain implicit rules instead of communicating by means of instructions or data at execution time. For example, the debugger looks at information placed in the symbol table by a `.frame` directive at compilation time. This technique enables the debugger to tolerate the lack of a register containing a frame pointer at execution time.
- The linker performs code optimizations based on information that is not available at compile time. For example, the linker can, in some cases, replace the general calling sequence to a procedure with a single instruction.

6.2 Program Model

A program consists of an executable image and zero or more shared images. Each image has an independent text and data area.

Each data segment contains a global offset table (GOT), which contains address constants for procedures and data locations that the text segment references. The GOT provides the means to access arbitrary 64-bit addresses and allows the text segment to be position independent.

The size of the GOT is limited only by the maximum image size. However, because only 64KB can be addressed by a single memory-format instruction, the GOT is segmented into one or more sections of 64KB or less.

In addition to providing efficient access to the GOT, the `gp` register is also used to access global data within ±2GB of the global pointer. This area of memory is known as the global data area.

A static executable image is not a special case in the program model. It is simply an executable image that uses no shared libraries. However, it is possible for the linker to perform code optimizations. In particular, if a static executable image's GOT is less than or equal to 64KB (that is, has only one segment), the code to load, save, and restore the `gp` register is not necessary because all procedures will access the same GOT segment.

6.3 General Coding Concerns

This section describes three general areas of concern to the assembly language programmer:

- Usable and restricted registers
- Control of section and location counters with directives
- Stack frame requirements on entering and exiting a procedure

Another general coding consideration is the use of data structures to communicate between high-level language procedures and assembly

Programming Considerations 6

This chapter gives rules and examples to follow when creating an assembly-language program.

The chapter addresses the following topics:

- Why your assembly programs should use the calling conventions observed by the C compiler. (Section 6.1)
- An overview of the composition of executable programs. (Section 6.2)
- The use of registers, section and location counters, and stack frames. (Section 6.3)
- A technique for coding an interface between an assembly-language procedure and a procedure written in a high-level language. (Section 6.4)
- The default memory-allocation scheme used by the Alpha system. (Section 6.5)

This chapter does not address coding issues related to performance or optimization. See Appendix A of the *Alpha Architecture Reference Manual* for information on how to optimize assembly code.

6.1 Calling Conventions

When you write assembly-language procedures, you should use the same calling conventions that the C compiler observes. The reasons for using the same calling conventions are as follows:

- Often your code must interact with compiler-generated code, accepting and returning arguments or accessing shared global data.
- The symbolic debugger gives better assistance in debugging programs that use standard calling conventions.

The conventions observed by the Digital UNIX compiler system are more complicated than those of some other compiler systems, mostly to enhance the speed of each procedure call. Specifically:

- The C compiler uses the full, general calling sequence only when necessary; whenever possible, it omits unneeded portions of the sequence. For example, the C compiler does not use a register as a frame pointer if it is unnecessary to do so.

Table 6-1: (continued)

Register Name	Software Name (from regdef.h)	Use
$29 or $gp	gp	Contains the global pointer. Not preserved across procedure calls.
$30 or $sp	sp	Contains the stack pointer. Preserved across procedure calls.
$31	zero	Always has the value 0.

Table 6-2: Floating-Point Registers

Register Name	Use
$f0–f1	Used to hold floating-point type function results ($f0) and complex type function results ($f0 has the real part, $f1 has the imaginary part). Not preserved across procedure calls.
$f2–f9	Saved registers. Preserved across procedure calls.
$f10–f15	Temporary registers used for expression evaluation. Not preserved across procedure calls.
$f16–f21	Used to pass the first six single- or double-precision actual arguments. Not preserved across procedure calls.
$f22–f30	Temporary registers used for expression evaluations. Not preserved across procedure calls.
$f31	Always has the value 0.0.

6.3.2 Using Directives to Control Sections and Location Counters

Assembled code and data are stored in the object file sections shown in Figure 6-1. Each section has an implicit location counter that begins at zero and increments by one for each byte assembled in the section. Location control directives (.align, .data, .rconst, .rdata, .sdata, .space, and .text) can be used to control what is stored in the various sections and to adjust location counters.

The assembler always generates the text section before other sections. Additions to the text section are done in 4-byte units.

The bss (block started by symbol) section holds data items (usually variables) that are initialized to zero. If a .lcomm directive defines a variable, the

procedures. In most cases, this communication is handled by means of simple variables: pointers, integers, Booleans, and single- and double-precision real numbers. Describing the details of the various high-level data structures that can also be used – arrays, records, sets, and so on – is beyond the scope of this manual.

6.3.1 Register Use

The main processor has 32 64-bit integer registers. The uses and restrictions of these registers are described in Table 6-1.

The floating-point co-processor has 32 floating-point registers. Each register can hold either a single-precision (32 bit) or double-precision (64 bit) value. Refer to Table 6-2 for details.

Table 6-1: Integer Registers

Register Name	Software Name (from regdef.h)	Use
$0	v0	Used for expression evaluations and to hold the integer function results. Not preserved across procedure calls.
$1–8	t0–t7	Temporary registers used for expression evaluations. Not preserved across procedure calls.
$9–14	s0–s5	Saved registers. Preserved across procedure calls.
$15 or $fp	s6 or fp	Contains the frame pointer (if needed); otherwise, a saved register.
$16–21	a0–a5	Used to pass the first six integer type actual arguments. Not preserved across procedure calls.
$22–25	t8–t11	Temporary registers used for expression evaluations. Not preserved across procedure calls.
$26	ra	Contains the return address. Preserved across procedure calls.
$27	pv or t12	Contains the procedure value and used for expression evaluation. Not preserved across procedure calls.
$28 or $at	AT	Reserved for the assembler. Not preserved across procedure calls.

6.3.3 The Stack Frame

The C compiler classifies each procedure into one of the following categories:

- *Nonleaf procedures*. These procedures call other procedures.
- *Leaf procedures*. These procedures do not themselves call other procedures. Leaf procedures are of two types: those that require stack storage for local variables and those that do not.

You must decide the procedure category before determining the calling sequence.

To write a program with proper stack frame usage and debugging capabilities, you should observe the conventions presented in the following list of steps. Steps 1 through 6 describe the code you must provide at the beginning of a procedure, step 7 describes how to pass parameters, and steps 8 through 12 describe the code you must provide at the end of a procedure:

1. Regardless of the type of procedure, you should include a `.ent` directive and an entry label for the procedure:

```
        .ent    procedure_name
procedure_name:
```

   The `.ent` directive generates information for the debugger, and the entry label is the procedure name.

2. If you are writing a procedure that references static storage, calls other procedures, uses constants greater than 31 bits in size, or uses floating constants, you must load the `$gp` register with the global pointer value for the procedure:

```
        ldgp    $gp,0($27)
```

   Register `$27` contains the procedure value (the address of this procedure as supplied by the caller).

3. If you are writing a leaf procedure that does not use the stack, skip to step 4. For a nonleaf procedure or a leaf procedure that uses the stack, you must adjust the stack size by allocating all of the stack space that the procedure requires:

```
        lda     $sp,-framesize($sp)
```

   The *framesize* operand is the size of frame required, in bytes, and must be a multiple of 16. You must allocate space on the stack for the following items:

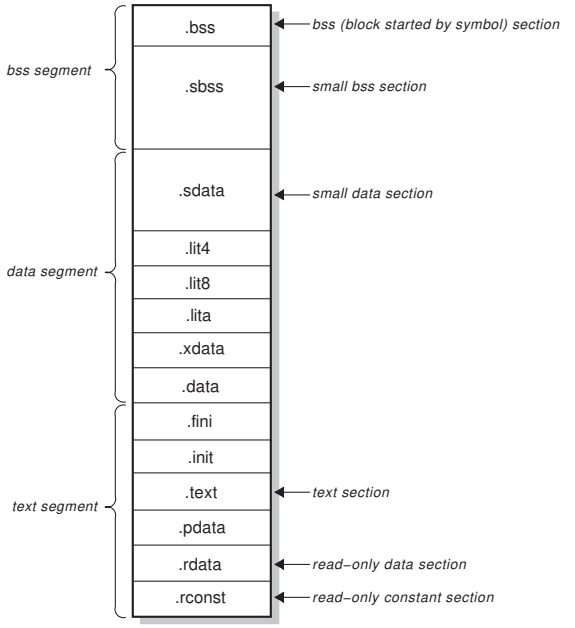
   - Local variables.
   - Saved general registers. Space should be allocated only for those registers saved. For nonleaf procedures, you must save register `$26`, which is used in the calls to other procedures from this procedure. If you use registers `$9` to `$15`, you must also save them.

assembler assigns that variable to either the `.bss` section or the `.sbss` (small bss) section, depending on the variable's size.

The default size for variables in the `.sbss` section is eight or fewer bytes. You can change the size using the `-G` compilation option for the C compiler or the assembler. Items smaller than or equal to the specified size go in the `.sbss` section. Items greater than the specified size go in the `.bss` section.

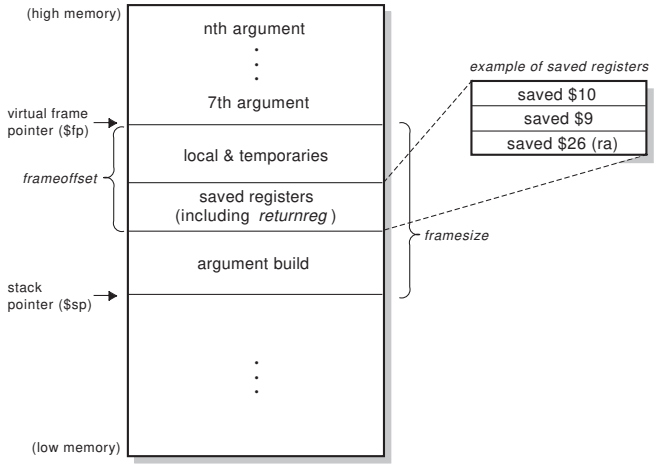
At run time, the `$gp` register points into the area of memory occupied by the `.lita` section. The `.lita` section is used to hold address literals for 64-bit addressing.

Figure 6-1: Sections and Location Counters for Nonshared Object Files



See Chapter 7 for more information on section data.

Figure 6-2: Stack Organization



The *returnreg* argument for the `.frame` directive specifies the register that contains the return address (usually register `$26`). These usual values may change if you use a varying stack pointer or are specifying a kernel trap procedure.

5. If the procedure is a leaf procedure that does not use the stack, skip to step 11. Otherwise, you must save the registers for which you allocated space in step 3.

   Saving the general registers requires the following operations:

   - Specify which registers are to be saved using the following `.mask` directive:

     ```
     .mask   bitmask,frameoffset
     ```

     The bit setting in *bitmask* indicate which registers are to be saved. For example, if register `$9` is to be saved, bit 9 in *bitmask* must be set to 1. The value for *frameoffset* is the offset (negative) from the virtual frame pointer to the start of the register save area.

   - Use the following `stq` instruction to save the registers specified in

   - Saved floating-point registers. Space should be allocated only for those registers saved. If you use registers `$f2` to `$f9`, you must also save them.
   - Procedure call argument area. You must allocate the maximum number of bytes for arguments of any procedure that you call from this procedure; this area does not include space for the first six arguments because they are always passed in registers.

Note

Once you have modified register `$sp`, you should not modify it again in the remainder of the procedure.

4. To generate information used by the debugger and exception handler, you must include a `.frame` directive:

   ```
   .frame  framereg,framesize,returnreg
   ```

   The virtual frame pointer does not have a register allocated for it. It consists of the *framereg* (`$sp`, in most cases) added to the *framesize* (see step 3). Figure 6-2 illustrates the stack components.

Table 6-3 summarizes the location of procedure arguments in the register or stack.

Table 6-3: Argument Locations

Argument Number	Integer Register	Floating-Point Register	Stack
1	$16 (a0)	$f16	
2	$17 (a1)	$f17	
3	$18 (a2)	$f18	
4	$19 (a3)	$f19	
5	$20 (a4)	$f20	
6	$21 (a5)	$f21	
7–*n*			0($sp)..(*n*–7)*8($sp)

8. On procedure exit, you must restore registers that were saved in step 5. To restore general purpose registers:

```
ldq     reg,framesize+frameoffset+N($sp)
```

   To restore the floating-point registers:

```
ldt     reg,framesize+frameoffset+N($sp)
```

   (Refer to step 5 for a discussion of the value of *N*.)

9. Get the return address:

```
ldq     $26,framesize+frameoffset($sp)
```

10. Clean up the stack:

```
lda     $sp,framesize($sp)
```

11. Return:

```
ret     $31,($26),1
```

12. End the procedure:

```
.end    procedurename
```

6.3.4 Examples

The examples in this section show procedures written in C and equivalent procedures written in assembly language.

Example 6-1 shows a nonleaf procedure. Notice that it creates a stack frame and saves its return address. It saves its return address because it must put a new return address into register $26 when it makes a procedure call.

the mask directive:

```
stq     reg,framesize+frameoffset+N($sp)
```

The value of *N* is the size of the argument build area for the first register and is incremented by 8 for each successive register. If the procedure is a nonleaf procedure, the return address is the first register to be saved. For example, a nonleaf procedure that saves register $9 and $10 would use the following stq instructions:

```
stq     $26,framesize+frameoffset($sp)
stq     $9,framesize+frameoffset+8($sp)
stq     $10,framesize+frameoffset+16($sp)
```

(Figure 6-2 illustrates the order in which the registers in the preceding example would be saved.)

Then, save any floating-point registers for which you allocated space in step 3:

```
.fmask  bitmask,frameoffset
stt     reg,framesize+frameoffset+N($sp)
```

Saving floating-point registers is identical to saving integer registers except you use the .fmask directive instead of .mask, and the storage operations involve single- or double-precision floating-point data. (The previous discussion about how to save integer registers applies here as well.)

6. The final step in creating the procedure's prologue is to mark its end as follows:

```
.prologue flag
```

   The *flag* is set to 1 if the prologue contains an ldgp instruction (see step 2); otherwise, it is set to 0.

7. This step describes parameter passing: how to access arguments passed into your procedure and how to pass arguments correctly to other procedures. For information on high-level language-specific constructs (call-by-name, call-by-value, string or structure passing), see the programmer's guides for the high-level languages used to write the procedures that interact with your program.

   General registers $16 to $21 and floating-point registers $f16 to $f21 are used for passing the first six arguments. All nonfloating-point arguments in the first six arguments are passed in general registers. All floating-point arguments in the first six arguments are passed in floating-point registers.

   Stack space is used for passing the seventh and subsequent arguments. The stack space allocated to each argument is an 8-byte multiple and is aligned on an 16-byte boundary.

Example 6-1: Nonleaf Procedure

```
int
nonleaf(i, j)
  int i, *j;
  {
  int abs();
  int temp;

  temp = i - *j;
  return abs(temp);
  }

        .globl  nonleaf
 #    1 int
 #    2 nonleaf(i, j)
 #    3   int i, *j;
 #    4   {
        .ent    nonleaf 2
nonleaf:
        ldgp    $gp, 0($27)
        lda     $sp, -16($sp)
        stq     $26, 0($sp)
        .mask   0x04000000, -16
        .frame  $sp, 16, $26, 0
        .prologue       1
        addl    $16, 0, $18
 #    5   int abs();
 #    6   int temp;
 #    7
 #    8   temp = i - *j;
        ldl     $1, 0($17)
        subl    $18, $1, $16
 #    9   return abs(temp);
        jsr     $26, abs
        ldgp    $gp, 0($26)
        ldq     $26, 0($sp)
        lda     $sp, 16($sp)
        ret     $31, ($26), 1
        .end    nonleaf
```

Example 6-2 shows a leaf procedure that does not require stack space for local variables. Notice that it does not create a stackframe and does not save a return address.

Example 6-2: Leaf Procedure Without Stack Space for Local Variables

```
int
leaf(p1, p2)
  int p1, p2;
  {
  return (p1 > p2) ? p1 : p2;
  }

        .globl  leaf
 #    1 leaf(p1, p2)
 #    2   int p1, p2;
 #    3   {
        .ent    leaf 2
leaf:
        ldgp    $gp, 0($27)
        .frame  $sp, 0, $26, 0
        .prologue       1
        addl    $16, 0, $16
        addl    $17, 0, $17
 #    4   return (p1 > p2) ? p1 : p2;
        bis     $17, $17, $0
        cmplt   $0, $16, $1
        cmovne  $1, $16, $0
        ret     $31, ($26), 1
        .end    leaf
```

Example 6-3 shows a leaf procedure that requires stack space for local variables. Notice that it creates a stack frame but does not save a return address.

Example 6-3: Leaf Procedure With Stack Space for Local Variables

```
int
leaf_storage(i)
  int i;
  {
  int a[16];
  int j;
  for (j = 0; j < 10; j++)
    a[j] = '0' + j;
  return a[i];
  }

        .globl  leaf_storage
 #    1 int
 #    2 leaf_storage(i)
 #    3   int i;
 #    4   {
        .ent    leaf_storage 2
```

- Study the assembly-language listing and then, using the code in the listing as a guideline, write your assembly-language code.

Section 6.4.1 and Section 6.4.2 describe techniques you can use to create interfaces between procedures written in assembly language and procedures written in a high-level language. The examples show what to look for in creating your interface. Details such as register numbers will vary according to the number, order, and data types of the arguments. In writing your particular interface, you should write and compile realistic examples of the code you want to write in assembly language.

6.4.1 Calling a High-Level Language Procedure

The following steps show an approach to use in writing an assembly-language procedure that calls `atof`(3), a procedure written in C that converts ASCII characters to numbers:

1. Write a C program that calls `atof`. Pass global variables instead of local variables; this makes them easy to recognize in the assembly-language version of the C program (and ensures that optimization does not remove any of the code on the grounds that it has no effect).

   The following C program is an example of a program that calls `atof`:

   ```
   char c[] = "3.1415";
   double d, atof();
   float f;
   caller()
     {
     d = atof(c);
     f = (float)atof(c);
     }
   ```

2. Compile the program using the following compiler options:

   ```
   cc -S -O caller.c
   ```

   The `-S` option causes the compiler to produce the assembly-language listing; the `-O` option, though not required, reduces the amount of code generated, making the listing easier to read.

3. After compilation, examine the file `caller.s`. The comments in the file show how the parameters are passed, the execution of the call, and how the returned values are retrieved:

   ```
           .globl  c
           .data
   c:
           .ascii  "3.1415\X00"
           .comm   d 8
           .comm   f 4
           .text
           .globl  caller
   ```

Example 6-3: (continued)

```
leaf_storage:
        ldgp    $gp, 0($27)
        lda     $sp, -80($sp)
        .frame  $sp, 80, $26, 0
        .prologue       1
        addl    $16, 0, $1
 #    5   int a[16];
 #    6   int j;
 #    7   for (j = 0; j < 10; j++)
        ldil    $2, 48
        stl     $2, 16($sp)
        ldil    $3, 49
        stl     $3, 20($sp)
        ldil    $0, 2
        lda     $16, 24($sp)
$32:
 #    8     a[j] = '0' + j;
        addl    $0, 48, $4
        stl     $4, 0($16)
        addl    $0, 49, $5
        stl     $5, 4($16)
        addl    $0, 50, $6
        stl     $6, 8($16)
        addl    $0, 51, $7
        stl     $7, 12($16)
        addl    $0, 4, $0
        addq    $16, 16, $16
        subq    $0, 10, $8
        bne     $8, $32
 #    9   return a[i];
        mull    $1, 4, $22
        addq    $22, $sp, $0
        ldl     $0, 16($0)
        lda     $sp, 80($sp)
        ret     $31, ($26), 1
        .end    leaf_storage
```

6.4 Developing Code for Procedure Calls

The rules and parameter requirements for passing control and exchanging data between procedures written in assembly language and procedures written in other languages are varied and complex. The simplest approach to coding an interface between an assembly procedure and a procedure written in a high-level language is to do the following:

- Use the high-level language to write a skeletal version of the procedure that you plan to code in assembly language.
- Compile the program using the `-S` option, which creates an assembly-language (`.s`) version of the compiled source file.

```
boolean global_b;

boolean callee(float *r, int i, str s)
  {
  global_r = *r;
  global_i = i;
  global_s[0] = s[0];
  return i == 3;
  }
```

2. Compile the program using the following compiler options:

   ```
   cc -S -O callee.c
   ```

   The `-S` option causes the compiler to produce the assembly-language listing; the `-O` option, though not required, reduces the amount of code generated, making the listing easier to read.

3. After compilation, examine the file `callee.s`. The comments in the file show how the parameters are passed, the execution of the call, and how the returned values are retrieved:

```
        .comm   global_r 4
        .comm   global_i 4
        .comm   global_s 10
        .comm   global_b 4
        .text
        .globl  callee
 #   10   {
        .ent    callee 2
callee:
        ldgp    $gp, 0($27)
        .frame  $sp, 0, $26, 0
        .prologue       1
        addl    $17, 0, $17
 #   11   global_r = *r;
        lds     $f10, 0($16)
        sts     $f10, global_r
 #   12   global_i = i;
        stl     $17, global_i
 #   13   global_s[0] = s[0];
        ldq_u   $1, 0($18)
        extbl   $1, $18, $1
        .set     noat
        lda     $28, global_s
        ldq_u   $2, 0($28)
        insbl   $1, $28, $3
        mskbl   $2, $28, $2
        bis     $2, $3, $2
        stq_u   $2, 0($28)
        .set     at
 #   14   return i == 3;
        cmpeq   $17, 3, $0
        ret     $31, ($26), 1
        .end    callee
```



```
 #    1 char c[] = "3.1415";
 #    2 double d, atof();
 #    3 float f;
 #    4 caller()
 #    5   {
        .ent    caller 2
caller:
        ldgp    $gp, 0($27)
        lda     $sp, -16($sp)
        stq     $26, 0($sp)
        .mask   0x04000000, -16
        .frame  $sp, 16, $26, 0
        .prologue       1
 #    6   d = atof(c);
        lda     $16, c
        jsr     $26, atof
        ldgp    $gp, 0($26)
        stt     $f0, d
 #    7   f = (float)atof(c);
        lda     $16, c
        jsr     $26, atof
        ldgp    $gp, 0($26)
        cvtts   $f0, $f10
        sts     $f10, f
 #    8   }
        ldq     $26, 0($sp)
        lda     $sp, 16($sp)
        ret     $31, ($26), 1
        .end    caller
```

6.4.2 Calling an Assembly-Language Procedure

The following steps show an approach to use in writing an assembly-language procedure that can be called by a procedure written in a high-level language:

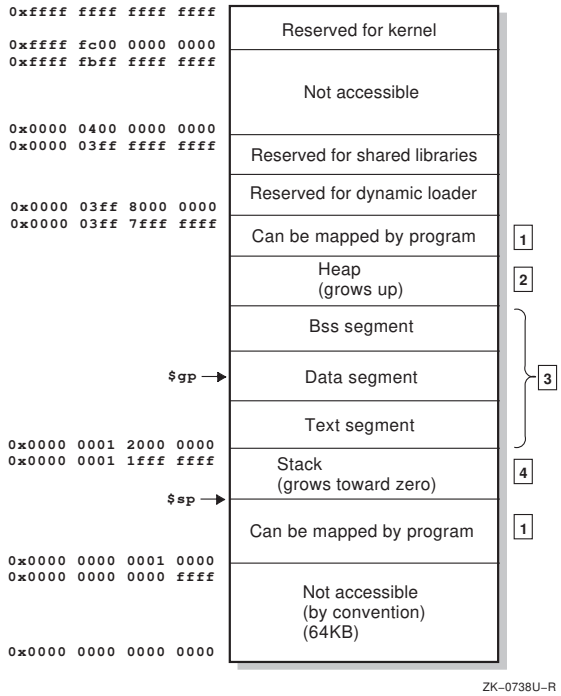
1. Using a high-level language, write a facsimile of the assembly-language procedure you want to call. In the body of the procedure, write statements that use the same arguments you intend to use in the final assembly-language procedure. Copy the arguments to global variables instead of local variables to make it easy for you to read the resulting assembly-language listing.

   The following C program is a facsimile of the assembly-language program:

   ```
   typedef char str[10];
   typedef int boolean;

   float global_r;
   int global_i;
   str global_s;
   ```

Figure 6-3: Default Layout of Memory (User Program View)



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1. This area is not allocated until a user requests it. (The same behavior is observed in System V shared memory regions.)
2. The heap is reserved for `sbrk` and `brk` system calls, and it is not always present.
3. See Section 7.2.4 for details on the sections contained within the bss, data, and text segments.
4. The stack is used for local data in C programs.

6.5 Memory Allocation

The default memory allocation scheme used by the Alpha system gives every process two storage areas that can grow without bounds. A process exceeds virtual storage only when the sum of the two areas exceeds virtual storage space. By default, the linker and assembler use the scheme shown in Figure 6-3.

- The linker strips the entire symbol table from the object file when the user specifies the `-s` option (strip) for the link-edit phase.

Any new assembler or linker designed to work with the compiler system should lay out the object file sections in the order shown in Figure 7-1. The linker can process object files that are ordered differently, but performance may be degraded.

The standard System V COFF (common object file format) differs from the Digital UNIX compiler system format in the following ways:

- The file header definition is based on the System V header file `filehdr.h` with the following modifications:
  - The symbol table file pointer and the number of symbol table entries now specify the file pointer and the size of the symbolic header, respectively.
  - All tables that specify symbolic information have their file pointers and number of entries in the symbolic header. See Chapter 8 for information about the symbolic header.
- The definition of the optional header has the same format as specified in the System V header file `aouthdr.h`, except the following fields have been added: `bldrev`, `bss_start`, `gprmask`, `fprmask`, and `gp_value` (see Table 7-4).
- The definition of the section header has the same format as the System V header file `scnhdr.h`, except the line number fields are used for global pointers (see Table 7-6).

The definition of the section relocation information is similar to UNIX 4.3 BSD, which has local relocation types. Section 7.2.5 provides information on differences between local and external relocation entries.

Object Files 7

This chapter provides details on how compiler-system object files are formatted and processed.

The chapter addresses the following topics:

- The components that make up the object file and the differences between the object-file format used by the Digital UNIX compiler system and the System V common object file format (COFF). (Section 7.1)
- The headers and sections of the object file. Detailed information is given on the logic followed by the assembler and linker in handling relocation entries. (Section 7.2)
- The formats of object files (OMAGIC, NMAGIC, and ZMAGIC). (Section 7.3)
- Information used by the dynamic loader in loading object files at run time. (Section 7.4)
- Archive files. (Section 7.5)
- The symbols defined by the linker. (Section 7.6)

7.1 Object File Overview

The assembler and the linker generate object files. The sections in the object files are ordered as shown in Figure 7-1. Sections that do not contain data are omitted, except for the file header, optional header, and section header, which are always present.

Object files also contain a symbol table, which is also divided into sections. Figure 7-1 shows all of the possible sections in a symbol table. The sections of the symbol table that appear in a final object file can vary:

- The optimization symbols table and auxiliary symbols table appear only when a debugging option is in effect (when the user specifies one of the `-g1`, `-g2`, or `-g3` compilation options).
- When you specify the `-x` option (strip nonglobals) for the link-edit phase, the linker updates the procedure descriptor table and strips the following tables from the object file: line number table, local symbols table, optimization symbols table, auxiliary symbols table, local strings table, and relative file descriptor table.

7.2 Object File Sections

The following sections describe the components of an object file. Headers are informational and provide the means for navigating the object file. Sections contain program instructions or data (or both).

7.2.1 File Header

The format of the file header is shown in Table 7-1. The file header and all of the fields described in this section are defined in `filehdr.h`.

Table 7-1: File Header Format

Declaration Type	Field	Description
`unsigned short`	`f_magic`	Target-machine magic number (see Table 7-2)
`unsigned short`	`f_nscns`	Number of sections
`int`	`f_timdat`	Time and date stamp
`long`	`f_symptr`	File pointer to symbolic header (see Chapter 8 for a description of the symbolic header)
`int`	`f_nsyms`	Size of symbolic header
`unsigned short`	`f_opthdr`	Size of optional header
`unsigned short`	`f_flags`	Flags (see Table 7-3)

The magic number in the `f_magic` field in the file header specifies the target machine on which an object file can execute. Table 7-2 shows the octal values and mnemonics for the magic numbers.

Table 7-2: File Header Magic Numbers

Symbol	Value	Description
`ALPHAMAGIC`	0603	Machine-code object file
`ALPHAUMAGIC`	0617	Ucode object file

The `f_flags` field in the file header describes the object file characteristics. Table 7-3 lists the flags and gives their hexadecimal values and their meanings. The table notes those flags that do not apply to compiler system object files.

Figure 7-1: Object File Format

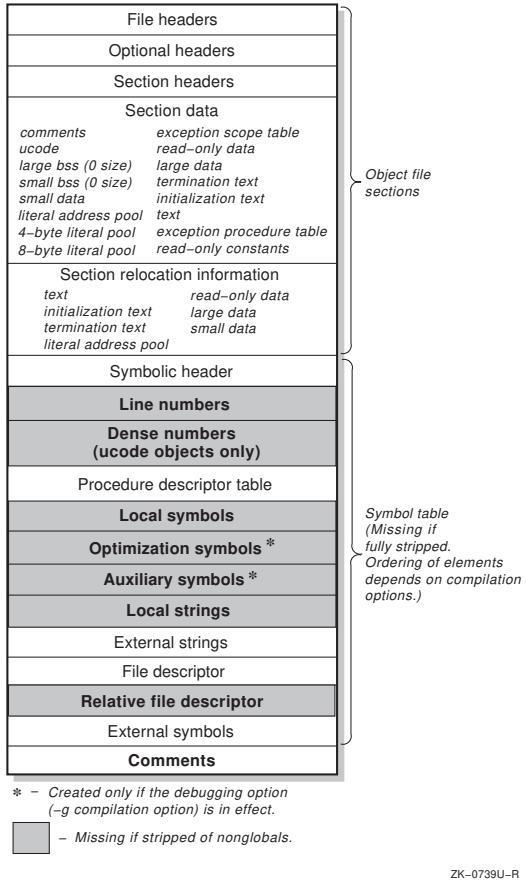

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Table 7-3: File Header Flags

Symbol	Value	Description
F_RELFLG	0x0001	Relocation information stripped from file
F_EXEC	0x0002	File is executable (that is, no unresolved external references)
F_LNNO	0x0004	Line numbers stripped from file
F_LSYMS	0x0008	Local symbols stripped from file
F_NO_SHARED	0x0010	Object file cannot be used to create a shared library
F_NO_CALL_SHARED	0x0020	Object file cannot be used to create a `-call_shared` executable file
F_LOMAP	0x0040	Allows an executable file to be loaded at an address less than VM_MIN_ADDRESS
F_AR16WR[a]	0x0080	File has the byte ordering of an AR16WR machine (for example, PDP-11/70)
F_AR32WR[a]	0x0100	File has the byte ordering of an AR32WR machine (for example, VAX)
F_AR32W[a]	0x0200	File has the byte ordering of an AR32W machine (for example, 3b, maxi, MC68000)
F_PATCH[a]	0x0400	File contains ''patch'' list in optional header
F_NODF[a]	0x0400	(Minimal file only.) No decision functions for replaced functions
F_MIPS_NO_SHARED	0x1000	Cannot be dynamically shared
F_MIPS_SHARABLE	0x2000	A dynamically shared object
F_MIPS_CALL_SHARED	0x3000	Dynamic executable file
F_MIPS_NO_REORG	0x4000	Do not reorder sections
F_MIPS_NO_REMOVE	0x8000	Do not remove nops

Table Note:

a. Not used by compiler system object modules.

7.2.2 Optional Header

The linker and the assembler fill in the optional header, and the dynamic loader, or other program that loads the object module at run time, uses the information it contains, as described in Section 7.4.

Table 7-4 shows the format of the optional header (which is defined in the header file `aouthdr.h`).

Table 7-4: Optional Header Definitions

Declaration	Field	Description
short	magic	Object-file magic numbers (see Table 7-5)
short	vstamp	Version stamp
short	bldrev	Revision of build tools
long	tsize	Text size in bytes, padded to 16-byte boundary
long	dsize	Initialized data in bytes, padded to 16-byte boundary
long	bsize	Uninitialized data in bytes, padded to 16-byte boundary
long	entry	Entry point
long	text_start	Base of text used for this file
long	data_start	Base of data used for this file
long	bss_start	Base of bss used for this file
int	gprmask	General-purpose register mask
int	fprmask	Floating-point register mask
long	gp_value	The gp (global pointer) value used for this object

Table 7-5 shows the octal values of the `magic` field for the optional header; the header file `aouthdr.h` contains the macro definitions.

Table 7-5: Optional Header Magic Numbers

Symbol	Value	Description
OMAGIC	0407	Impure format – The text is not write-protected or shareable; the data segment is contiguous with the text segment.
NMAGIC	0410	Shared text – The data segment starts at the next page following the text segment, and the text segment is write-protected.
ZMAGIC	0413	The object file is to be paged in on demand (demand paged) and has a special format; the text and data segments are separated. The Alpha system provides write-protection for the text segment. (Other systems using COFF may not provide write-protection.) The object can be either dynamic or static.

See Section 7.3 for information on the format of OMAGIC, NMAGIC, and ZMAGIC files.

Table 7-7: (continued)

Declaration	Field Contents	Description
_DYNSTR[a]	.dynstr	Dynamic linking strings
_HASH[a]	.hash	Symbol hash table
_MSYM[a]	.msym	Additional dynamic linking symbol table
_CONFLICT[a]	.conflict	Additional dynamic linking information
_REGINFO[a]	.reginfo	Register usage information
_XDATA	.xdata	Exception scope table
_PDATA	.pdata	Exception procedure table

Table Notes:

a. These sections exist only in ZMAGIC-type files and are used during dynamic linking.

Table 7-8 shows the defined hexadecimal values for the s_flags field. (Those flags that are not used by compiler system object files are noted in the table.)

Table 7-8: Format of s_flags Section Header Entry

Symbol	Value	Description
STYP_REG	0x00	Regular section: allocated, relocated, loaded
STYP_DSECT[a]	0x01	Dummy section: not allocated, relocated, not loaded
STYP_NOLOAD[a]	0x02	Noload section: allocated, relocated, not loaded
STYP_GROUP[a]	0x04	Grouped section: formed of input sections
STYP_PAD[a]	0x08	Padding section: not allocated, not relocated, loaded
STYP_COPY[a]	0x10	Copy section (for decision function used by field update): not allocated, not relocated, loaded
STYP_TEXT	0x20	Text only
STYP_DATA	0x40	Data only
STYP_BSS	0x80	Bss only
STYP_RDATA	0x100	Read-only data only
STYP_SDATA	0x200	Small data only
STYP_SBSS	0x400	Small bss only
STYP_UCODE	0x800	Ucode only
STYP_GOT[b]	0x1000	Global offset table
STYP_DYNAMIC[b]	0x2000	Dynamic linking information

7.2.3 Section Headers

Table 7-6 shows the format of the section header (which is defined in the header file scnhdr.h).

Table 7-6: Section Header Format

Declaration	Field	Description
char	s_name[8]	Section name (see Table 7-7)
long	s_paddr	Physical address
long	s_vaddr	Virtual address
long	s_size	Section size
long	s_scnptr	File pointer to raw data for the section
long	s_relptr	File pointer to relocations for the section
long	s_lnnoptr	For .pdata, indicates the number of entries contained in the section; otherwise, reserved.
unsigned short	s_nreloc	Number of relocation entries
unsigned short	s_nlnno	Number of global pointer tables
int	s_flags	Flags (see Table 7-8)

Table 7-7 shows the defined section names for the s_name field of the section header.

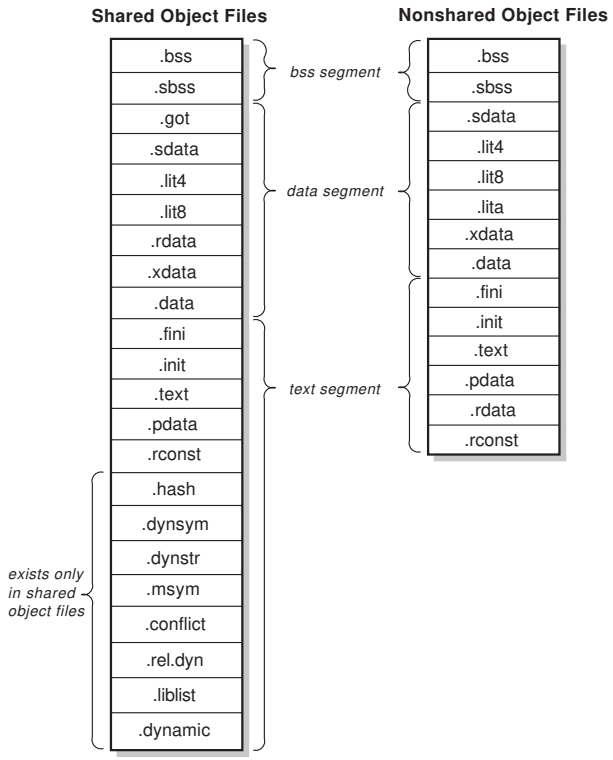
Table 7-7: Section Header Constants for Section Names

Declaration	Field Contents	Description
_TEXT	.text	Text section
_INIT	.init	Initialization text section for shared libraries
_FINI	.fini	Cleanup text section
_RCONST	.rconst	Read-only constant section
_RDATA	.rdata	Read-only data section
_DATA	.data	Large data section
_LITA	.lita	Literal address pool section
_LIT8	.lit8	8-byte literal pool section
_LIT4	.lit4	4-byte literal pool section
_SDATA	.sdata	Small data section
_BSS	.bss	Large bss section
_SBSS	.sbss	Small bss section
_UCODE	.ucode	ucode section
_GOT[a]	.got	Global offset table
_DYNAMIC[a]	.dynamic	Dynamic linking information
_DYNSYM[a]	.dynsym	Dynamic linking symbol table
_REL_DYN[a]	.rel.dyn	Relocation information

7.2.4 Section Data

Object files contain instructions and data. The instructions and data are stored in appropriate sections according to their use. Figure 7-2 shows the layout of section data in object files.

Figure 7-2: Organization of Section Data



The sections that are present in the section data and the ordering of the sections depends on the options that are in effect for a particular compilation.

Table 7-8: (continued)

Symbol	Value	Description
STYP_DYNSYM[b]	0x4000	Dynamic linking symbol table
STYP_REL_DYN[b]	0x8000	Dynamic relocation information
STYP_DYNSTR[b]	0x10000	Dynamic linking symbol table
STYP_HASH[b]	0x20000	Dynamic symbol hash table
STYP_MSYM[b]	0x80000	Additional dynamic linking symbol table
STYP_CONFLICT[b]	0x100000	Additional dynamic linking information
STYP_REGINFO[b]	0x200000	Register usage information
STYP_FINI	0x01000000	.fini section text
STYP_COMMENT	0x02000000	Comment section
STYP_RCONST	0x02200000	Read-only constants
STYP_XDATA	0x02400000	Exception scope table
STYP_PDATA	0x02800000	Exception procedure table
STYP_LITA	0x04000000	Address literals only
STYP_LIT8	0x08000000	8-byte literals only
STYP_LIT4	0x10000000	4-byte literals only
S_NRELOC_OVFL	0x20000000	`s_nreloc` overflowed, the value is in `r_vaddr` of the first entry
STYP_INIT	0x80000000	Section initialization text only

Table Notes:

a. Not used by compiler system object modules.

b. These sections exist only in ZMAGIC type files and are used during dynamic linking.

The `S_NRELOC_OVFL` flag is used when the number of relocation entries in a section overflows the `s_nreloc` field of the section header. In this case, `s_nreloc` contains the value 0xffff and the `s_flags` field has the `S_NRELOC_OVFL` flag set; the value true is in the `r_vaddr` field of the first relocation entry for that section. That relocation entry has a type of `R_ABS` and all other fields are zero, causing it to be ignored under normal circumstances.

Note

For performance reasons, the linker uses the `s_flags` entry instead of `s_name` to determine the type of section. The linker does correctly fill in the `s_name` entry, however.

A section is described by and referenced through the section header (see Section 7.2.3); the optional header (see Section 7.2.2) provides the same information for segments.

The linker references the data shown in Figure 7-2 as both sections and segments. It references the sections through the section header and the segments through the optional header. However, the dynamic loader, when loading the object file at run time, references the same data only by segment, through the optional header.

7.2.5 Section Relocation Information

Program instructions and data may contain addresses that must be adjusted when the object file is linked. Relocations locate the addresses within the section and indicate how they are to be adjusted.

7.2.5.1 Relocation Table Entry

Table 7-9 shows the format of an entry in the relocation table (defined in the header file `reloc.h`).

Table 7-9: Format of a Relocation Table Entry

Declaration	Field	Description
`long`	`r_vaddr`	Virtual address of an item to be relocated.
`unsigned`	`r_symndx`	For an external relocation entry, `r_symndx` is an index into external symbols. For a local relocation entry, `r_symndx` is the number of the section containing the symbol.
`unsigned`	`r_type:8`	Relocation type (see Table 7-11).
`unsigned`	`r_extern:1`	Set to 1 for an external relocation entry. Set to 0 for a local relocation entry.
`unsigned`	`r_offset:6`	For `R_OP_STORE`, `r_offset` is the bit offset of a field within a quadword.
`unsigned`	`r_reserved:11`	Must be zero.
`unsigned`	`r_size:6`	For `R_OP_STORE`, `r_size` is the bit size of a field.

The setting of `r_extern` and the contents of `r_symndx` vary for external and local relocation entries:

- For external relocation entries, `r_extern` is set to 1 and `r_symndx` is the index into external symbols. In this case, the value of the symbol is used as the value for relocation (see Figure 7-3).

The `.conflict`, `.dynamic` `.dynstr`, `.dynsym`, `.got`, `.hash`, `.liblist`, `.msym`, and `.rel.dyn` sections exist only in shared object files and are used during dynamic linking. These sections are described in more detail in Chapter 9. The following table describes the uses of the other sections:

Section Name	Use
`.ucode`	Intermediate code (if present, all other sections are excluded)
`.bss`	Block started by symbol
`.data`	Large data
`.fini`	Process termination text
`.init`	Initialization text
`.lit4`	4-byte literal pool
`.lit8`	8-byte literal pool
`.lita`	Literal address pool (only present in nonshared object files)
`.pdata`	Exception procedure table for pdata
`.rconst`	Read-only constants
`.rdata`	Read-only data
`.sbss`	Small block started by symbol
`.sdata`	Small data
`.text`	Machine instructions to be executed
`.xdata`	Exception scope table for xdata

The `.text` section contains the machine instructions that are to be executed; the `.sdata`, `.lit4`, `.lit8`, `.rdata`, `.data`, and `.rconst` sections contain initialized data; and the `.bss` and `.sbss` sections reserve space for uninitialized data that is created by the dynamic loader for the program before execution and filled with zeros. The only difference between `.rdata` and `.rconst` is that only `.rdata` can have dynamic relocations.

As indicated in Figure 7-2, the sections are grouped into segments:

- The text segment contains the `.rdata` (for nonshared object files), `.fini`, `.init`, `.text`, and `.rconst` sections in all files except shared object files, which contain additional sections. (The `.rdata` section can go in either the text or data segment, depending on the object file type.)
- The data segment contains the sections `.got` (for shared object files), `.sdata`, `.lit4`, `.lit8`, `.lita` (for nonshared object files), `.rdata` (for shared object files), and `.data`.
- The bss segment contains the `.bss` and `.sbss` sections.

Table 7-11: (continued)

Symbol	Value	Description
R_GPDISP	0x6	Identifies an lda/ldah instruction pair that is used to initialize a procedure's global-pointer register. The r_vaddr field identifies one instruction of the pair. The r_symndx contains a byte offset, which when added to the r_vaddr field, produces the address of the other instruction of the pair.
R_BRADDR	0x7	21-bit branch reference to the symbol's virtual address.
R_HINT	0x8	14-bit jsr hint reference to the symbol's virtual address.
R_SREL16	0x9	16-bit self-relative reference to the symbol's virtual address.
R_SREL32	0xa	32-bit self-relative reference to the symbol's virtual address.
R_SREL64	0xb	64-bit self-relative reference to the symbol's virtual address.
R_OP_PUSH	0xc	Push symbol's virtual address on relocation expression stack.
R_OP_STORE	0xd	Pop value from the relocation expression stack and store at the symbol's virtual address. The r_size field determines the number of bits stored. The r_offset field designates the bit offset from the symbol to the target.
R_OP_PSUB	0xe	Pop value from the relocation expression stack and substract the symbol's virtual address. The result is pushed on the relocation expression stack.
R_OP_PRSHIFT	0xf	Pop value from the relocation expression stack and shift right by the symbol's value. The result is pushed on the relocation expression stack.
R_GPVALUE	0x10	Specifies a new gp value is to be used starting with the address specified by the r_vaddr field. The gp value is the sum of the optional header's gp_value field and the r_symndx field. The r_extern field must be zero.
R_GPRELHIGH	0x11	Most significant 16 bits of 32-bit displacement from $gp value. This is the ldah instruction of an ldah/lda, ldah/ldq, or ldah/stq pair that is calculating an address as a displacement from the $gp value. Sign-extension of both offsets is assumed. This relocation must be followed immediately by one or more corresponding R_GPRELLOW relocations.

- For local relocation entries, r_extern is set to 0, and r_symndx contains a constant that refers to a section (see Figure 7-4). In this case, the starting address of the section to which the constant refers is used as the value for relocation.

Table 7-10 gives the section numbers for r_symndx; the reloc.h file contains the macro definitions.

Table 7-10: Section Numbers for Local Relocation Entries

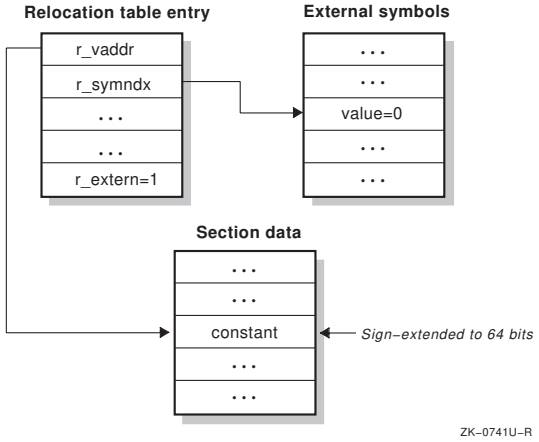
Symbol	Value	Description
R_SN_TEXT	1	.text section
R_SN_RDATA	2	.rdata section
R_SN_DATA	3	.data section
R_SN_SDATA	4	.sdata section
R_SN_SBSS	5	.sbss section
R_SN_BSS	6	.bss section
R_SN_INIT	7	.init section
R_SN_LIT8	8	.lit8 section
R_SN_LIT4	9	.lit4 section
R_SN_XDATA	10	.xdata section
R_SN_PDATA	11	.pdata section
R_SN_FINI	12	.fini section
R_SN_LITA	13	.lita section
R_SN_ABS	14	for R_OP_*xxxx* constants
R_SN_RCONST	15	section

Table 7-11 shows valid symbolic entries for the r_type field (which is defined in the header file reloc.h).

Table 7-11: Relocation Types

Symbol	Value	Description
R_ABS	0x0	Relocation already performed.
R_REFLONG	0x1	32-bit reference to the symbol's virtual address.
R_REFQUAD	0x2	64-bit reference to the symbol's virtual address.
R_GPREL32	0x3	32-bit displacement from the global pointer to the symbol's virtual address.
R_LITERAL	0x4	Reference to a literal in the literal address pool as an offset from the global pointer.
R_LITUSE	0x5	Identifies an instance of a literal address previously loaded into a register. The r_symndx field identifies the specific usage of the register. Table 7-12 lists the valid usage types.

Figure 7-3: Relocation Table Entry for Undefined External Symbols



The assembler creates a relocation table entry for an undefined external symbol as follows:

1. Sets `r_vaddr` to point to the item to be relocated.
2. Places a constant to be added to the value for relocation at the address for the item to be relocated (`r_vaddr`).
3. Sets `r_symndx` to the index of the external symbols entry that contains the symbol value (which is used as the value for relocation).
4. Sets `r_type` to the constant for the type of relocation types. Table 7-11 shows the valid constants for the relocation type.
5. Sets `r_extern` to 1.

Note

The assembler always sets the value of the undefined external symbols entry to 0. It may assign a constant value to be added to the relocated value at the address where the location is to be done. For relocation types other than `R_HINT`, the linker flags this as an error if the width of the constant is less than a full quadword and an overflow occurs after relocation.

Table 7-11: (continued)

Symbol	Value	Description
`R_GPRELLOW`	0x12	Least significant 16 bits of a 32-bit displacement from `$gp` value. This is the second instruction of an `ldah/lda`, `ldah/ldq`, or `ldah/stq` pair that is calculating an address as a displacement from the `$gp` value. This relocation should follow the corresponding `R_GPRELHIGH` relocation. Each `R_GPRELHIGH` relocation can have one or more `R_GPRELLOW` relocations.

Table 7-12 shows valid symbolic entries for the symbol index (`r_symndx`) field for the relocation type `R_LITUSE`.

Table 7-12: Literal Usage Types

Symbol	Description
`R_LU_BASE`	The base register of a memory format instruction (except `ldah`) contains a literal address.
`R_LU_BYTOFF`	The byte offset register (`Rb`) of a byte-manipulation instruction contains a literal address.
`R_LU_JSR`	The target register of a `jsr` instruction contains a literal address.

7.2.5.2 Assembler and Linker Processing of Relocation Entries

Object modules with all external references defined have the same format as relocatable modules and are executable without relinking.

Local relocation entries must be used for symbols that are defined, and external relocation entries are used only for undefined symbols. Figure 7-3 gives an overview of the relocation table entry for an undefined external symbol.

The following examples show the use of external relocation entries:

- **Example 1: 64-Bit Reference — R_REFQUAD**

  This example shows assembly statements that set the value at location b to the global data value y.

```
    .globl y
    .data
b:  .quad y # R_REFQUAD relocation type at address b for
            # symbol y
```

  In processing this statement, the assembler generates a relocation entry of type R_REFQUAD for the address b and the symbol y. After determining the address for the symbol y, the linker adds the 64-bit address of y to the 64-bit value at location b and places the sum in location b.

  The linker handles 32-bit addresses (R_REFLONG) in the same manner, except it checks for overflow after determining the relocation value.

- **Example 2: 21-Bit Branch — R_BRADDR**

  This example shows assembly statements that call routine x from location c.

```
    .text
x:  #routine x
    ...
c:  bsr x # R_BRADDR relocation type at address c for symbol x
```

  In processing these statements, the assembler generates a relocation entry of type R_BRADDR for the address and the symbol x. After determining the address for the routine, the linker subtracts the address c+4 to form the displacement to the routine. Then, the linker adds this result (sign-extended and multiplied by 4) to the 21 low-order bits of the instruction at address c, and after checking for overflow, places the result (divided by 4) back into the 21 low-order bits at address c.

  R_BRADDR relocation entries are produced for the assembler's br (branch) and bsr (branch subroutine) instructions.

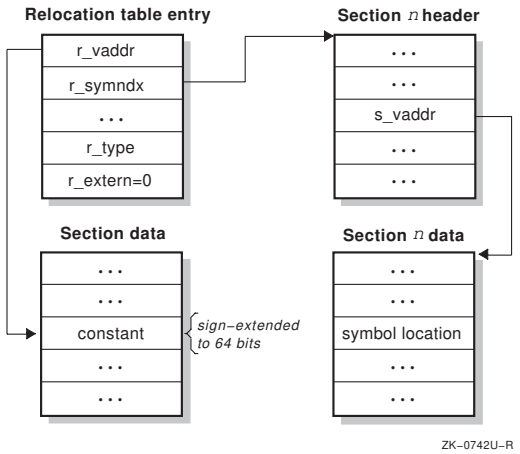
  If the entry is a local relocation type, the target of the branch instruction is assembled in the instruction at the address to be relocated. Otherwise, the instruction's displacement field contains a signed offset from the external symbol.

- **Example 3: 32-bit GP-Relative Reference — R_GPREL32**

  This example shows assembly language statements that set the value at

When the linker determines that an external symbol is defined, it changes the relocation table entry for the symbol to a local relocation entry. Figure 7-4 gives an overview of the new entry.

Figure 7-4: Relocation Table Entry for a Local Relocation Entry



To change this entry from an external relocation entry to a local relocation entry, the linker performs the following steps:

1. Picks up the constant from the address to be relocated (r_vaddr).
2. If the width of the constant is less than 64 bits, sign-extends the constant to 64 bits.
3. Adds the value for relocation (the value of the symbol) to the constant and places it back in the address to be relocated.
4. Sets r_symndx to the section number that contains the external symbol.
5. Sets r_extern to 0.

used by the assembler from gp_value in the optional header (see Table 7-4).

- **Example 6: GP Displacement Reference — R_GPDISP**

  This example shows an assembly language statement that reloads the value of the global pointer after a call to procedure x.

```
    # call to procedure x returns here with return address in ra
    ldgp $gp, 0(ra)
```

  In processing this statement, the assembler generates the following code:

```
j:  lda $at, <gp_disp>[0:15](ra) # R_GPDISP relocation type
                                 # at address j;
                                 # r_symndx contains byte offset
                                 # from address j to address k
k:  ldah $gp, <gp_disp>[16:31]($at)
```

  The assembler determines the 32-bit displacement from the address of the ldgp instruction to the global pointer and stores it into the offset fields of the lda and ldah instructions. The linker gets the value of the global pointer used by the assembler from gp_value in the optional header (see Table 7-4).

- **Example 7: JSR Hint — R_HINT**

  This example shows an assembly language statement that makes an indirect jump through register 24 and specifies to the branch-prediction logic that the target of the jsr instruction is the address of the symbol x.

```
    # get address of procedure to call into register 24
m:  jsr ra, ($24), x # R_HINT relocation type at address m
                     # for symbol x
```

  In processing this statement, the assembler generates a relocation entry of type R_HINT for the address m and the symbol x.

7.3 Object-File Formats (OMAGIC, NMAGIC, ZMAGIC)

The linker creates files with the following object-file formats:

- Impure format (OMAGIC)
- Shared text format (NMAGIC)
- Demand paged format (ZMAGIC)

To understand the descriptions of these formats, you should be familiar with the format and contents of the text, data, and bss segments as described in Section 7.2.4.

The following constraints are imposed on the address at which an object can be loaded and the boundaries of its segments:

location a to the offset from the global pointer to the global data value z.

```
    .globl z
    .data
a:  .gprel32 z # R_GPREL32 relocation type at address a for
               # symbol z
```

In processing this statement, the assembler generates a relocation entry of type R_GPREL32 for the address a and the symbol z. After determining the address for the symbol z, the linker adds the 64-bit displacement of z from the the global pointer to the signed 32-bit value at location a, and places the sum in location a. The linker checks for overflow when performing the above operation.

- **Example 4: Literal Address Reference — R_LITERAL**

  This example shows an assembly language statement that loads the address of the symbol y into register 22.

```
    lda $22, y
```

  In processing this statement, the assembler generates the following code:

```
    .lita
x:  .quad y # R_REFQUAD relocation type at address x for
            # symbol y

    .text
h:  ldq $22, n($gp) # R_LITERAL relocation type at address h
                    # for symbol x
```

  The assembler uses the difference between the address for the symbol x and the value of the global pointer as the value of the displacement (n) for the instruction. The linker gets the value of the global pointer used by the assembler from gp_value in the optional header (see Table 7-4).

- **Example 5: Literal Usage Reference — R_LITUSE**

  This example shows an assembly language statement that loads the 32-bit value stored at address y into register 22.

```
    ldl $22, y
```

  In processing this statement, the assembler generates the following code:

```
    .lita
x:  .quad y # R_REFQUAD relocation type at address x for
            # symbol y

    .text
h:  ldq $at, n($gp) # R_LITERAL relocation type at address h
                    # for symbol x
i:  ldl $22, 0($at) # R_LITUSE relocation type at address i;
                    # r_symndx == R_LU_BASE
```

  The assembler uses the difference between the address for the symbol x and the value of the global pointer as the value of the displacement (n) for the ldq instruction. The linker gets the value of the global pointer

- Segments must not overlap.
- Space should be reserved for the stack, which starts just below the base of the text segment and grows through lower addresses; that is, the value of each subsequent address is less than that of the previous address.
- For ZMAGIC and NMAGIC files, the default text segment address is 0x120000000, with the data segment starting at 0x140000000.
- For OMAGIC files, the default text segment address is 0x10000000, with the data segment following the text segment.

The operating system can dictate additional constraints.

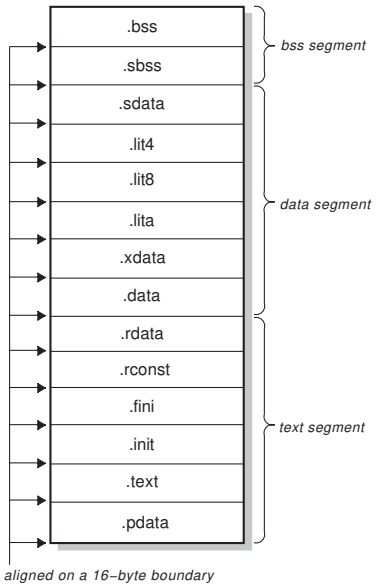
7.3.1 Impure Format (OMAGIC) Files

An OMAGIC file has the format shown in Figure 7-5.

The OMAGIC format has the following characteristics:

- Each section follows the other in virtual address space aligned on a 16-byte boundary.
- The sections are not blocked.
- Text and data segments can be placed anywhere in the virtual address space using the linker's `-T` and `-D` options.
- The addresses specified for the segments must be rounded to 16-byte boundaries.

Figure 7-5: Layout of OMAGIC Files in Virtual Memory



7.3.2 Shared Text (NMAGIC) Files

An NMAGIC file has the format shown in Figure 7-6.

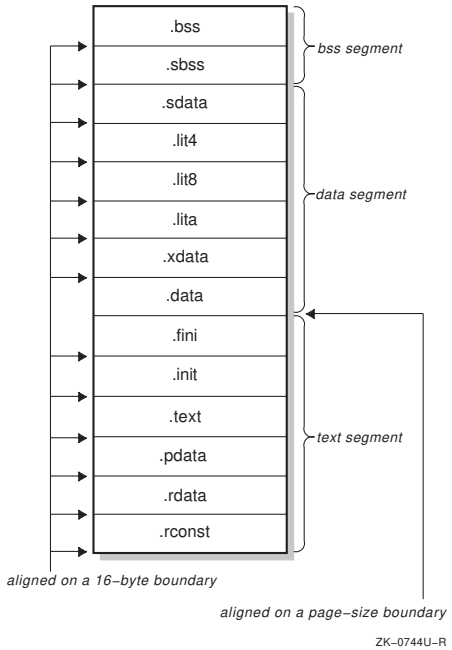
7.3.3 Demand Paged (ZMAGIC) Files

A ZMAGIC file is a demand paged file. Figure 7-7 shows the format of a ZMAGIC file as it appears in virtual memory and on disk.

A ZMAGIC file has the following characteristics:

- The text segment and the data segment are blocked, with *pagesize* as the blocking factor. Blocking reduces the complexity of paging in the files.
- The size of the sum of the file header, optional header, and headers from each of the sections is rounded to 16 bytes and included in blocking of the text segment. See Table 7-1, Table 7-4, and Table 7-6, respectively, for details on the headers.
- The text segment starts by default at 0x120000000.
- Only the start of the text and data segments, using the linker's `-T` and `-D` options can be specified for a demand paged format file and must be a multiple of the page size.

Figure 7-6: Layout of NMAGIC Files in Virtual Memory



An NMAGIC file has the following characteristics:

- The virtual address of the `.data` section is on a *pagesize* boundary.
- The sections are not blocked.
- Each section follows the other in virtual address space aligned on a 16-byte boundary.
- Only the start of the text and data segments, using the linker's `-T` and `-D` options, can be specified for a shared text format file; the start of the text and data segments must be a multiple of the page size.

7.3.4 Ucode Objects

A ucode object contains only a file header, the ucode section header, the ucode section, and all of the symbolic information. A ucode section never appears in a machine-code object file.

7.4 Loading Object Files

The linker produces object files with their sections in a fixed order similar to the order that was used in UNIX system object files that existed prior to the implementation of the common object file format (COFF). Figure 7-1 shows the ordering of the sections, and Section 7.2 contains information on how the sections are formatted.

The sections are grouped into segments, which are described in the optional header. To load an object file for execution, the dynamic loader needs only the magic number in the file header and the optional header to load an object file for execution.

The starting addresses and sizes of the segments for all types of object files are specified similarly, and the segments are loaded in the same manner.

After reading in the file header and the optional header, the dynamic loader must examine the file magic number to determine if the program can be loaded. Then, the dynamic loader loads the text and data segments.

The starting offset in the file for the text segment is given by the following macro in the header file `a.out.h`:

```
N_TXTOFF(f,a)
```

where `f` is the file header structure and `a` is the option header structure for the object file to be loaded.

The `tsize` field in the optional header (Table 7-4) contains the size of the text segment and `text_start` contains the address at which it is to be loaded. The starting offset of the data segment follows the text segment. The `dsize` field in the section header (Table 7-6) contains the size of the data segment; `data_start` contains the address at which it is to be loaded.

The dynamic loader must fill the `.bss` section with zeros. The `bss_start` field in the optional header specifies the starting address; `bsize` specifies the number of bytes to be filled with zeros. In ZMAGIC files, the linker adjusts `bsize` to account for the zero-filled area it created in the data segment that is part of of the `.sbss` or `.bss` sections.

If the object file itself does not load the global pointer register, it must be set to the `gp_value` field in the optional header (Table 7-4).

Figure 7-7: Layout of ZMAGIC Files

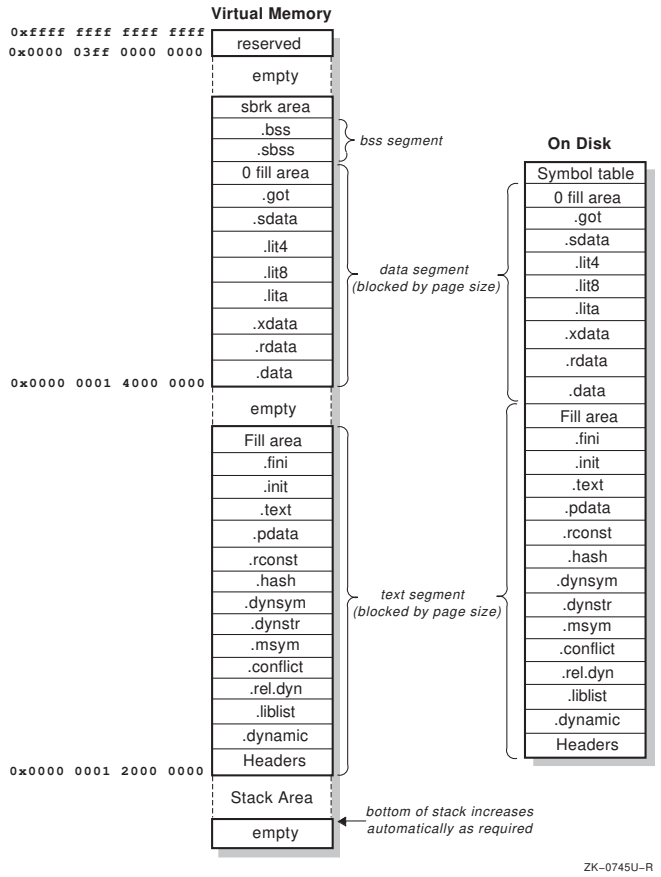


Table 7-13: (continued)

Symbol	Value	Description
PROCEDURE TABLE_SIZE	_procedure_table_size	Run-time procedure table size
PROCEDURE STRING_TABLE	_procedure_string_table	String table for run-time procedure
_COBOL_MAIN	_cobol_main	First COBOL main symbol
_WEAK_ETEXT[b]	etext	Weak symbol for first location after text segment
_WEAK_EDATA[b]	edata	Weak symbol for first location after data segment
_WEAK_END[b]	end	Weak symbol for first location after bss segment
	_BASE_ADDRESS[c]	Base address of file
	_DYNAMIC_LINK[c]	1 if creating a dynamic executable file, 0 otherwise
	_DYNAMIC[c]	Address of .dynamic section
	_GOT_OFFSET[c]	Address of .got section for dynamic executable file

Table Notes:

a. Compiler system only.

b. Not defined with `-std`.

c. No symbol entry. Not defined in `sym.h`.

The dynamic linker also reserves and defines certain symbols; see Chapter 9 for more information.

The first three symbols in Table 7-13 (`_ETEXT`, `_EDATA`, and `_END`) come from the standard UNIX system linker. The remaining symbols are compiler-system specific.

The linker symbol `_COBOL_MAIN` is set to the symbol value of the first external symbol with the `cobol_main` bit set. COBOL objects use this symbol to determine the main routine.

The other fields in the optional header are `gprmask` and `fprmask`, whose bits show the registers used in the `.text`, `.init`, and `.fini` sections. They can be used by the operating system, if desired, to avoid save register relocations when a context-switch operation occurs.

7.5 Archive Files

The linker can link object files in archives created by the archiver. The archiver and the format of the archives are based on the System V portable archive format. To improve performance, the format of the archives symbol table was changed to a hash table, not a linear list.

The archive hash table is accessed through the `ranhashinit()` and `ranlookup()` library routines in `libmld.a`, which are documented in `ranhash`(3). The archive format definition is in the header file `ar.h`.

7.6 Linker Defined Symbols

Certain symbols are reserved and their values are defined by the linker. A user program can reference these symbols, but cannot define them; an error is generated if a user program attempts to define one of these symbols. Table 7-13 lists the names and values of these symbols; the header file `sym.h` contains their preprocessor macro definitions.

Table 7-13: Linker Defined Symbols

Symbol	Value	Description
_ETEXT	_etext	First location after text segment
_EDATA	_edata	First location after data segment
_END	_end	First location after bss segment
_FTEXT[a]	_ftext	First location of text segment
_FDATA[a]	_fdata	First location of data segment
_FBSS[a]	_fbss	First location of the bss segment
_GP	_gp	gp value stored in optional header
PROCEDURE TABLE	_procedure_table	Run-time procedure table
PROCEDURE		

The following symbols relate to the run-time procedure table:

- `_PROCEDURE_TABLE`
- `_PROCEDURE_TABLE_SIZE`
- `_PROCEDURE_STRING_TABLE`

The run-time procedure table is used by the exception systems in languages that have exception-handling capabilities built into them. Its description is found in the header file `sym.h`. The table is a subset of the procedure descriptor table portion of the symbol table with one additional field, `exception_info`.

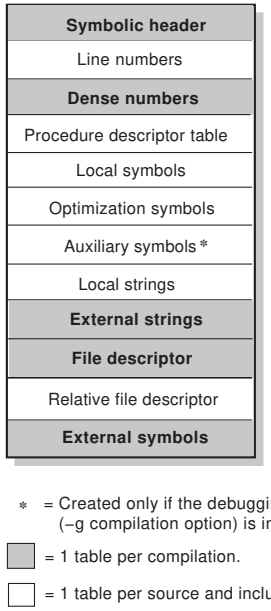
When the procedure table entry is for an external procedure and an external symbol table exists, the linker fills in `exception_info` with the address of the external table. Otherwise, it fills in `exception_info` with zeros.

The name of the run-time procedure table is the procedure name concatenated with the string `_exception_info` (that is, the default value of the preprocessor macro `EXCEPTION_SUFFIX`, as defined in the header file `excpt.h`).

The run-time procedure table provides enough information to allow a program to unwind its stack. It is typically used by the routines in `libexc.a`. The comments in the header file `excpt.h` describe the routines in that library.

- The linker eliminates duplicate information in the external symbol table and the external string table, removes tables with duplicate information, updates the local symbol table with relocation information, and creates the relative file descriptor table.

Figure 8-1: Symbol Table Overview



The symbol table elements shown in Figure 8-1 are summarized in the paragraphs that follow. Some of the major elements are described in more detail later in the chapter.

Symbolic Header

The symbolic header (HDRR) contains the sizes and locations (as an offset from the beginning of the file) of the subtables that make up the symbol table. Figure 8-2 shows the relationship of the header to the

Symbol Table 8

This chapter describes the symbol table and the routines used to create and make entries in the table. The chapter addresses the following major topics:

- The purpose of the symbol table, a summary of its components, and their relationship to each other. (Section 8.1)
- The structures of symbol table entries[1] and the values you assign them through the symbol table routines. (Section 8.2)

8.1 Symbol Table Overview

The symbol table is created by the compiler front-end as a stand-alone file. The purpose of the table is to provide information that the linker and the debugger need to perform their respective functions. At the option of the user, the linker includes information from the symbol table in the final object file for use by the debugger. (See Figure 7-1 for details about object file format.)

The elements (subtables) contained by the symbol table are shown in Figure 8-1.

The compiler front-end creates one group of subtables that contain global information relative to the entire compilation. It also creates a unique group of subtables for the source file and each of its include files. (Figure 8-1 uses shading to differentiate the two types of subtables: compilation-wide subtables are shaded and file-specific subtables are unshaded.)

Compiler front-ends, the assembler, and the linker interact with the symbol table in the following ways:

- The front-end, using calls to routines supplied with the compiler system, enters symbols and their descriptions in the table.
- The assembler fills in line numbers and optimization symbols, and updates the local symbol table, external symbol table, and procedure descriptor table.

[1] Third Eye Software, Inc. owns the copyright (dated 1984) to the format and nomenclature of the symbol table used by the compiler system as documented in this chapter. Third Eye Software, Inc. grants reproduction and use rights to all parties, PROVIDED that this comment is maintained in the copy. Third Eye makes no claims about the applicability of this symbol table to a particular use.

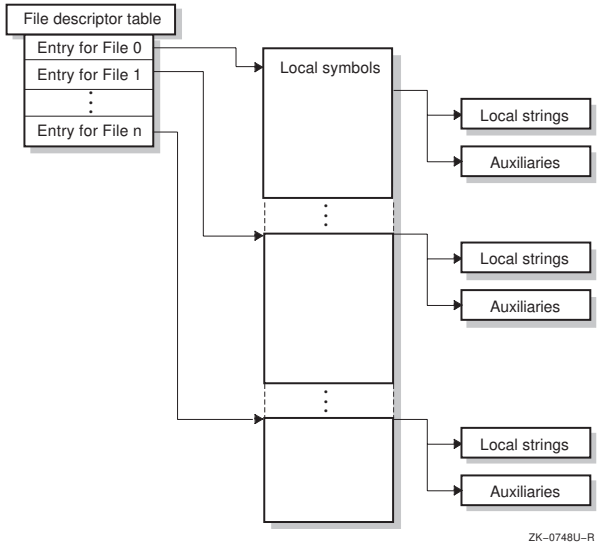
for procedures and the frame information for stack traces. (See Section 8.2.3 for additional information on the procedure discriptor table.)

Local Symbol Table

The local symbol table contains descriptions of program variables, types, and structures, which the debugger uses to locate and interpret run-time values. The table gives the symbol type, storage class, and offsets into other tables that further define the symbol.

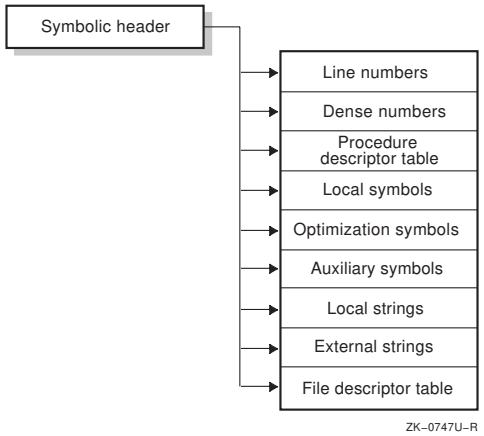
A unique local symbol table exists for every source and include file; the compiler locates the table through an offset from the file descriptor entry that exists for every file. The entries in the local symbol table can reference related information in the local string table and auxiliary symbol table. This relationship is shown in Figure 8-3. (See Section 8.2.4 for additional information on the local symbol table.)

Figure 8-3: Logical Relationship Between the File Descriptor Table and Local Symbols



other tables. (See Section 8.2.1 for additional information on the symbolic header.)

Figure 8-2: Functional Overview of the Symbolic Header



Line Number Table

The assembler creates the line number table. The line number table contains an entry for every instruction. Internally, the information is stored in an encoded form. The debugger uses the entries to map instructions to the source lines and vice versa. (See Section 8.2.2 for additional information on the line number table.)

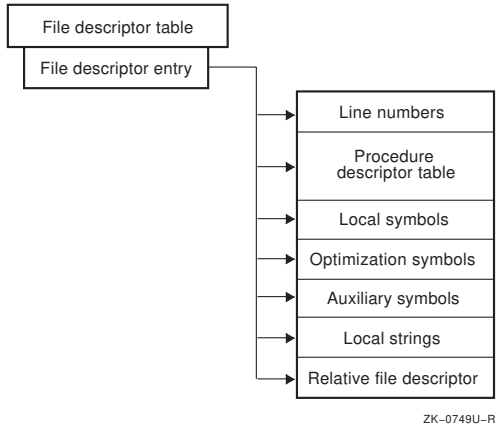
Dense Number Table

The dense number table is an array of pairs. An index into this table is called a dense number. Each pair consists of a file table index (`ifd`) and an index (`isym`) into the local symbol table. The table facilitates symbol look-up for the assembler, optimizer, and code generator by allowing direct table access to be used instead of hashing.

Procedure Descriptor Table

The procedure descriptor table contains register and frame information, and offsets into other tables that provide detailed information on the procedure. The compiler front-end creates the table and links it to the local symbol table. The assembler enters information on registers and frames. The debugger uses the entries in determining the line numbers

Figure 8-4: Physical Relationship of a File Descriptor Entry to Other Tables



The file descriptor entry allows the compiler to access a group of subtables unique to one file. The logical relationship between entries in the file descriptor table and its subtables is shown in Figure 8-5.

Optimization Symbol Table
To be defined at a future date.

Auxiliary Symbol Table
The auxiliary symbol tables contain data type information specific to one language. Each entry is linked to an entry in the Local Symbol Table. The entry in the local symbol table can have multiple, contiguous entries. The format of an auxiliary entry depends on the symbol type and storage class. Table entries are required only when one of the debugging options (`-g` compilation options) is in effect. (See Section 8.2.5 for additional information on the auxiliary symbol table.)

Local String Table
The local string tables contain the names of local symbols.

External String Table
The external string table contains the names of external symbols.

File Descriptor Table
The file descriptor table contains one entry each for each source file and each of its include files. Each entry is composed of pointers to a group of subtables related to a file. The structure of an entry is shown in Table 8-12, and the physical layout of the subtables is shown in Figure 8-4. (See Section 8.2.6 for additional information on the file descriptor table.)

External Symbol Table

The external symbol table contains global symbols entered by the compiler front-end. The symbols are defined in one module and referenced in one or more other modules. The assembler updates the entries, and the linker merges the symbols and resolves their addresses. (See Section 8.2.7 for additional information on the external symbol table.)

8.2 Format of Symbol Table Entries

The symbol table is comprised of several subtables. The symbolic header acts as a directory for the subtables; it provides the locations of the subtables and gives their sizes.

The following sections describe the symbolic header and the subtables.

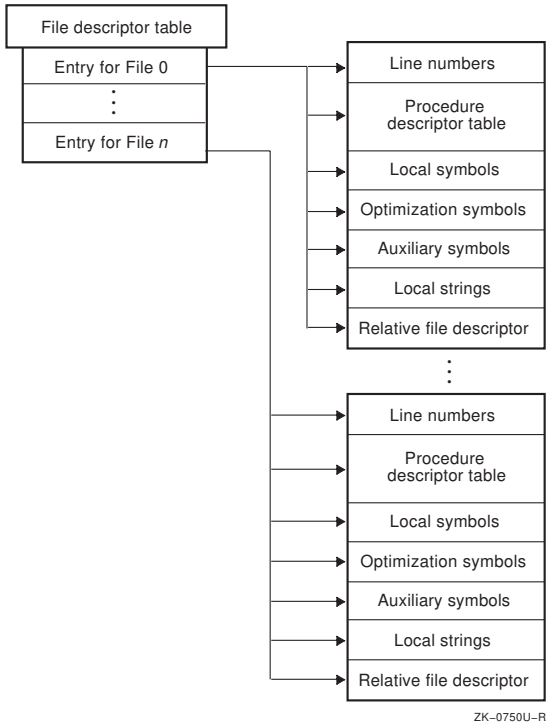
8.2.1 Symbolic Header

The structure of the symbolic header is shown in Table 8-1. The header file `sym.h` contains the header declaration.

Table 8-1: Format of the Symbolic Header

Declaration	Name	Description
short	magic	To verify validity of the table
short	vstamp	Version stamp
int	ilineMax	Number of line number entries
int	idnMax	Maximum index into dense numbers
int	ipdMax	Number of procedures
int	isymMax	Number of local symbols
int	ioptMax	Maximum index into optimization entries
int	iauxMax	Number of auxiliary symbols
int	issMax	Maximum index into local strings
int	issExtMax	Maximum index into external strings
int	ifdMax	Number of file descriptors
int	crfd	Number of relative file descriptors
int	iextMax	Maximum index into external symbols
long	cbLine	Number of bytes for line number entries
long	cbLineOffset	Index to start of line numbers
long	cbDnOffset	Index to start dense numbers
long	cbPdOffset	Index to procedure descriptors
long	cbSymOffset	Index to start of local symbols
long	cbOptOffset	Index to start of optimization entries
long	cbAuxOffset	Index to the start of auxiliary symbols
long	cbSsOffset	Index to start of local strings
long	cbSsExtOffset	Index to the start of external strings

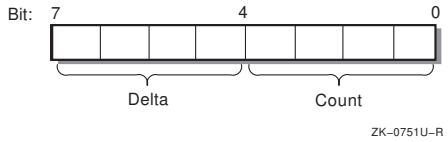
Figure 8-5: Logical Relationship Between the File Descriptor Table and Other Tables



Relative File Descriptor Table

Each file in the symbol table contains a relative file descriptor for each file it was compiled with (including itself and include files). The relative file descriptor maps the index of each file at compile time to its index after linking. All file indices inside the local symbols and auxiliary table must be mapped through the relative file descriptor table for the file they occur in. A missing file descriptor table implies the identity function.

Figure 8-6: Layout of Line Number Entries



The compiler assigns a line number only to those lines of source code that generate executable instructions.

The uses of the delta and count fields are as follows:

- Delta is a 4-bit field with a value in the range -7 to 7. It defines the number of source lines between the current source line and the previous line generating executable instructions. The delta value of the first line number entry is the displacement from the `lnLow` field in the procedure descriptor table.
- Count is a 4-bit field with a value in the range 0 to 15 indicating the number (1 – 16) of executable instructions associated with a source line. If more than 16 instructions (15+1) are associated with a source line, new line number entries are generated when the delta value is zero.

An extended format of the line number entry is used when the delta value is outside the range -7 to 7. Figure 8-7 shows the layout of an extended line number entry on disk.

Table 8-1: (continued)

Declaration	Name	Description
`long`	`cbFdOffset`	Index to file descriptor
`long`	`cbRfdOffset`	Index to relative file descriptors
`long`	`cbExtOffset`	Index to the start of external symbols

The lower byte of the `vstamp` field contains `LS_STAMP` and the upper byte contains `MS_STAMP` (see the header file `stamp.h`). These values are defined in the `stamp.h` file.

The `iMax` fields and the `cbOffset` fields must be set to zero if one of the tables shown in Table 8-1 is not present.

The `magic` field must contain the constant `magicSym`, which is also defined in `symconst.h`.

8.2.2 Line Number Table

Table 8-2 shows the format of an entry in the line number table; the header file `sym.h` contains its declaration.

Table 8-2: Format of a Line Number Entry

Declaration	Name
`int`	`LINER`
`int *`	`pLINER`

The line number section in the symbol table is rounded to the nearest 4-byte boundary.

Line numbers map executable instructions to source lines; one line number is stored for each instruction associated with a source line. Line numbers are stored as integers in memory and in packed format on disk. Figure 8-6 shows the layout of a line number entry on disk.

```
15           * 6
16           * 7
17           */
18           printf("%c", c);
19       } /* end for */
20   } /* end main */
```

The compiler generates line numbers only for the lines 3, 6, 8, 18, and 20; the other lines are either blank or contain comments.

The following table shows the LINER entries for each source line:

Source Line	LINER Contents	Meaning
3	03	Delta 0, count 3
6	35	Delta 3, count 5
8	2a	Delta 2, count 10
18[a]	89 00 0a	Delta 10, count 9
20	23	Delta 2, count 3

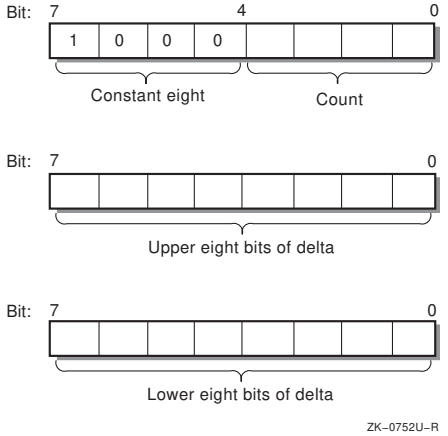
Table Note:

a. Extended format (delta is greater than 7 lines).

The compiler generates the following instructions for the example program:

```
[main.c:   3] 0x0:    27bb0001        ldah    gp, 1(t12)
[main.c:   3] 0x4:    23bd80d0        lda     gp, -32560(gp)
[main.c:   3] 0x8:    23deffe0        lda     sp, -32(sp)
[main.c:   3] 0xc:    b75e0008        stq     ra, 8(sp)
[main.c:   6] 0x10:   a61d8010        ldq     a0, -32752(gp)
[main.c:   6] 0x14:   22108000        lda     a0, -32768(a0)
[main.c:   6] 0x18:   a77d8018        ldq     t12, -32744(gp)
[main.c:   6] 0x1c:   6b5b4000        jsr     ra, (t12), printf
[main.c:   6] 0x20:   27ba0001        ldah    gp, 1(ra)
[main.c:   6] 0x24:   23bd80b0        lda     gp, -32592(gp)
[main.c:   8] 0x28:   a61d8020        ldq     a0, -32736(gp)
[main.c:   8] 0x2c:   a77d8028        ldq     t12, -32728(gp)
[main.c:   8] 0x30:   6b5b4000        jsr     ra, (t12), fgetc
[main.c:   8] 0x34:   27ba0001        ldah    gp, 1(ra)
[main.c:   8] 0x38:   23bd809c        lda     gp, -32612(gp)
[main.c:   8] 0x3c:   b41e0018        stq     v0, 24(sp)
[main.c:   8] 0x40:   44000401        bis     v0, v0, t0
[main.c:   8] 0x44:   48203f41        extqh   t0, 0x1, t0
[main.c:   8] 0x48:   48271781        sra     t0, 0x38, t0
[main.c:   8] 0x4c:   40203402        addq    t0, 0x1, t1
[main.c:   8] 0x50:   f440000a        bne     t1, 0x7c
[main.c:  18] 0x54:   a61d8010        ldq     a0, -32752(gp)
[main.c:  18] 0x58:   22108020        lda     a0, -32736(a0)
[main.c:  18] 0x5c:   44000411        bis     v0, v0, a1
[main.c:  18] 0x60:   4a203f51        extqh   a1, 0x1, a1
[main.c:  18] 0x64:   4a271791        sra     a1, 0x38, a1
```


Figure 8-7: Layout of Extended Line Number Entries



Note

Between two source lines that produce executable code, the compiler allows a maximum of 32,767 comment lines, blank lines, continuation lines, and other lines not producing executable instructions.

The following source listing can be used to show how the compiler assigns line numbers:

```
1    #include <stdio.h>
2    main()
3    {
4        char c;
5
6        printf("this program just prints input\n");
7        for (;;) {
8           if ((c =fgetc(stdin)) != EOF) break;
9        /*   this is a greater than 7-line comment
10           * 1
11           * 2
12           * 3
13           * 4
14           * 5
```

```
[main.c:  18] 0x68:   a77d8018        ldq     t12, -32744(gp)
[main.c:  18] 0x6c:   6b5b4000        jsr     ra, (t12), printf
[main.c:  18] 0x70:   27ba0001        ldah    gp, 1(ra)
[main.c:  18] 0x74:   23bd8060        lda     gp, -32672(gp)
[main.c:  18] 0x78:   c3ffffeb        br      zero, 0x28
[main.c:  20] 0x7c:   47ff0400        bis     zero, zero, v0
[main.c:  20] 0x80:   a75e0008        ldq     ra, 8(sp)
[main.c:  20] 0x84:   23de0020        lda     sp, 32(sp)
[main.c:  20] 0x88:   6bfa8001        ret     zero, (ra), 1
```

8.2.3 Procedure Descriptor Table

Table 8-3 shows the format of an entry in the procedure descriptor table; the header file `sym.h` contains its declaration.

Table 8-3: Format of a Procedure Descriptor Table Entry

Declaration	Name	Description
unsigned long	`adr`	Memory address of start of procedure
long	`cbLineOffset`	Byte offset for this procedure from the base of the file descriptor entry
int	`isym`	Start of local symbols
int	`iline`[a]	Procedure's line numbers
int	`regmask`	Saved register mask
int	`regoffset`[b]	Saved register offset
int	`iopt`	Procedure's optimization symbol entries
int	`fregmask`	Save floating-point register mask
int	`fregoffset`	Save floating-point register offset
int	`frameoffset`	Frame size
int	`lnLow`	Lowest line in the procedure
int	`lnHigh`	Highest line in the procedure
unsigned	`gp_prologue : 8`[c]	Byte size of gp prologue
unsigned	`gp_used : 1`	True if the procedures uses gp
unsigned	`reg_frame : 1`	True if register frame procedure
unsigned	`reserved : 14`	N/A
unsigned	`localoff : 8`	Offset of local variables from vfp
short	`framereg`	Frame pointer register
short	`pcreg`	Index or reg of return program counter

Table Notes:

a. If the value of `iline` is null and the `cycm` field in the file descriptor table is zero, the `iline` field is indexed to the actual table.

b. If the value of `reg_frame` is 1, the `regoffset` field contains the register number of the register in which the return address is stored.

c. If the value of `gp_prologue` is zero and `gp_used` is 1, a gp prologue is present but has been scheduled into the procedure prologue.

8.2.4 Local Symbol Table

Table 8-4 shows the format of an entry in the local symbol table; the header file `sym.h` contains its declaration.

Table 8-4: Format of a Local Symbol Table Entry

Declaration	Name	Description
`long`	`value`[a]	Value of symbol
`int`	`iss`[b]	Index into local strings of symbol name
`unsigned`	`st : 6`[c]	Symbol type
`unsigned`	`sc : 5`[d]	Storage class
`unsigned`	`reserved : 1`	N/A
`unsigned`	`index : 20`[e]	Index into local or auxiliary symbols

Table Notes:

a. An integer representing an address, size, offset from a frame pointer. The value is determined by the symbol type, as illustrated in Table 8-5.

b. The index into string space (`iss`) is an offset from the `issBase` field of an entry in the file descriptor table to the name of the symbol.

c. The symbol type (`st`) defines the symbol. The valid `st` Constants are given in Table 8-6. These constants are defined in `symconst.h`.

d. The storage class (`sc`), where applicable, explains how to access the symbol type in memory. The valid `sc` constants are given in Table 8-7. These constants are defined in `symconst.h`.

e. An offset into either the local symbol table or auxiliary symbol tables, depending of the storage type (`st`) as shown in Table 8-5. The compiler uses `isymBase` in the file descriptor entry as the base for an entry in the local symbol table and `iauxBase` for an entry in the auxiliary symbol table.

Table 8-5: (continued)

Symbol Type	Storage Class	Index	Value
stTypedef	scInfo	iaux	0

Table Notes:

a. The scD/B storage class (data, sdata, bss, or sbss) is determined by the assembler.

b. The *frame offset* value is the offset from the virtual frame pointer.

c. The isymFull index is the isym of the corresponding full parameter description.

d. The *bit offset* value is computed from the beginning of the procedure.

e. The isymMac index is the isym of the corresponding stEnd symbol plus 1.

f. The *relative address* value is the relative displacement from the beginning of the procedure.

g. The isymTag index is the isym to the symbol that is the tag for the variant.

h. The iauxRanges index is the iaux to the ranges for the variant arm.

i. The isymStart index is the isym of the corresponding begin block (for example, stBlock, stFile, or stProc).

The linker ignores all symbols except the types that it will relocate: stLabel, stStatic, stProc, and stStaticProc. Other symbols are used only by the debugger and need to be entered in the table only when one of the debugging options (-g compilation options) is in effect.

8.2.4.1 Symbol Type (st) Constants

Table 8-6 gives the allowable constants that can be specified in the st field of entries in the local symbol table; the header file symconst.h contains the declarations for the constants.

Table 8-6: Symbol Type (st) Constants

Constant	Value	Description
stNil	0	Dummy entry
stGlobal	1	External symbol
stStatic	2	Static

Table 8-5: Index and Value as a Function of Symbol Type and Storage Class

Symbol Type	Storage Class	Index	Value
stFile	scText	isymMac	Address of symbol
stLabel	scText	indexNil	Address of symbol
stGlobal	scD/B[a]	iaux	Address of symbol
stStatic	scD/B[a]	iaux	Address of symbol
stParam	scAbs	iaux	Frame offset[b]
	scRegister	iaux	Register containing address of symbol
	scSymRef	isymFull[c]	Frame offset[b]
	scVar	iaux	Frame offset[b]
	scVarRegister	iaux	Register containing address of symbol
stLocal	scAbs	iaux	Frame offset[b]
	scRegister	iaux	Register containing address of symbol
stProc	scText	iaux	Address of symbol
	scNil	iaux	(unused)
	scUndefined	iaux	(unused)
	scVar	iaux	Frame offset[b]
	scVarRegister	iaux	Register containing address of symbol
stStaticProc	scText	iaux	Address of symbol
stMember			
enumeration	scInfo	indexNil	Ordinal
structure	scInfo	iaux	Bit offset[d]
union	scInfo	iaux	Bit offset[d]
stBlock			
enumeration	scInfo	isymMac[e]	Max enumeration
structure	scInfo	isymMac[e]	Size
text block	scText	isymMac[e]	Relative address[f]
common block	scCommon	isymMac[e]	Size
variant	scVariant	isymMac[e]	isymTag[g]
variant arm	scInfo	isymMac[e]	iauxRanges[h]
union	scInfo	isymMac[e]	Size
stEnd			
enumeration	scInfo	isymStart[i]	0
file	scText	isymStart[i]	Relative address[f]
procedure	scText	isymStart[i]	Relative address[f]
structure	scInfo	isymStart[i]	0
text block	scText	isymStart[i]	Relative address[f]
union	scInfo	isymStart[i]	0
common block	scCommon	isymStart[i]	0
variant	scVariant	isymStart[i]	0
variant arm	scInfo	isymStart[i]	0

Table 8-7: (continued)

Constant	Value	Description
scUserStruct	12	Address in struct user for current process
scSData	13	Small data (load time only)
scSBss	14	Small common (load time only)
scRData	15	Read only data (load time only)
scVar	16	Fortran or Pascal: Var parameter
scCommon	17	Common variable
scSCommon	18	Small common
scVarRegister	19	Var parameter in a register
scVariant	20	Variant records
scFileDesc	20	COBOL: File descriptor
scSUndefined	21	Small undefined
scInit	22	`init` section symbol
scReportDesc	23	COBOL: Report descriptor
scXData	24	Exception handling data
scPData	25	Exception procedure section
scFini	26	`fini` section symbol
scRConst	27	Read-only constant symbol
scSymRef	28	Parameter is described by referenced symbol
scMax	32	Maximum number of storage classes

8.2.5 Auxiliary Symbol Table

Table 8-8 shows the format of an entry in the auxiliary symbol table; the `sym.h` file contains its declaration. Note that the entry is declared as a union; Table 8-8 lists the members of the union.

Table 8-8: Auxiliary Symbol Table Entries

Declaration	Name	Description
TIR	ti[a]	Type information record
RNDXR	rndx[b]	Relative index into local symbols
int	dnLow	Low dimension of array
int	dnHigh	High dimension of array
int	isym[c]	Index into local symbols for `stEnd`
int	iss	Index into local strings (not used)
int	width	Width of a structured field not declared with the default value for size
int	count[d]	Count of ranges for variant arm

Table 8-6: (continued)

Constant	Value	Description
stParam	3	Procedure argument
stLocal	4	Local variable
stLabel	5	Label
stProc	6	Procedure
stBlock	7	Start of block
stEnd	8	End block, file, or procedures
stMember	9	Member of structure, union, or enumeration
stTypedef	10	Type definition
stFile	11	File name
stStaticProc	14	Load-time-only static procs
stConstant	15	Constant
stStaParam	16	Fortran static parameters
stBase	17	C++ base class
stVirtBase	18	C++ virtual base class
stTag	19	C++ tag
stInter	20	C++ interlude
stSplit	21	Split lifetime variable
stModule	22	Module definition
stModview	23	Modifiers for current view of given module

8.2.4.2 Storage Class (sc) Constants

Table 8-7 gives the allowable constants that can be specified in the `sc` field of entries in the local symbol table; the header file `symconst.h` contains the declarations for the constants.

Table 8-7: Storage Class Constants

Constant	Value	Description
scNil	0	Dummy entry
scText	1	Text symbol
scData	2	Initialized data symbol
scBss	3	Uninitialized data symbol
scRegister	4	Value of symbol is register number
scAbs	5	Symbol value is absolute; not to be relocated
scUndefined	6	Used but undefined in the current module
scUnallocated	7	No storage or register allocated
scBits	8	Bit field
scDbx	9	Used internally by `dbx`
scRegImage	10	Register value saved on stack
scInfo	11	Symbol contains debugger information

Table 8-10: Basic Type (bt) Constants

Constant	Value	Default Size[a]	Description
btNil	0	0	Undefined, void
btAdr32	1	32	Address (32 bits)
btChar	2	8	Symbol character
btUChar	3	8	Unsigned character
btShort	4	16	Short (16 bits)
btUShort	5	16	Unsigned short
btInt	6	32	Integer
btUInt	7	32	Unsigned integer
btLong32	8	32	Long (32 bits)
btULong32	9	32	Unsigned long (32 bits)
btFloat	10	32	Floating point (real)
btDouble	11	64	Double-precision floating-point real
btStruct	12	n/a	Structure (record)
btUnion	13	n/a	Union (variant)
btEnum	14	32	Enumerated
btTypedef	15	n/a	Defined by means of a typedef; rndx points at a stTypedef symbol
btRange	16	32	Subrange of integer
btSet	17	32	Pascal: Sets
btComplex	18	64	Fortran: Complex
btDComplex	19	128	Fortran: Double complex
btIndirect	20	n/a	Indirect definition; rndx points to an entry in the auxiliary symbol table that contains a TIR (type information record)
btFixedBin	21	n/a	COBOL: Fixed binary
btDecimal	22	n/a	COBOL: Packed or unpacked decimal
btVoid	26	n/a	Void
btPtrMem	27	64	C++: Pointer to member
btScaledBin	27	n/a	COBOL: Scaled binary
btVptr	28	n/a	C++: Virtual function table
btArrayDesc	28	n/a	Fortran90: Array descriptor
btClass	29	n/a	C++: Class (record)
btLong64	30	64	Address (64 bits)
btLong	30	64	Synonym for btLong64
btULong64	31	64	Unsigned long (64 bits)
btULong	31	64	Synonym for btUlong64
btLongLong	32	64	Long long (64 bits)
btULongLong	33	64	Unsigned long long (64 bits)
btAdr64	34	64	Address (64 bits)
btAdr	34	64	Synonym for btAdr64
btInt64	35	64	64-bit integer
btUInt64	36	64	64-bit unsigned integer
btLDouble	37	128	Long double (real*15)

Table Notes:

a. Table 8-9 shows the format of a ti entry; the sym.h file contains its declaration.

b. The compiler front-end fills this field in describing structures, enumerations, and other complex types. The relative file index is a pair of indexes. One index is an offset from the start of the file descriptor table to one of its entries. The second is an offset from the file descriptor entry to an entry in the local symbol table or auxiliary symbol table.

c. This index is always an offset to an stEnd entry denoting the end of a procedure.

d. Used in describing case variants. Gives the number of elements that are separated by commas in a case variant.

Table 8-9: Format of a Type Information Record Entry

Declaration	Name	Description
unsigned	fBitfield : 1	Set if bit width is specified
unsigned	continued : 1	Next auxiliary entry has tq information
unsigned	bt : 6	Basic type
unsigned	tq4 : 4	Type qualifier
unsigned	tq5 : 4	Type qualifier
unsigned	tq0 : 4	Type qualifier
unsigned	tq1 : 4	Type qualifier
unsigned	tq2 : 4	Type qualifier
unsigned	tq3 : 4	Type qualifier

All groups of auxiliary entries have a type information record with the following entries:

- fbitfield is set if the basic type (bt) is of nonstandard width.
- bt (for basic type) specifies the type of the symbol (for example, integer, real, complex, or structure). The valid entries for this field are shown in Table 8-10; the sym.h file contains its declaration.
- tq (for type qualifier) defines whether the basic type (bt) has an *array of*, *function returning*, or *pointer to* qualifier. The valid entries for this field are shown in Table 8-11; the sym.h file contains its declaration.

Table 8-12: (continued)

Declaration	Name	Description
int	cline	Count of line number entries
int	ioptBase	Start of optimization symbol entries
int	copt	Count of optimization symbol entries
int	ipdFirst	Start of procedure descriptor table
int	cpd	Count of procedures descriptors
int	iauxBase	Start of auxiliary symbol entries
int	caux	Count of auxiliary symbol entries
int	rfdBase	Index into relative file descriptors
int	crfd	Relative file descriptor count
unsigned	lang : 5	Language for this file
unsigned	fMerge : 1	Whether this file can be merged
unsigned	fReadin : 1	True if it was read in (not just created)
unsigned	fBigendian : 1	Not used
unsigned	glevel : 2	Level this file was compiled with
unsigned	reserved : 22	Reserved for future use

8.2.7 External Symbol Table

The external symbol table has the same format as the local symbol table, except an offset (ifd) field has been added to the file descriptor table. This field is used to locate information associated with the symbol in an auxiliary symbol table. Table 8-13 shows the format of an entry in the external symbol table; the sym.h file contains its declaration.

Table 8-13: External Symbol Table Entries

Declaration	Name	Description
SYMR	asym	Same as local symbol table
unsigned short	weakext : 1	Symbol is weak external
unsigned short	reserved : 15	Reserved for future use
int	ifd	Pointer to entry in file descriptor table

Table 8-10: (continued)

Constant	Value	Default Size[a]	Description
btInt8	38	8	8-bit integer
btUInt8	39	8	8-bit unsigned integer
btMax	64	n/a	

Table Notes:

a. Size in bits.

Table 8-11: Type Qualifier (tq) Constants

Constant	Value	Description
tqNil	0	Place holder; no qualifier
tqPtr	1	Pointer
tqProc	2	Procedure or function
tqArray	3	Array
tqVol	5	Volatile
tqConst	6	Constant
tqRef	7	Reference
tqMax	8	Number of type qualifiers

8.2.6 File Descriptor Table

Table 8-12 shows the format of an entry in the file descriptor table; the header file sym.h contains its declaration.

Table 8-12: Format of File Descriptor Entry

Declaration	Name	Description
unsigned long	adr	Memory address of start of file
long	cbLineOffset	Byte offset from header or file lines
long	cbLine	Size of lines for the file
long	cbSs	Number of bytes in local strings
int	rss	Source file name
int	issBase	Start of local strings
int	isymBase	Start of local symbol entries
int	csym	Count of local symbol entries
int	ilineBase	Start of line number entries

9.1.2 Base Addresses

Executable files and shared library files have a base address, which is the lowest virtual address associated with the process image of the program. The base address is used to relocate the process image during dynamic linking.

During program loading, the base address is calculated from the memory load address, the maximum page size, and the lowest virtual address of the program's loadable segment.

9.1.3 Segment Access Permissions

A program that is to be loaded by the system must have at least one loadable segment, even though this is not required by the file format. When the process image is created, the segments are assigned access permissions, which are determined by the type of segment and type of program image. Table 9-1 shows the access permissions for the various segment and image types.

Table 9-1: Segment Access Permissions

Image	Segment	Access Permissions
OMAGIC	text, data, bss	Read, Write, Execute
NMAGIC	text	Read, Execute
NMAGIC	data, bss	Read, Write, Execute
ZMAGIC	text	Read, Execute
ZMAGIC	data, bss	Read, Write, Execute

9.1.4 Segment Contents

An object file segment can contain one or more sections. The number of sections in a segment is not important for program loading, but specific information must be present for linking and execution. Figure 9-1 illustrates typical segment contents for executable files and shared object files. The order of sections within a segment may vary.

Text segments contain instructions and read-only data, and data segments contain writable data. Text segments and data segments typically include the sections shown in Figure 9-1.

Program Loading and Dynamic Linking 9

Executable files and shared library files are used to create a process image when a program is started by the system. This chapter describes the object file structures that relate to program execution and also describes how the process image is created from executable and shared object files.

This chapter addresses the following topics:

- Factors that influence linking and loading operations. (Section 9.1)
- The loading process. (Section 9.2)
- Dynamic linking and loading. (Section 9.3)

9.1 Object File Considerations

The following sections describe several general factors that are involved in the linking and loading process.

9.1.1 Structures

The following object file structures contain information that is used in linking and loading operations:

- File Header – The file header identifies a file as an object file and additionally indicates whether the object is a static executable file, a shared executable file, or a shared library file.
- Optional Header – The optional header immediately follows the file header and identifies the size, location, and virtual addresses of the object's segments.
- Section Headers – Section headers describe the individual sections that comprise the object's segments. Section headers are normally not used in program loading; however, the section headers are used to locate the dynamic section in shared executable files and shared libraries.

See Chapter 7 for further details on file headers, optional headers, and section headers.

- The first text page contains the COFF file header, section headers, and other information.
- The last text page may hold a copy of the beginning of data.
- The first data page may have a copy of the end of text.
- The last data page may contain file information not relevant to the running process.

Logically, the system enforces the memory permissions as if each segment were complete and separate; segment's addresses are adjusted to ensure that each logical page in the address space has a single set of permissions.

The end of the data segment requires special handling for uninitialized data, which must be set to zero. If a file's last data page includes information not in the logical memory page, the extraneous data must be set to zero, not the contents of the executable file.

9.3 Dynamic Linking

An executable file is loaded at fixed addresses; the system creates its segments using the virtual addresses from the optional header. The system transfers control directly to the entry point of the executable file.

An executable file that uses dynamic linking requires one or more shared libraries to be loaded in addition to the executable file. Instead of loading the executable file, the system loads the dynamic loader, which in turn loads the executable file and its shared libraries.

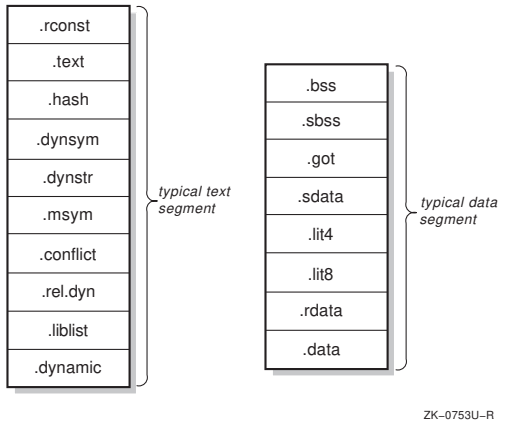
9.3.1 Dynamic Loader

When building an executable file that uses dynamic linking, the linker adds the flag `F_MIPS_CALL_SHARED` to the `f_flags` field of the file header. This flag tells the system to invoke the dynamic loader to load the executable file. Typically, the dynamic loader requested is `/sbin/loader`, the default loader. The `exec` function and the dynamic loader cooperate to create the process image. Creating the process image involves the following operations:

- Adding segments of the file to the process image
- Adding segments of shared object files to the process image
- Performing relocations for the executable file and its shared library files
- Transferring control to the program, making it appear that the program received control directly from `exec`

To assist the dynamic loader, the linker also constructs the following data items for shared library files and shared executable files:

Figure 9-1: Text and Data Segments of Object Files



9.2 Program Loading

As the system creates or augments a process image, it logically copies a file's segment to a virtual memory segment. The time at which the system physically reads the file depends on the program's execution behavior, system load, and other factors. A process does not require a physical page unless it references the logical page during execution.

Processes commonly leave many pages unreferenced. This improves system performance because delaying physical reads frequently obviates them. To obtain this efficiency in practice, shared executable files and shared library files must have segment images whose virtual addresses are zero, modulo the file system block size.

Virtual addresses for the text and data segments must be aligned on 64KB (0x10000) or larger power of 2 boundaries. File offsets must be aligned on 8KB (0x2000) or larger power of 2 boundaries.

Because the page size can be larger than the alignment restrictions of a segment's file offset, up to seven file pages (depending on page size) can hold text or data that is not logically part of the segment. The contents of the various file pages are as follows:

The dynamic section is an array with entries of the following type:

```
typedef struct {
    Elf32_Sword     d_tag;
    union {
        Elf32_Word  d_val;
        Elf32_Addr  d_ptr;
    } d_un;
} Elf32_Dyn;
```

The structure and union members in the preceding structure definition provide the following information:

`d_tag`
: Indicates how the `d_un` field is to be interpreted.

`d_val`
: Represents integer values.

`d_ptr`
: Represents program virtual addresses. A file's virtual addresses may not match the memory virtual addresses during execution. The dynamic loader computes actual addresses based on the virtual address from the file and the memory base address. Object files do not contain relocation entries to correct addresses in the dynamic section.

The `d_tag` requirements for shared executable files and shared library files are summarized in Table 9-2. ''Mandatory'' indicates that the dynamic linking array must contain an entry of that type; ''optional'' indicates that an entry for the tag may exist but is not required.

Table 9-2: Dynamic Array Tags (d_tag)

Name	Value	d_un	Executable	Shared Object
DT_NULL	0	ignored	mandatory	mandatory
DT_NEEDED	1	d_val	optional	optional
DT_PLTRELSZ[a]	2	d_val	optional	optional
DT_PLTGOT	3	d_ptr	optional	optional
DT_HASH	4	d_ptr	mandatory	mandatory
DT_STRTAB	5	d_ptr	mandatory	mandatory
DT_SYMTAB	6	d_ptr	mandatory	mandatory
DT_RELA[a]	7	d_ptr	mandatory	optional
DT_RELASZ[a]	8	d_val	mandatory	optional
DT_RELAENT[a]	9	d_val	mandatory	optional
DT_STRSZ	10	d_val	mandatory	mandatory
DT_SYMENT	11	d_val	mandatory	mandatory
DT_INIT	12	d_ptr	optional	optional
DT_FINI	13	d_ptr	optional	optional

- The `.dynamic` section contains the dynamic header. (See Section 9.3.2.)
- The `.got` section contains the global offset table. (See Section 9.3.3.)
- The `.dynsym` section contains the dynamic symbol table. (See Section 9.3.4.)
- The `.rel.dyn` section contains the dynamic relocation table. (See Section 9.3.5.)
- The `.msym` section contains the msym table. (See Section 9.3.6.)
- The `.hash` section contains a symbol hash table. (See Section 9.3.7.)
- The `.dynstr` section contains the dynamic string table. (See Section 9.3.8.)
- The `.liblist` section contains the library dependency table. (See Section 9.3.10.1.)
- The `.conflict` section contains the conflict symbol table. (See Section 9.3.10.2.)

These data items are located in loadable segments and are available during execution.

Shared library files may be located at virtual addresses that differ from the addresses in the optional header. The dynamic loader relocates the memory image and updates absolute addresses before control is given to the program.

If the environment variable `LD_BIND_NOW` has a non-null value, the dynamic loader processes all relocations before transferring control to the program. The dynamic loader may use the lazy binding technique to evaluate procedure linkage table entries, avoiding symbol resolution and relocation for functions that are not called. (See Section 9.3.3.1 for information about lazy binding.)

The following sections describe the various dynamic linking sections. The C language definitions are in the header files `elf_abi.h` and `elf_mips.h`.

9.3.2 Dynamic Section (.dynamic)

The dynamic section acts as a table of contents for dynamic linking information within the object. Dynamic sections are present only in shared executable files and shared library files.

The dynamic section is located by its section header. This section header is identified by its name (`.dynamic`) or its section type (`STYP_DYNAMIC`) in the flags field (`s_flags`).

Contains the address of the symbol table with `Elf32_Sym` entries.

DT_RELA
: Contains the address of a relocation table. Entries in the table have explicit addends, such as `Elf32_Rela`. An object file may have multiple relocation sections. When the linker builds the relocation table for an shared executable file or shared object file, these sections are concatenated to form a single table. While the sections are independent in the object file, the dynamic loader sees a single table. When the dynamic loader creates a process image or adds a shared library file to a process image, it reads the relocation table and performs the associated actions. If this entry is present, the dynamic structure must also contain `DT_RELASZ` and `DT_RELAENT` entries. When relocation is mandatory for a file, either `DT_RELA` or `DT_REL` may be present. (Not used by the default system linker and loader.)

DT_RELASZ
: Contains the size in bytes of the `DT_RELA` relocation table. (Not used by the default system linker and loader.)

DT_RELAENT
: Contains the size in bytes of a `DT_RELA` relocation table entry. (Not used by the default system linker and loader.)

DT_STRSZ
: Contains the size in bytes of the string table.

DT_SYMENT
: Contains the size in bytes of a symbol table entry.

DT_INIT
: Contains the address of the initialization function.

DT_FINI
: Contains the address of the termination function.

DT_SONAME
: Contains the string table offset of a null-terminated string that gives the name of the shared library file. The offset is an index into the table indicated in the `DT_STRTAB` entry.

DT_RPATH
: Contains the string table offset of a null-terminated library search path string. The offset is an index into the table indicated in the `DT_STRTAB` entry.

DT_SYMBOLIC
: If this entry is present, the dynamic loader uses a different symbol resolution algorithm for references within a library. The symbol search starts from the shared library file instead of the shared executable file. If

Table 9-2: (continued)

Name	Value	d_un	Executable	Shared Object
DT_SONAME	14	d_val	ignored	optional
DT_RPATH	15	d_val	optional	ignored
DT_SYMBOLIC	16	ignored	ignored	optional
DT_REL	17	d_ptr	mandatory	optional
DT_RELSZ	18	d_val	mandatory	optional
DT_RELENT	19	d_val	mandatory	optional
DT_PLTREL[a]	20	d_val	optional	optional
DT_DEBUG[a]	21	d_ptr	optional	ignored
DT_TEXTREL[a]	22	ignored	optional	optional
DT_JMPREL[a]	23	d_ptr	optional	optional
DT_LOPROC	0x70000000	unspecified	unspecified	unspecified
DT_HIPROC	0x7fffffff	unspecified	unspecified	unspecified

Table Notes:

a. Not used by the default system linker and loader.

The uses of the various dynamic array tags are as follows:

DT_NULL
: Marks the end of the array.

DT_NEEDED
: Contains the string table offset of a null terminated string that is the name of a needed library. The offset is an index into the table indicated in the `DT_STRTAB` entry. The dynamic array may contain multiple entries of this type. The order of these entries is significant.

DT_PLTRELSZ
: Contains the total size in bytes of the relocation entries associated with the procedure linkage table. If an entry of type `DT_JMPREL` is present, it must have an associated `DT_PLTRELSZ` entry. (Not used by the default system linker and loader.)

DT_PLTGOT
: Contains an address associated with either the procedure linkage table, the global offset table, or both.

DT_HASH
: Contains the address of the symbol hash table.

DT_STRTAB
: Contains the address of the string table.

DT_SYMTAB

Table 9-3: Processor-Specific Dynamic Array Tags (d_tag)

Name	Value	d_un	Executable	Shared Object
DT_MIPS_RLD_VERSION	0x70000001	d_val	mandatory	mandatory
DT_MIPS_TIME_STAMP	0x70000002	d_val	optional	optional
DT_MIPS_ICHECKSUM	0x70000003	d_val	optional	optional
DT_MIPS_IVERSION	0x70000004	d_val	optional	optional
DT_MIPS_FLAGS	0x70000005	d_val	mandatory	mandatory
DT_MIPS_BASE_ADDRESS	0x70000006	d_ptr	mandatory	mandatory
DT_MIPS_CONFLICT	0x70000008	d_ptr	optional	optional
DT_MIPS_LIBLIST	0x70000009	d_ptr	optional	optional
DT_MIPS_LOCAL_GOTNO	0x7000000A	d_val	mandatory	mandatory
DT_MIPS_CONFLICTNO	0x7000000B	d_val	optional	optional
DT_MIPS_LIBLISTNO	0x70000010	d_val	optional	optional
DT_MIPS_SYMTABNO	0x70000011	d_val	optional	optional
DT_MIPS_UNREFEXTNO	0x70000012	d_val	optional	optional
DT_MIPS_GOTSYM	0x70000013	d_val	mandatory	mandatory
DT_MIPS_HIPAGENO[a]	0x70000014	d_val	mandatory	mandatory

Table Notes:

a. Not used by the default system linker and loader.

The uses of the various processor-specific dynamic array tags are as follows:

DT_MIPS_RLD_VERSION
: Holds an index into the object file's string table, which holds the version of the run-time linker interface. The version is 1 for executable objects that have a single GOT and 2 for executable objects that have multiple GOTs.

DT_MIPS_TIME_STAMP
: Contains a 32-bit time stamp.

DT_MIPS_ICHECKSUM
: Contains a value that is the sum of all of the COMMON sizes and the names of defined external symbols.

DT_MIPS_IVERSION
: Contains the string table offset of a series of colon-separated version strings. An index value of zero means no version string was specified.

the shared library file does not supply the referenced symbol, the shared executable file and other shared library file are searched.

DT_REL
: Contains the address of the relocation table. An object file can have multiple relocation sections. When the linker builds the relocation table for a shared executable file or shared library file, these sections are concatenated to form a single table. While the sections are independent in the object file, the dynamic loader sees a single table. When the dynamic loader creates a process image or adds a shared library file to a process image, it reads the relocation table and performs the associated actions. If this entry is present, the dynamic structure must contain the `DT_RELSZ` entry.

DT_RELSZ
: Contains the size in bytes of the relocation table pointed to by the `DT_REL` entry.

DT_RELENT
: Contains the size in bytes of a `DT_REL` entry.

DT_PLTREL
: Specifies the type of relocation entry referred to by the procedure linkage table. The `d_val` member holds `DT_REL` or `DT_RELA`, as appropriate. All relocations in a procedure linkage table must use the same relocation. (Not used by the default system linker and loader.)

DT_DEBUG
: Used for debugging. The contents of this entry are not specified. (Not used by the default system linker and loader.)

DT_TEXTREL
: If this entry is not present, no relocation entry should cause a modification to a nonwritable segment. If this entry is present, one or more relocations might request modifications to a nonwritable segment. (Not used by the default system linker and loader.)

DT_JMPREL
: If this entry is present, its `d_ptr` field contains the address of relocation entries associated only with the procedure linkage table. The dynamic loader may ignore these entries during process initialization if lazy binding is enabled. See Section 9.3.3.1 for information about lazy binding. (Not used by the default system linker and loader.)

DT_LOPROC through DT_HIPROC
: Reserved for processor-specific semantics.

DT_MIPS_GOTSYM
Holds the index of the first dynamic symbol table entry that corresponds to an entry in the global offset table. The dynamic array contains one of these entries for each GOT.

DT_MIPS_HIPAGENO
Holds the number of page table entries in the global offset table. A page table entry here refers to 64KB of data space. This entry is used by the profiling tools and is optional. (Not used by the default system linker and loader.)

All other tag values are reserved. Entries may appear in any order, except for the relative order of the DT_NEEDED entries and the DT_NULL entry at the end of the array.

9.3.2.1 Shared Object Dependencies

When the linker processes an archive library, library members are extracted and copied into the output object file. These statically linked services are available during execution and do not involve the dynamic loader. Shared executable files also provide services that require the dynamic loader to include the appropriate shared library files in the process image. To accomplish this, shared executable files and shared library files must describe their dependencies.

The dependencies, indicated by the DT_NEEDED entries of the dynamic structure, indicate which shared library files are required for the program. The dynamic loader builds a process image by connecting the referenced shared library files and their dependencies. When resolving symbolic references, the dynamic loader looks first at the symbol table of the shared executable program, then at the symbol tables of the DT_NEEDED entries (in order), then at the second-level DT_NEEDED entries, and so on. Shared library files must be readable by the process.

Note

Even if a shared object is referenced more than once in the dependency list, the dynamic loader includes only one instance of the object in the process image.

Names in the dependency list are copies of the DT_SONAME strings.

If a shared library name has one or more slash characters in its name, such as /usr/lib/libz, the dynamic loader uses the string as the pathname. If the name has no slashes, such as liba, the object is searched as follows:

1. The dynamic array tag DT_RPATH may give a string that holds a list of directories separated by colons, such as /usr/newlib:/usr/local/lib. The dynamic loader searches

DT_MIPS_FLAGS
Contains a set of 1-bit flags. The following flags are defined for DT_MIPS_FLAGS:

Flag	Value	Meaning
RHF_QUICKSTART	0x00000001	Object may be quickstarted by loader
RHF_NOTPOT	0x00000002	Hash size not a power of two
RHF_NO_LIBRARY_REPLACEMENT	0x00000004	Use default system libraries only
RHF_NO_MOVE	0x00000008	Do not relocate
RHF_RING_SEARCH	0x10000000	Symbol resolution same as DT_SYMBOLIC
RHF_DEPTH_FIRST	0x20000000	Depth first symbol resolution
RHF_USE_31BIT_ADDRESSES	0x40000000	TASO (Truncated Address Support Option) objects

DT_MIPS_BASE_ADDRESS
Contains the base address.

DT_MIPS_CONFLICT
Contains the address of the .conflict section.

DT_MIPS_LIBLIST
Contains the address of the .liblist section.

DT_MIPS_LOCAL_GOTNO
Contains the number of local GOT entries. The dynamic array contains one of these entries for each GOT.

DT_MIPS_CONFLICTNO
Contains the number of entries in the .conflict section and is mandatory if there is a .conflict section.

DT_MIPS_LIBLISTNO
Contains the number of entries in the .liblist section.

DT_MIPS_SYMTABNO
Indicates the number of entries in the .dynsym section.

DT_MIPS_UNREFEXTNO
Holds an index into the dynamic symbol table. The index is the entry of the first external symbol that is not referenced within the object.

corresponds to the second quadword, and so on. Each quadword in the external entry part of the GOT contains the actual address for its corresponding symbol.

The external entries for defined symbols must contain actual addresses. If an entry corresponds to an undefined symbol and the table entry contains a zero, the entry must be resolved by the dynamic loader, even if the dynamic loader is performing a **quickstart**. (See Section 9.3.10 for information about quickstart processing.)

After the system creates memory segments for a loadable object file, the dynamic loader may process the relocation entries. The only relocation entries remaining are type R_REFQUAD or R_REFLONG, referring to local entries in the GOT and data items containing addresses. The dynamic loader determines the associated symbol (or section) values, calculates their absolute addresses, and sets the proper values. Although the absolute addresses may be unknown when the linker builds an object file, the dynamic loader knows the addresses of all memory segments and can find the correct symbols and calculate the absolute addresses.

If a program requires direct access to the absolute address of a symbol, it uses the appropriate GOT entry. Because the shared executable file and shared library file have separate global offset tables, a symbol's address may appear in several tables. The dynamic loader processes all necessary relocations before giving control to the process image, thus ensuring the absolute addresses are available during execution.

The zero (first) entry of the .dynsym section is reserved and holds a null symbol table entry. The corresponding zero entry in the GOT is reserved to hold the address of the entry point in the dynamic loader to call when using **lazy binding** to resolve text symbols (see Section 9.3.3.1 for information about resolving text symbols using lazy binding).

The system may choose different memory segment addresses for the same shared library file in different programs; it may even choose different library addresses for different executions of the same program. Nonetheless, memory segments do not change addresses once the process image is established. As long as a process exists, its memory segments reside at fixed virtual addresses.

A single GOT can hold a maximum of 8190 local and global entries. If a program references 8K or more global symbols, it will have multiple GOTs. Each GOT in a multiple-GOT object is referenced by means of a different global pointer value. A single .got section holds all of the GOTs in a multiple-GOT object.

The DT_MIPS_LOCAL_GOTNO and DT_PLTGOT entries of the dynamic section describe the attributes of the global offset table.

these directories in order and, if a library is not located, it then searches the current directory.

2. The environment variable LD_LIBRARY_PATH can hold a list of colon-separated directories, optionally followed by a semicolon and another directory list. These directories are searched after those specified by DT_RPATH.
3. If the library was not located in any of the directories specified by DT_RPATH or LD_LIBRARY_PATH, the dynamic loader searches /usr/shlib, /usr/ccs/lib, /usr/lib/cmplrs/cc, /usr/lib, and then /usr/local/lib.

The following environment variables are defined:

_RLD_ARGS	Argument to dynamic loader
_RLD_ROOT	Prefix that the dynamic loader adds to all paths except those specified by LD_LIBRARY_PATH

Note

For security, the dynamic loader ignores environmental search specifications, such as LD_LIBRARY_PATH, for set-user-ID and set-group-ID programs.

9.3.3 Global Offset Table (.got)

Position-independent code cannot contain absolute virtual addresses. Global offset tables (GOTs) hold absolute addresses in private data, thus making the addresses available without compromising the position-independence and sharability of a program's text. A program references its global offset table using position-independent addressing and extracts absolute values, thus redirecting position-independent references to absolute locations.

The global offset table is split into two logically separate subtables – local and external:

- Local entries reside in the first part of the table; these are entries for which there are standard local relocation entries. These entries only require relocation if they occur in a shared library file with a memory load address that differs from the virtual address of its loadable segments. As with the defined external entries in the global offset table, these local entries contain actual addresses.
- External entries reside in the second part of the section. Each entry in the external part of the GOT corresponds to an entry in the .dynsym section. The first referenced global symbol in the .dynsym section corresponds to the first quadword of the table, the second symbol

The LD_BIND_NOW environment variable can also change dynamic loader behavior. If its value is non-null, the dynamic loader evaluates all symbol-table entries of type STT_FUNC, replacing their stub addresses in the GOT with the actual address of the referenced function.

Note

Lazy binding generally improves overall application performance because unused symbols do not incur the dynamic loader overhead. Two situations, however, make lazy binding undesirable for some applications:

- The initial reference to a function in a shared object file takes longer than subsequent calls because the dynamic loader intercepts the call to resolve the symbol. Some applications cannot tolerate this unpredictability.
- If an error occurs and the dynamic loader cannot resolve the symbol, the dynamic loader terminates the program. Under lazy binding, this might occur at arbitrary times. Once again, some applications cannot tolerate this unpredictability.

By turning off lazy binding, the dynamic loader forces the failure to occur during process initialization, before the application receives control.

9.3.4 Dynamic Symbol Section (.dynsym)

The dynamic symbol section provides information on all external symbols, either imported or exported from an object.

All externally visible symbols, both defined and undefined, must be hashed into the hash table (see Section 9.3.7).

Undefined symbols of type STT_FUNC that have been referenced only by jsr instructions may contain nonzero values in their st_value field denoting the stub address used for lazy evaluation for this symbol. The dynamic loader uses this to reset the GOT entry for this external symbol to its stub address when unloading a shared library file. All other undefined symbols must contain zero in their st_value fields.

Defined symbols in a shared executable file cannot be preempted. The symbol table in the shared executable file is always searched first to resolve any symbol references.

9.3.3.1 Resolving Calls to Position-Independent Functions

The GOT is used to hold addresses of position-independent functions as well as data addresses. It is not possible to resolve function calls from one shared executable file or shared library file to another at static link time, so all of the function address entries in the GOT would normally be resolved at run time by the dynamic loader. Through the use of specially constructed pieces of code known as stubs, this run-time resolution can be deferred through a technique known as lazy binding.

Using the lazy binding technique, the linker builds a stub for each called function and allocates GOT entries that initially point to the stubs. Because of the normal calling sequence for position-independent code, the call invokes the stub the first time that the call is made.

```
stub_xyz:
    ldq  t12, .got_index(gp)
    lda  $at, .dynsym_index_low(zero)
    ldah $at, .dynsym_index_high($at)
    jmp  t12, (t12)
```

The stub code loads register t12 with an entry from the GOT. The entry loaded into register t12 is the address of the procedure in the dynamic loader that handles lazy binding. The stub code also loads register $at with the index into the .dynsym section of the referenced external symbol. The code then transfers control to the dynamic loader and loads register t12 with the address following the stub. The dynamic loader determines the correct address for the called function and replaces the address of the stub in the GOT with the address of the function.

Most undefined text references can be handled by lazy text evaluation, except when the address of a function is used in other than a jsr instruction. In the exception case, the program uses the address of the stub instead of the actual address of the function. Determining which case is in effect is based on the following processing:

- The linker generates symbol-table entries for all function references with the st_shndx field containing SHN_UNDEF and the st_type field containing STT_FUNC.
- The dynamic loader examines each symbol-table entry when it starts execution:
  - If the st_value field for one of these symbols is nonzero, only jsr references were made to the function and nothing needs to be done to the GOT entry.
  - If the field is zero, some other kind of reference was made to the function and the GOT entry must be replaced with the actual address of the referenced function.

Value	Description
STT_OBJECT	Indicates that the symbol is a data object.
STT_FUNC	Indicates that the symbol is a function.
STT_SECTION	Indicates that the symbol is associated with a program section.
STT_FILE	Indicates that the symbol as the name of a source file.

st_other
Currently holds a value of zero and has no defined meaning.

st_shndx
Identifies the section to which this symbol is related.

All symbols are defined relative to some program section. The st_shndx field identifies the section and can have one of the following values:

Value	Description
SHN_UNDEF	Indicates that the symbol is undefined.
SHN_ABS	Indicates that the symbol has an absolute value.
SHN_COMMON	Indicates that the symbol has common storage (unallocated).
SHN_MIPS_ACOMMON	Indicates that the symbol has common storage (allocated).
SHN_MIPS_TEXT	Indicates that the symbol is in a text segment.
SHN_MIPS_DATA	Indicates that the symbol is in a data segment.

The entries of the dynamic symbol section are ordered as follows:

- A single null entry.
- Symbols local to the object.
- Unreferenced global symbols, that is, symbols that are defined within the object but not referenced.
- Referenced global symbols. These symbols correspond one-to-one with the GOT entries for global symbols.

Figure 9-2 shows the layout of the .dynsym section and its relationship to the .got section.

The dynamic symbol section contains an array of entries of the following type:

```
typedef struct {
    Elf32_Word      st_name;
    Elf32_Addr      st_value;
    Elf32_Word      st_size;
    unsigned char   st_info;
    unsigned char   st_other;
    Elf32_Half      st_shndx;
} Elf32_Sym;
```

The structure members in the preceding structure definition provide the following information:

st_name
Contains the offset of the symbol's name in the dynamic string section.

st_value
Contains the value of the symbol for those symbols defined within the object; otherwise, contains the value zero.

st_size
Identifies the size of symbols with common storage allocation; otherwise, contains the value zero. For STB_DUPLICATE symbols, the size field holds the index of the primary symbol.

st_info
Identifies the symbol's binding and type. The macros ELF32_ST_BIND and ELF32_ST_TYPE are used to access the individual values.

A symbol's binding determines the linkage visibility and behavior. The binding is encoded in the st_info field and can have one of the following values:

Value	Description
STB_LOCAL	Indicates that the symbol is local to the object.
STB_GLOBAL	Indicates that the symbol is visible to other objects.
STB_WEAK	Indicates that the symbol is a weak global symbol.
STB_DUPLICATE	Indicates the symbol is a duplicate. (Used for objects that have multiple GOTs.)

A symbol's type identifies its use. The type is encoded in the st_info field and can have one of the following values:

Value	Description
STT_NOTYPE	Indicates that the symbol has no type or its type is unknown.

r_offset
: Identifies the location within the object to be adjusted.

r_info
: Identifies the relocation type and the index of the symbol that is referenced. The macros ELF32_R_SYM and ELF32_R_TYPE access the individual attributes. The relocation type must be either R_REFQUAD or R_REFLONG.

The entries of the dynamic relocation section are ordered by symbol index value.

The DT_REL and DT_RELSZ entries of the dynamic section describe the attributes of the dynamic relocation section.

9.3.6 Msym Section (.msym)

The optional .msym section contains precomputed hash values and dynamic relocation indexes for each entry in the dynamic symbol table. Each entry in the .msym section maps directly to an entry in the .dynsym section. The .msym section is an array of entries of the following type:

```
typedef struct
{
    Elf32_Word  ms_hash_value;
    Elf32_Word  ms_info;
} Elf32_Msym;
```

The structure members in the preceding structure definition provide the following information:

ms_hash_value
: The hash value computed from the name of the corresponding dynamic symbol.

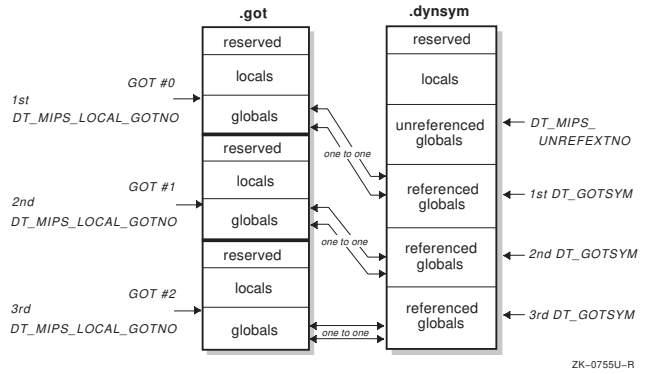
ms_info
: Contains both the dynamic relocation index and the symbol flags field. The macros ELF32_MS_REL_INDEX and ELF32_MS_FLAGS are used to acess the individual values.

  The dynamic relocation index identifies the first entry in the .rel.dyn section that references the dynamic symbol corresponding to this msym entry. If the index is 0, no dynamic relocations are associated with the symbol.

The symbol flags field is reserved for future use.

The DT_MIPS_MSYM entry of the dynamic section contains the address of the .msym section.

Figure 9-2: Relationship Between .dynsym and .got



The DT_SYMENT and DT_SYMTAB entries of the dynamic section describe the attributes of the dynamic symbol table.

9.3.5 Dynamic Relocation Section (.rel.dyn)

The dynamic relocation section describes all locations within the object that must be adjusted if the object is loaded at an address other than its linked base address.

Only one dynamic relocation section is used to resolve addresses in data items, and it must be called .rel.dyn. Shared executable files can contain normal relocation sections in addition to a dynamic relocation section. The normal relocation sections may contain resolutions for any absolute values in the main program. The dynamic linker does not resolve these or relocate the main program.

As noted previously, only R_REFQUAD and R_REFLONG relocation entries are supported in the dynamic relocation section.

The dynamic relocation section is an array of entries of the following type:

```
typedef struct {
    Elf32_Addr      r_offset;
    Elf32_Word      r_info;
} Elf32_Rel;
```

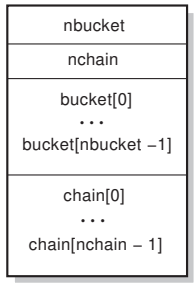
The structure members in the preceding structure definition provide the following information:

9.3.7 Hash Table Section (.hash)

A hash table of `Elf32_Word` entries provides fast access to symbol entries in the dynamic symbol section. Figure 9-3 shows the contents of a hash table. The entries in the hash table contain the following information:

- The `nbucket` entry indicates the number of entries in the `bucket` array.
- The `nchain` entry indicates the number of entries in the `chain` array.
- The `bucket` and `chain` entries hold symbol table indexes; the entries in `chain` parallel the symbol table. The number of symbol table entries should be equal to `nchain`; symbol table indexes also select `chain` entries.

Figure 9-3: Hash Table Section



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The hashing function accepts a symbol name and returns a value that can be used to compute a `bucket` index. If the hashing function returns the value `X` for a name, `bucket[X % nbucket]` gives an index, `Y`, into the symbol table and `chain` array. If the symbol table entry indicated is not the correct one, `chain[Y]` indicates the next symbol table entry with the same hash value. The `chain` links can be followed until the correct symbol table entry is located or until the `chain` entry contains the value `STN_UNDEF`.

The `DT_HASH` entry of the dynamic section contains the address of the hash table section.

9.3.8 Dynamic String Section (.dynstr)

The dynamic string section is the repository for all strings referenced by the dynamic linking sections. Strings are referenced by using a byte offset within the dynamic string section. The end of the string is denoted by a byte containing the value zero.

The `DT_STRTAB` and `DT_STRSZ` entries of the dynamic section describe the attributes of the dynamic string section.

9.3.9 Initialization and Termination Functions

After the dynamic loader has created the process image and performed relocations, each shared object file gets the opportunity to execute initialization code. The initialization functions are called in reverse-dependency order. Each shared object file's initialization functions are called only after the initialization functions for its dependencies have been executed. All initialization of shared object files occurs before the executable file gains control.

Similarly, shared object files can have termination functions that are executed by the `atexit` mechanism when the process is terminating. Termination functions are called in dependency order – the exact opposite of the order in which initialization functions are called.

Shared object files designate initialization and termination functions through the `DT_INIT` and `DT_FINI` entries in the dynamic structure. Typically, the code for these functions resides in the `.init` and `.fini` sections.

Note

Although `atexit` termination processing normally is done, it is not guaranteed to have executed when the process terminates. In particular, the process does not execute the termination processing if it calls `_exit` or if the process terminates because it received a signal that it neither caught nor ignored.

9.3.10 Quickstart

The quickstart capability provided by the assembler supports several sections that are useful for faster startup of programs that have been linked with shared library files. Some ordering constraints are imposed on these sections. The group of structures defined in these sections and the ordering constraints allow the dynamic loader to operate more efficiently. These additional sections are also used for more complete dynamic shared library file version control.

LL_IGNORE_INT_VER
: At run time, ignore any version incompatibility between the dynamic shared library file and the shared library file used at static link time.

  Normally, if neither LL_EXACT_MATCH nor LL_IGNORE_INT_VER bits are set, the dynamic loader requires that the version of the dynamic shared library match at least one of the colon separated version strings indexed by the l_version string table index.

The DT_MIPS_LIBLIST and DT_MIPS_LIBLISTNO entries of the dynamic section describe the attributes of the shared object list section.

9.3.10.2 Conflict Section (.conflict)

Each .conflict section is an array of indexes into the .dynsym section. Each index entry identifies a symbol that is multiply defined in either of the following ways:

- The symbol is defined in the shared object file and one or more of the shared library files that the shared object file depends on.
- The symbol is defined in two or more or the shared library files that the shared object file depends on.

The shared library files that the shared object file depends on are identified at static link time.

The symbols identified in this section must be resolved by the dynamic loader, even if the object is quickstarted. The dynamic loader resolves all references of a multiply-defined symbol to a single definition.

The .conflict section is an array of Elf32_Conflict elements:

```
typedef Elf32_Word Elf32_Conflict;
```

The DT_MIPS_CONFLICT and DT_MIPS_CONFLICTNO entries of the dynamic section describe the attributes of the conflict section.

9.3.10.3 Ordering of Sections

In order to take advantage of the quickstart capability, ordering constraints are imposed on the .rel.dyn section. The .rel.dyn section must have all local entries first, followed by the external entries. Within these subsections, the entries must be ordered by symbol index. This groups each symbol's relocations together.

9.3.10.1 Shared Object List (.liblist)

A shared object list section is an array of Elf32_Lib structures that contains information about the various dynamic shared library files used to statically link the shared object file. Each shared library file used has an entry in the array. Each entry has the following format:

```
typedef struct {
    Elf32_Word l_name;
    Elf32_Word l_time_stamp;
    Elf32_Word l_checksum;
    Elf32_Word l_version;
    Elf32_Word l_flags;
} Elf32_Lib;
```

The structure members in the preceding structure definition provide the following information:

l_name
: Specifies the name of a shared library file. Its value is a string table index. This name can be a full pathname, relative pathname, or file name.

l_time_stamp
: Contains a 32-bit time stamp. The value can be combined with the l_checksum value and the l_version string to form a unique identifier for this shared library file.

l_checksum
: Contains the sum of all common sizes and all string names of externally visible symbols.

l_version
: Specifies the interface version. Its value is a string table index. The interface version is a string containing no colons. It is compared to a colon separated string of versions pointed to by a dynamic section entry of the shared library file. Shared library file with matching names may be considered incompatible if the interface version strings are deemed incompatible. An index value of zero means no version string is specified and is equivalent to the string _null.

l_flags
: Specifies a set of 1-bit flags.

  The l_flags field can have one or both of the following flags set:

  LL_EXACT_MATCH
  : At run time, use a unique ID composed of the l_time_stamp, l_checksum, and l_version fields to demand that the run-time dynamic shared library file match exactly the shared library file used at static link time.

Operand Specifier	Description
val_immed	An immediate value that is to be used in an operation.
jhint	An address operand that provides a hint of where a `jmp` or `jsr` instruction will transfer control.
rhint	An immediate operand that provides software with a hint about how a `ret` or `jsr_coroutine` instruction is used.

The tables in this appendix are segmented into groups of instructions that have the same operand options; the operands specified within a particular segment of the table apply to all of the instructions contained in that segment.

Table A-1: Main Instruction Set Summary

Instruction	Mnemonic	Operands
Load Address	`lda`[a]	*d_reg, address*
Load Byte	`ldb`	
Load Byte Unsigned	`ldbu`	
Load Word	`ldw`	
Load Word Unsigned	`ldwu`	
Load Sign Extended Longword	`ldl`[a]	
Load Sign Extended Longword Locked	`ldl_l`[a]	
Load Quadword	`ldq`[a]	
Load Quadword Locked	`ldq_l`[a]	
Load Quadword Unaligned	`ldq_u`[a]	
Load Unaligned Word	`uldw`	
Load Unaligned Word Unsigned	`uldwu`	
Load Unaligned Longword	`uldl`	
Load Unaligned Quadword	`uldq`	
Store Byte	`stb`	*s_reg, address*
Store Word	`stw`	
Store Longword	`stl`[a]	
Store Longword Conditional	`stl_c`[a]	
Store Quadword	`stq`[a]	
Store Quadword Conditional	`stq_c`[a]	
Store Quadword Unaligned	`stq_u`[a]	
Store Unaligned Word	`ustw`	
Store Unaligned Longword	`ustl`	
Store Unaligned Quadword	`ustq`	

Instruction Summaries A

The tables in this appendix summarize the assembly-language instruction set:

- Table A-1 summarizes the main instruction set.
- Table A-2 summarizes the floating-point instruction set.
- Table A-3 summarizes the rounding and trapping modes supported by some floating-point instructions.

Most of the assembly-language instructions translate into single instructions in machine code.

The tables in this appendix show the format of each instruction in the main instruction set and the floating-point instruction set. The tables list the instruction names and the forms of operands that can be used with each instruction. The specifiers used in the tables to identify operands have the following meanings:

Operand Specifier	Description
address	A symbolic expression whose effective value is used as an address.
b_reg	Base register. A register containing a base address to which is added an offset (or displacement) value to produce an effective address.
d_reg	Destination register. A register that receives a value as a result of an operation.
d_reg/s_reg	One register that is used as both a destination register and a source register.
label	A label that identifies a location in a program.
no_operands	No operands are specified.
offset	An immediate value that is added to the contents of a base register to calculate an effective address.
palcode	A value that determines the operation performed by a PAL instruction.
s_reg, s_reg1, s_reg2	Source registers. Registers whose contents are to be used in an operation.
val_expr	An expression whose value is used as an absolute value.

Table A-1: (continued)

Instruction	Mnemonic	Operands
Absolute Value Longword	absl	{ *s_reg,d_reg* / *d_reg/s_reg* / *val_immed,d_reg* }
Absolute Value Quadword	absq	
Move	mov	
Negate Longword (without overflow)	negl	
Negate Longword (with overflow)	neglv	
Negate Quadword (without overflow)	negq	
Negate Quadword (with overflow)	negqv	
Logical Complement (NOT)	not	
Sign-Extension Byte	sextb	
Sign-Extension Longword	sextl	
Sign-Extension Word	sextw	
Add Longword (without overflow)	addl	{ *s_reg1,s_reg2,d_reg* / *d_reg/s_reg1,s_reg2* / *s_reg1,val_immed,d_reg* / *d_reg/s_reg1,val_immed* }
Add Longword (with overflow)	addlv	
Add Quadword (without overflow)	addq	
Add Quadword (with overflow)	addqv	
Scaled Longword Add by 4	s4addl	
Scaled Quadword Add by 4	s4addq	
Scaled Longword Add by 8	s8addl	
Scaled Quadword Add by 8	s8addq	
Compare Signed Quadword Equal	cmpeq	
Compare Signed Quadword Less Than	cmplt	
Compare Signed Quadword Less Than or Equal	cmple	
Compare Unsigned Quadword Less Than	cmpult	
Compare Unsigned Quadword Less Than or Equal	cmpule	
Multiply Longword (without overflow)	mull	
Multiply Longword (with overflow)	mullv	
Multiply Quadword (without overflow)	mulq	
Multiply Quadword (with overflow)	mulqv	
Subtract Longword (without overflow)	subl	
Subtract Longword (with overflow)	sublv	
Subtract Quadword (without overflow)	subq	
Subtract Quadword (with overflow)	subqv	
Scaled Longword Subtract by 4	s4subl	
Scaled Quadword Subtract by 4	s4subq	
Scaled Longword Subtract by 8	s8subl	

Table A-1: (continued)

Instruction	Mnemonic	Operands
Load Address High	ldah[a]	*d_reg,offset(b_reg)*
Load Global Pointer	ldgp	
Load Immediate Longword	ldil	*d_reg,val_expr*
Load Immediate Quadword	ldiq	
Branch if Equal to Zero	beq	*s_reg,label*
Branch if Not Equal to Zero	bne	
Branch if Less Than Zero	blt	
Branch if Less Than or Equal to Zero	ble	
Branch if Greater Than Zero	bgt	
Branch if Greater Than or Equal to Zero	bge	
Branch if Low Bit is Clear	blbc	
Branch if Low Bit is Set	blbs	
Branch	br	{ *d_reg,label* / *label* }
Branch to Subroutine	bsr	
Jump	jmp[a]	{ *d_reg,(s_reg),jhint* / *d_reg,(s_reg)* / *(s_reg),jhint* / *(s_reg)* / *d_reg,address* / *address* }
Jump to Subroutine	jsr[a]	
Return from Subroutine	ret	{ *d_reg,(s_reg),rhint* / *d_reg,(s_reg)* / *d_reg,rhint* / *d_reg* / *(s_reg),rhint* / *(s_reg)* / *rhint* / *no_operands* }
Jump to Subroutine Return	jsr_ coroutine[a]	
Architecture Mask	amask	{ *s_reg,d_reg* / *val_immed,d_reg* }
Clear	clr	*d_reg*
Implementation Version	implver	

Table A-1: (continued)

Instruction	Mnemonic	Operands
Insert Word High	inswh	(see previous page)
Insert Word High	inswh	
Insert Longword High	inslh	
Insert Quadword High	insqh	
Mask Byte Low	mskbl	
Mask Word Low	mskwl	
Mask Longword Low	mskll	
Mask Quadword Low	mskql	
Mask Word High	mskwh	
Mask Longword High	msklh	
Mask Quadword High	mskqh	
Zero Bytes	zap	
Zero Bytes NOT	zapnot	
Call Privileged Architecture Library	call_pal	*palcode*
Prefetch Data	fetch	*offset*(*b_reg*)
Prefetch Data, Modify Intent	fetch_m	
Read Process Cycle Counter	rpcc	*d_reg*
No Operation	nop	*no_operands*
Universal No Operation	unop	
Trap Barrier	trapb	
Exception Barrier	excb	
Memory Barrier	mb	
Write Memory Barrier	wmb	

Table Notes:

a. In addition to the normal operands that can be specified with this instruction, relocation operands can also be specified (see Section 2.6.4).

A number of the floating-point instructions in Table A-2 support qualifiers that control rounding and trapping modes. Table notes identify the qualifiers that can be used with a particular instruction. (The notes also identify the isntructions on which relocation operands can be specified.) Qualifiers are appended as suffixes to the particular instructions that support them, for example, the instruction `cvtdg` with the `sc` qualifier would be coded `cvtdgsc`. The qualifier suffixes consist of one or more characters, with each character identifying a particular rounding or trapping mode. Table A-3 defines the rounding or trapping modes associated with each character.

Table A-1: (continued)

Instruction	Mnemonic	Operands
Scaled Quadword Subtract by 8	s8subq	(see previous page)
Scaled Quadword Subtract by 8	s8subq	
Unsigned Quadword Multiply High	umulh	
Divide Longword	divl	
Divide Longword Unsigned	divlu	
Divide Quadword	divq	
Divide Quadword Unsigned	divqu	
Longword Remainder	reml	
Longword Remainder Unsigned	remlu	
Quadword Remainder	remq	
Quadword Remainder Unsigned	remqu	
Logical Product (AND)	and	
Logical Sum (OR)	bis	
Logical Sum (OR)	or	
Logical Difference (XOR)	xor	
Logical Product with Complement (ANDNOT)	bic	
Logical Product with Complement (ANDNOT)	andnot	
Logical Sum with Complement (ORNOT)	ornot	
Logical Equivalence (XORNOT)	eqv	
Logical Equivalence (XORNOT)	xornot	
Move if Equal to Zero	cmoveq	
Move if Not Equal to Zero	cmovne	
Move if Less Than Zero	cmovlt	
Move if Less Than or Equal to Zero	cmovle	
Move if Greater Than Zero	cmovgt	
Move if Greater Than or Equal to Zero	cmovge	
Move if Low Bit Clear	cmovlbc	
Move if Low Bit Set	cmovlbs	
Shift Left Logical	sll	
Shift Right Logical	srl	
Shift Right Arithmetic	sra	
Compare Byte	cmpbge	
Extract Byte Low	extbl	
Extract Word Low	extwl	
Extract Longword Low	extll	
Extract Quadword Low	extql	
Extract Word High	extwh	
Extract Longword High	extlh	
Extract Quadword High	extqh	
Insert Byte Low	insbl	
Insert Word Low	inswl	
Insert Longword Low	insll	
Insert Quadword Low	insql	

Table A-2: Floating-Point Instruction Set Summary

Instruction	Mnemonic	Operands
Load F_Floating	ldf[a]	*d_reg,address*
Load G_Floating (Load D_Floating)	ldg[a]	
Load S_Floating (Load Longword)	lds[a]	
Load T_Floating (Load Quadword)	ldt[a]	
Store F_Floating	stf[a]	*s_reg,address*
Store G_Floating (Store D_Floating)	stg[a]	
Store S_Floating (Store Longword)	sts[a]	
Store T_Floating (Store Quadword)	stt[a]	
Load Immediate F_Floating	ldif	*d_reg, val_expr*
Load Immediate D_Floating	ldid	
Load Immediate G_Floating	ldig	
Load Immediate S_Floating	ldis	
Load Immediate T_Floating	ldit	
Branch Equal to Zero	fbeq	{ *s_reg, label* / *label* }
Branch Not Equal to Zero	fbne	
Branch Less Than Zero	fblt	
Branch Less Than or Equal to Zero	fble	
Branch Greater Than Zero	fbgt	
Branch Greater Than or Equal to Zero	fbge	
Floating Clear	fclr	*d_reg*
Floating Move	fmov	{ *s_reg, d_reg* / *d_reg/s_reg* }
Floating Negate	fneg	
Floating Absolute Value	fabs	
Negate F_Floating	negf[b]	
Negate G_Floating	negg[b]	
Negate S_Floating	negs[c]	
Negate T_Floating	negt[c]	

Table A-2: (continued)

Instruction	Mnemonic	Operands
Copy Sign	cpys	{ *s_reg1, s_reg2, d_reg* / *d_reg/s_reg1, s_reg2* }
Copy Sign Negate	cpysn	
Copy Sign and Exponent	cpyse	
Move if Equal to Zero	fcmoveq	
Move if Not Equal to Zero	fcmovne	
Move if Less Than Zero	fcmovlt	
Move if Less Than or Equal to Zero	fcmovle	
Move if Greater Than Zero	fcmovgt	
Move if Greater Than or Equal to Zero	fcmovge	
Add F_Floating	addf[d]	
Add G_Floating	addg[d]	
Add S_Floating	adds[e]	
Add T_Floating	addt[e]	
Compare G_Floating Equal	cmpgeq[b]	
Compare G_Floating Less Than	cmpglt[b]	
Compare G_Floating Less Than or Equal	cmpgle[b]	
Compare T_Floating Equal	cmpteq[c]	
Compare T_Floating Less Than	cmptlt[c]	
Compare T_Floating Less Than	cmptlt[c]	
Compare T_Floating Unordered	cmptun[c]	
Compare T_Floating Less Than or Equal	cmptle[c]	
Divide F_Floating	divf[d]	
Divide G_Floating	divg[d]	
Divide S_Floating	divs[e]	
Divide T_Floating	divt[e]	
Multiply F_Floating	mulf[d]	
Multiply G_Floating	mulg[d]	
Multiply S_Floating	muls[e]	
Multiply T_Floating	mult[e]	
Subtract F_Floating	subf[d]	
Subtract G_Floating	subg[d]	
Subtract S_Floating	subs[e]	
Subtract T_Floating	subt[e]	
Convert Quadword to Longword	cvtql[f]	{ *s_reg, d_reg* / *d_reg/s_reg* }
Convert Longword to Quadword	cvtlq	
Convert G_Floating to Quadword	cvtgq[g]	
Convert T_Floating to Quadword	cvttq[h]	
Convert Quadword to F_Floating	cvtqf[i]	
Convert Quadword to G_Floating	cvtqg[i]	
Convert Quadword to S_Floating	cvtqs[j]	
Convert Quadword to T_Floating	cvtqt[j]	
Convert D_Floating to G_Floating	cvtdg[d]	
Convert G_Floating to D_Floating	cvtgd[d]	
Convert G_Floating to F_Floating	cvtgf[d]	
Convert T_Floating to S_Floating	cvtts[e]	
Convert S_Floating to T_Floating	cvtst[b]	

Table A-2: (continued)

Instruction	Mnemonic	Operands
Move From FP Control Register	mf_fpcr	*d_reg*
Move To FP Control Register	mt_fpcr	*s_reg*
Floating No Operation	fnop	*no_operands*

Table notes:

a. In addition to the normal operands that can be specified with this instruction, relocation operands can also be specified (see Section 2.6.4).

b. s

c. su

d. c, u, uc, s, sc, su, suc

e. c, m, d, u, uc, um, ud, su, suc, sum, sud, sui, suic, suim, suid

f. sv, v

g. c, v, vc, s, sc, sv, svc

h. c, v, vc, sv, svc, svi, svic, d, vd, svd, svid

i. c

j. c, m, d, sui, suic, suim, suid

See the text immediately preceding Table A-2 for a description of the table notes.

Table A-3: Rounding and Trapping Modes

Suffix	Description
(no suffix)	Normal rounding
c	Chopped rounding
d	Dynamic rounding
m	Minus infinity rounding
s	Software completion
u	Underflow trap enabled
v	Integer overflow trap enabled
i	Inexact trap enabled

In addition, the assembler provides the following longword macro instructions:

- Divide Longword (`divl, divlu`)
- Remainder Longword (`reml, remlu`)
- Negate Longword (`negl, neglv`)
- Unaligned Load Longword (`uldl`)
- Load Immediate Longword (`ldil`)
- Absolute Value Longword (`absl`)
- Sign-Extension Longword (`sextl`)

All longword instructions, with the exception of `stl` and `stl_c`, generate results in canonical form.

All longword instructions that have source operands produce correct results regardless of whether the data items in the source registers are in canonical form.

See Chapter 3 for a detailed description of the longword instructions.

B.3 Quadword Instructions for Longword Operations

The following quadword instructions, if presented with two canonical longword operands, produce a canonical longword result:

- Logical AND (`and`)
- Logical OR (`bis`)
- Logical Exclusive OR (`xor`)
- Logical OR NOT (`ornot`)
- Logical Equivalence (`eqv`)
- Conditional Move (`cmov`*xx*)
- Compare (`cmp`*xx*)
- Conditional Branch (`b`*xx*)
- Arithmetic Shift Right (`sra`)

Note that these instructions, unlike the longword instructions, must have operands in canonical form to produce correct results.

See Chapter 3 for a detailed description of the quadword instructions.

32-Bit Considerations B

The Alpha AXP architecture is a quadword (64-bit) architecture, with limited backward compatibility for longword (32-bit) operations. The Alpha AXP architecture's design philosophy for longword operations is to use the quadword instructions wherever possible and to include specialized longword instructions for high-frequency operations.

B.1 Canonical Form

Longword operations deal with longword data stored in canonical form in quadword registers. The canonical form has the longword data in the low 32 bits (0-31) of the register, with bit 31 replicated in the high 32 bits (32-63). Note that the canonical form is the same for both signed and unsigned longword data.

To create a canonical form operand from longword data, use the `ldl`, `ldl_l`, or `uldl` instruction.

To create a canonical form operand from a constant, use the `ldil` instruction. The `ldil` instruction is a macro instruction that expands into a series of instructions, including the `lda` and `ldah` instructions.

B.2 Longword Instructions

The Alpha architecture includes the following longword instructions:

- Load Longword (`ldl`)
- Load Longword Locked (`ldl_l`)
- Store Longword (`stl`)
- Store Longword Conditional (`stl_c`)
- Add Longword (`addl, addlv`)
- Subtract Longword (`subl, sublv`)
- Multiply Longword (`mull, mullv`)
- Scaled Longword Add (`s4addl, s8addl`)
- Scaled Longword Subtract (`s4subl, s8subl`)

B.4 Logical Shift Instructions

No instructions, either machine or macro, exist for performing logical shifts on canonical longwords.

To perform a logical shift left, the following instruction sequence can be used:

```
sll  $rx, xx, $ry    # noncanonical result
addl $ry, 0, $ry     # sign-extend bit-31
```

To perform a logical shift right, the following instruction sequence can be used:

```
zap  $rx, 0xf0, $ry  # noncanonical result
srl  $ry, xx, $ry    # if xx >= 1, bring in zeros
addl $ry, 0, $ry     # sign-extend bit-31
```

Note that the `addl` instruction is not needed if the shift count in the previous sequence is guaranteed to be non-zero.

B.5 Conversions to Quadword

A signed longword value in canonical form is also a proper signed quadword value and no conversions are needed.

An unsigned longword value in canonical form is not a proper unsigned quadword value. To convert an unsigned longword to a quadword, the following instruction sequence can be used:

```
zap  $rx, 0xf0, $ry  # clear bits 32-63
```

B.6 Conversions to Longword

To convert a quadword value to either a signed or unsigned longword, the following instruction sequence can be used:

```
addl $rx, 0, $ry     # sign-extend bit-31
```

Instruction	Registers Used
divq	AT,t9,t10,t11,t12
divlu	AT,t9,t10,t11,t12
divqu	AT,t9,t10,t11,t12
reml	AT,t9,t10,t11,t12
remq	AT,t9,t10,t11,t12
remlu	AT,t9,t10,t11,t12
remqu	AT,t9,t10,t11,t12

Table Notes:

a. Use of registers depends on the setting of the `.arch` directive or the `-arch` flag on the `cc` command line.

The registers that equate to the software names (from `regdef.h`) in the preceding table are as follows:

Software Name	Register
AT	$28 or $at
t9	$23
t10	$24
t11	$25
t12 or pv	$27

Note

The `div` and `rem` instructions destroy the contents of `t12` only if the third operand is a register other than `t12`. See Section C.5 for more details.

C.2 Addresses

If you use an address as an operand and it references a data item that does not have an absolute address in the range -32768 to 32767, the assembler may generate a machine-code instruction to load the address of the data (from the literal address section) into `$at`.

The assembler's `ldgp` (load global pointer) instruction generates an `lda` and `ldah` instruction. The assembler requires the `ldgp` instruction because `ldgp` couples relocation information with the instruction.

Basic Machine Definition C

The assembly-language instructions described in this book are a superset of the actual machine-code instructions. Generally, the assembly-language instructions match the machine-code instructions; however, in some cases the assembly-language instructions are macros that generate more than one machine-code instruction (the division instructions in assembly language are examples). This appendix describes the assembly-language instructions that generate more than one machine-code instruction.

You can, in most instances, consider the assembly-language instructions as machine-code instructions; however, for routines that require tight coding for performance reasons, you must be aware of the assembly-language instructions that generate more than one machine-code instruction.

C.1 Implicit Register Use

Register `$28` (`$at`) is reserved as a temporary register for use by the assembler.

Some assembly-language instructions require additional temporary registers. For these instructions, the assembler uses one or more of the general-purpose temporary registers (`t0` – `t12`). The following table lists the instructions that require additional temporary registers and the specific registers that they use:

Instruction	Registers Used
ldb	AT,t9
ldbu	AT,t9[a]
ldw	AT,t9
ldwu	AT,t9[a]
stb	AT,t9,t10[a]
stw	AT,t9,t10[a]
ustw	AT,t9,t10,t11,t12
ustl	AT,t9,t10,t11,t12
ustq	AT,t9,t10,t11,t12
uldw	AT,t9,t10
uldwu	AT,t9,t10
uldl	AT,t9,t10
uldq	AT,t9,t10
divl	AT,t9,t10,t11,t12

C.3 Immediate Values

If you use an immediate value as an operand and the immediate value falls outside the range -32768 to 32767 for the `ldil` and `ldiq` instructions or the range 0 – 255 for other instructions, multiple machine instructions are generated to load the immediate value into the destination register or `$at`.

C.4 Load and Store Instructions

On most processors that implement the Alpha architecture, loading and storing unaligned data or data less than 32 bits is done with multiple machine-code instructions. Except on EV56 Alpha processors, the following assembler instructions generate multiple machine-code instructions:

- Load Byte (`ldb`)
- Load Byte Unsigned (`ldbu`)
- Load Word (`ldw`)
- Load Word Unsigned (`ldwu`)
- Unaligned Load Word (`uldw`)
- Unaligned Load Word Unsigned (`uldwu`)
- Unaligned Load Longword (`uldl`)
- Unaligned Load Quadword (`uldq`)
- Store Byte (`stb`)
- Store Word (`stw`)
- Unaligned Store Word (`ustw`)
- Unaligned Store Longword (`ustl`)
- Unaligned Store Quadword (`ustq`)

Signed loads may require one more instruction than an unsigned load.

On EV56 Alpha processors, the following instructions from the preceding list generate a single instruction:

- Load Byte Unsigned (`ldbu`)
- Load Word Unsigned (`ldwu`)
- Store Byte (`stb`)
- Store Word (`stw`)

C.5 Integer Arithmetic Instructions

Multiply operations using constant powers of two are turned into `sll` or scaled add instructions.

There are no machine instructions for performing integer division (`divl`, `divlu`, `divq`, and `divqu`) or remainder operations (`reml`, `remlu`, `remq`, and `remqu`). The machine instructions generated for these assembler instructions depend on the operands specified on the instructions.

Division and remainder operations involving constant values are replaced by an instruction sequence that depends on the data type of the numerator and the value of the constant.

Division and remainder operations involving nonconstant values are replaced with a procedure call to a library routine to perform the operation. The library routines are in the C run-time library (`libc`). The library routines use a nonstandard parameter passing mechanism. The first operand is passed in register `t10` and the second operand is passed in `t11`. The result is returned in `t12`. If the operands specified are other than those just described, the assembler moves them to the correct registers. The library routines expect the return address in `t9`; therefore, a routine that uses divide instructions does not need to save register `ra` just because it uses divide instructions.

The `absl` and `absq` (absolute value) instructions generate two machine instructions.

C.6 Floating-Point Load Immediate Instructions

There are no floating-point instructions that accept an immediate value (except for 0.0). Whenever the assembler encounters a floating-point load immediate instruction, the immediate value is stored in the data section and a load instruction is generated to load the value.

C.7 One-to-One Instruction Mappings

Some assembler instructions generate single machine instructions. Such assembler instructions are sometimes referred to as pseudo-instructions. The following table lists these assembler instructions and their equivalent machine instructions:

Assembler Instruction		Machine Instruction	
`andnot`	`$rx,$ry,$rz`	`bic`	`$rx,$ry,$rz`
`clr`	`$rx`	`bis`	`$31,$31,$rx`
`fabs`	`$fx,$fy`	`cpys`	`$f31,$fx,$fy`
`fclr`	`$fx`	`cpys`	`$f31,$f31,$fx`
`fmov`	`$fx,$fy`	`cpys`	`$fx,$fx,$fy`

Assembler Instruction		Machine Instruction	
fneg	$fx,$fy	cpysn	$fx,$fx,$fy
fnop		cpys	$f31,$f31,$f31
mov	$rx,$ry	bis	$rx,$rx,$ry
mov	*val_immed*,$rx	bis	$31,*val_immed*,$rx
negf	$fx,$fy	subf	$f31,$fx,$fy
negfs	$fx,$fy	subfs	$f31,$fx,$fy
negg	$fx,$fy	subg	$f31,$fx,$fy
neggs	$fx,$fy	subgs	$f31,$fx,$fy
negl	$rx,$ry	subl	$31,$rx,$ry
neglv	$rx,$ry	sublv	$31,$rx,$ry
negq	$rx,$ry	subq	$31,$rx,$ry
negqv	$rx,$ry	subqv	$31,$rx,$ry
negs	$fx,$fy	subs	$f31,$fx,$fy
negssu	$fx,$fy	subssu	$f31,$fx,$fy
negt	$fx,$fy	subt	$f31,$fx,$fy
negtsu	$fx,$fy	subtsu	$f31,$fx,$fy
nop		bis	$31,$31,$31
not	$rx,$ry	ornot	$31,$rx,$ry
or	$rx,$ry,$rz	bis	$rx,$ry,$rz
sextl	$rx,$ry	addl	$rx,0,$ry
unop		ldq_u	$31,0($sp)
xornot	$rx,$ry,$rz	eqv	$rx,$ry,$rz

PALcode Instruction Summaries D

This appendix summarizes the Privileged Architecture Library (PALcode) instructions that are required to support an Alpha AXP system.

By including the file `pal.h` (use `#include <alpha/pal.h>`) in your assembly language program, you can use the symbolic names for the PALcode instructions.

D.1 Unprivileged PALcode Instructions

Table D-1 describes the unprivileged PALcode instructions.

Table D-1: Unprivileged PALcode Instructions

Symbolic Name	Number	Operation and Description
`PAL_bpt`	0x80	Break Point Trap – switches mode to kernel mode, builds a stack frame on the kernel stack, and dispatches to the breakpoint code.
`PAL_bugchk`	0x81	Bugcheck – switches mode to kernel mode, builds a stack frame on the kernel stack, and dispatches to the breakpoint code.
`PAL_callsys`	0x83	System call – switches mode to kernel mode, builds a callsys stack frame, and dispatches to the system call code.
`PAL_gentrap`	0xaa	Generate Trap – switches mode to kernel, builds a stack frame on the kernel stack, and dispatches to the gentrap code.
`PAL_imb`	0x86	I-Stream Memory Barrier – makes the I-cache coherent with main memory.
`PAL_rduniq`	0x9e	Read Unique – returns the contents of the process unique register.
`PAL_wruniq`	0x9f	Write Unique – writes the process unique register.

D.2 Privileged PALcode Instructions

The privileged PALcode instructions can be called only from kernel mode. They provide an interface to control the privileged state of the machine.

Table D-2 describes the privileged PALcode instructions.

Table D-2: Privileged PALcode Instructions

Symbolic Name	Number	Operation and Description
`PAL_halt`	0x00	Halt Processor – stops normal instruction processing. Depending on the halt action setting, the processor can either enter console mode or the restart sequence.
`PAL_rdps`	0x36	Read Process Status – return the current process status.
`PAL_rdusp`	0x3a	Read User Stack Pointer – reads the user stack pointer while in kernel mode and returns it.
`PAL_rdval`	0x32	Read System Value – reads a 64-bit per-processor value and returns it.
`PAL_rtsys`	0x3d	Return from System Call – pops the return address, the user stack pointer, and the user global pointer from the kernel stack. It then saves the kernel stack pointer, sets mode to user mode, enables interrupts, and jumps to the address popped off the stack.
`PAL_rti`	0x3f	Return from Trap, Fault, or Interrupt – pops certain registers from the kernel stack. If the new mode is user mode, the kernel stack is saved and the user stack is restored.
`PAL_swpctx`	0x30	Swap Privileged Context – saves the current process data in the current process control block (PCB). Then it switches to the PCB and loads the new process context.
`PAL_swpipl`	0x35	Swap IPL – returns the current IPL value and sets the IPL.
`PAL_tbi`	0x33	TB Invalidate – removes entries from the instruction and data translation buffers when the mapping entries change.

Table D-2: (continued)

Symbolic Name	Number	Operation and Description
PAL_whami	0x3c	Who Am I – returns the process number for the current processor. The processor number is in the range 0 to the number of processors minus one (0..numproc-1) that can be configured into the system.
PAL_wrfen	0x2b	Write Floating-Point Enable – writes a bit to the floating-point enable register.
PAL_wrkgp	0x37	Write Kernel Global Pointer – writes the kernel global pointer internal register.
PAL_wrusp	0x38	Write User Stack Pointer – writes a value to the user stack pointer while in kernel mode.
PAL_wrval	0x31	Write System Value – writes a 64-bit per-processor value.
PAL_wrvptptr	0x2d	Write Virtual Page Table Pointer – writes a pointer to the virtual page table pointer (vptptr).

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