HP Assembler Reference Manual

HP 9000 Computers

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Preface

This manual describes the use of the Precision Architecture RISC (PA-RISC) Assembler on HP 9000 computers.

You need to be familiar with the machine instructions to use the Assembler. For a complete description of the machine instruction set, refer to *PA-RISC 1.1 Architecture and Instruction Set Reference Manual* and *PA-RISC 2.0 Architecture*.

Note that, throughout this manual, there are references to PA-RISC 1.0, 1.1, and 2.0. Each version of the architecture is a superset of the preceding version.

Any program written for PA-RISC 1.0 machines will execute on PA-RISC 1.1 and 2.0 machines, but programs using instructions unique to PA-RISC 1.1 will not execute on PA-RISC 1.0 machines. Any program written for PA-RISC 1.1 machines will execute on PA-RISC 2.0 machines, but programs using features unique to PA-RISC 2.0 will not execute on PA-RISC 1.1 or 1.0 machines.

Printing History

New editions are complete revisions of the manual. Technical addendums or release notes may be released as supplements.

The software version is the version level of the software product at the time the manual was issued. Many product updates and fixes do not require manual changes and, conversely, manual corrections may be done without accompanying product changes. Therefore, do not expect a one-to-one correspondence between product updates and manual updates.

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Audience

This manual assumes that you are an experienced assembly language programmer. In addition, you should have detailed understanding of the PA-RISC and hardware features, and a working knowledge of the HP-UX operating system, program structures, procedure calling conventions, and stack unwind procedures.

Related Documentation

For more information on HP-UX programming, refer to the following documents:

- *PA-RISC 2.0 Architecture* by Gerry Kane (Prentice-Hall, ISBN 0-13-182734-0)

- *HP-UX Linker and Libraries Online User Guide*, (`ld +help`)
- *64-bit Runtime Architecture for PA-RISC 2.0*. URL: http://www.software.hp.com/STK/
- *ELF 64 Object File Format*. URL: http://www.software.hp.com/STK/

Typographical Conventions

Unless otherwise noted in the text, this manual uses the following symbolic conventions.

`computer font`	Computer font indicates commands, keywords, options, literals, source code, system output, and path names. In syntax formats, computer font indicates commands, keywords, and punctuation that you must enter exactly as shown.
`bold face text`	In examples, bold face text represents user input.
italic type	In syntax formats, words or characters in italics represent values that you must supply. Italics are also used for book titles and for emphasis.
`[ ]`	In syntax formats, square brackets enclose optional items.
`{ }`	In syntax formats, braces enclose a list from which you must choose an item.
`...`	In syntax formats, a horizontal ellipsis indicates that you can repeat the preceding item one or more times.
name(N)	An italicized word followed by a number in parentheses indicates an entry in *HP-UX Reference*. For example, *cc*(1) refers to the *cc* entry in Section 1 of *HP-UX Reference*.

In This Manual

The manual is organized as follows:

Chapter 1	Introduces the Assembler for HP 9000 computers.
Chapter 2	Explains assembly language program structure.

Chapter 3	Explains programming in Assembler for HP-UX.
Chapter 4	Describes the PA-RISC Assembler directives and pseudo-operations.
Chapter 5	Summarizes the pseudo-instructions for the PA-RISC machine instructions.
Chapter 6	Describes the assembly (`as`) command and the ways to invoke the PA-RISC Assembler under the HP-UX operating system.
Chapter 7	Contains several sample assembly language programs.
Chapter 8	Lists the diagnostic messages that the PA-RISC Assembler can generate.

Summary of Technical Changes for HP-UX 11.0

The following features have changed for HP-UX 11.00 to support PA-RISC 2.0W (wide), 64-bit mode. These changes are explained in detail in the appropriate locations in this manual.

- In 64-bit mode, the linkage pointer register is `%r27`. See Table 2-11, “Available Field Selectors,” on page 31.
- In 64-bit mode, the Executable and Linking Format (ELF) uses segments and sections rather than spaces and subspaces. See “Sections in 64-bit Mode” on page 44.
- The Assembler ignores the `.CALL` directive. This means that your program must ensure that the caller and called procedure agree on argument locations. See “.CALL Directive” on page 63.
- The .CALLINFO directive parameters include updates to support 64-bit mode.
- You can specify 2.0W with the .LEVEL directive to tell the the Assembler to generate 64-bit object code. For details, see “.LEVEL Directive” on page 93.
- New and changed Assembler error messages. For details, see Chapter 8, “Diagnostic Messages,” on page 141.

1 Introduction to PA-RISC Assembly Language

The HP 9000 Assembly Language represents machine language instructions symbolically, and permits declaration of addresses symbolically as well. The Assembler's function is to translate an assembly language program, stored in a *source file*, into machine language. The result of this translation resides in a *relocatable object file*. The object file is relocatable because it can still be combined with other relocatable object files and libraries. Therefore, it is necessary to relocate any addresses that the Assembler chooses for the symbols in the source program.

This process of combining object files and libraries is performed by the linker, `ld`. The linker's task is to transform one or more relocatable object files into an executable *program file*. Every program must be linked before it can be executed, even if the source file is complete within itself and does not need to be combined with other files.

Assembler Features

The Assembler provides a number of features to make assembly language programming convenient. These features include:

- **Mnemonic Instructions.** Each machine instruction is represented by a mnemonic operation code, which is easier to remember than the binary machine language operation code. The operation code, together with operands, directs the Assembler to output a binary machine instruction to the object file.
- **Symbolic Addresses.** You can select a symbol to refer to the address of a location in virtual memory. The address is often referred to as the *value* of the symbol, which should not be confused with the value of the memory locations at that address. These symbols are called *relocatable symbols* because the actual addresses represented by such symbols are subject to relocation by the linker.
- **Symbolic Constants.** A symbol can also be selected to stand for an integer constant. These symbols are called *absolute symbols* because the values of such symbols are not relocatable.

- **Expressions.** Arithmetic expressions can be formed from symbolic addresses and constants, integer constants, and arithmetic operators. Expressions involving only symbolic and integer constants, or the difference between two relocatable symbols, defined in the current module, are called *absolute expressions*. They can be used wherever an integer constant can be used. Expressions involving the sum or difference of a symbolic address and an absolute expression are called *relocatable expressions* or *address expressions*. The constant part of an expression, the part that does not refer to relocatable expressions, can use parenthesized subexpressions to alter operator precedence.
- **Storage Allocation.** In addition to encoding machine language instructions symbolically, storage may be initialized to constant values or simply reserved. Symbolic addresses and *labels* can be associated with these memory locations.
- **Symbol Scope.** When two or more object files are to be combined by the linker, certain symbolic addresses can be defined in one module and used in another. Such symbols must be *exported* from the defining module and *imported* into the using module. In the defining module, the symbol has *universal* scope, while in the using module, the symbol is *unsatisfied*. Other symbols declared in the source program that are not exported have *local* scope.
- **Subspaces and Location Counters.** You can organize code and data into separate subspaces, and into separate location counters within each subspace. The programmer can move among the subspaces and location counters, while the Assembler changes the code and data into the correct order. In 64-bit mode, however, the Executable and Linking Format (ELF) uses segments and sections rather than spaces and subspaces.
- **Macro Processing.** A *macro* is a user-defined word, which is replaced by a sequence of instructions. Including a macro in a source program causes the sequence of instructions to be inserted into the program wherever the macro appears.

Summary of Changes for PA-RISC 2.0

The following features have changed in PA-RISC 2.0 architecture. These changes are explained in more detail in the appropriate locations in this manual.

- A new .DWORD directive reserves 64 bits (a double word) of storage and initializes it to the given value.
- A .LEVEL 2.0 directive should be used as the first directive in the source file to assemble it for a PA-RISC 2.0 system.
- New +DA2.0 option
- New and changed Assembler error messages

Summary of Changes for PA-RISC 2.0W (Wide Mode, 64-bit)

The Assembler for PA-RISC 2.0W, the 64-bit version of PA-RISC 2.0, maintains the same source syntax as that of PA1.x and PA2.0 32-bit mode versions. However, PA2.0W features differ in the features listed below.

- To assemble a source file for a PA-RISC 64-bit system, use a .LEVEL 2.0W directive as the first directive in the source file. See ".LEVEL Directive" on page 93.
- The Assembler generates an Executable and Linking Format (ELF) object file format with PA-RISC 2.0W. Refer to the *ELF 64 Object File Format*, URL: http://www.software.hp.com/STK/ for details on ELF format.
- PA-RISC 2.0W supports a flat virtual address space of 2**64 bytes, and therefore does *not* support use of space registers. Use the following syntax when memory operations are used:

  ```
  ex: LDD disp(b), tgt
  ```

You can explicitly use space registers, however, the Assembler issues a warning if it is other than `sr0`.

- Some of the completers on `ADDB` and `ADDIB` instructions are not valid for PA2.0W. In addition, new completers are available.

  For example: `ZNV`, `SV`, and `OD` are not valid whereas *=, *<, and *<= are additional completers.

  Please refer to the *PA-RISC 2.0 Architecture* guide for details.

- The displacement on both general load/store and floating load/store instructions can be up to 16 bits. For example,

```
ex: FLDD disp(b),tgt       ; displacement can be up to 16 bits.
```

  Please refer to *PA-RISC 2.0 Architecture* for details.

- You must change any `.WORD` directives that are initialized with a code symbol or data symbol to `.DWORD`.

- You can not use space identification operations such as `MTSP` and `LDSID` used for dealing with space registers in user level code. Currently, the Assembler does *not* give any warning.

- The procedure calling conventions are different in the HP-UX PA-RISC 2.0 64-bit architecture. In PA 2.0W, you can pass the first eight parameters in registers (arg0-arg7). In earlier versions (PA1.0 and PA1.1) and on PA-RISC 2.0, you can only pass the first four parameters in registers(arg0-arg3). For more information, please refer to the *64-bit Runtime Architecture for PA-RISC 2.0*, at URL: http://www.software.hp.com/STK/.

2 Program Structure

An assembly language program is a sequence of *statements*. There are three classes of statements:

- Instructions
- Pseudo-operations
- Directives

Instructions represent a single machine instruction in symbolic form. Pseudo-operations cause the Assembler to initialize or reserve one or more words of storage for data, rather than machine instructions. Directives communicate information about the program to the Assembler, but do not generally cause the Assembler to output any machine instructions.

An assembly statement contains four *fields*:

- Label
- Opcode
- Operands
- Comments

Each of these fields is optional. However the operands field cannot appear without an opcode field.The *label* field is used to associate a symbolic address with an instruction or data location, or to define a symbolic constant using the `.EQU`, `.REG`, or `.MACRO` directives. This field is optional for all but a few statement types; if present, the label must begin in column one of a source program line. If a label appears on a line by itself, or with a comment only, the label is associated with the next address within the same subspace and location counter.

When the label field begins with the pound sign (#) character, it is not treated as a label. If # is followed by white space and an integer, the Assembler's line number counter, used when reporting errors, is reset to the value of the integer. Otherwise, the line beginning with # is ignored. This feature is for the use of the C language preprocessor `cpp`.

The *opcode* field contains either a mnemonic machine instruction, a pseudo-operation code, or the name of an Assembler directive. It must be separated from the label field by a blank or tab. For certain machine instructions, the opcode field can also contain *completers*, separated from the instruction mnemonic by commas.

The machine instruction mnemonics and completers are described in the *PA-RISC 1.1 Architecture and Instruction Set Reference Manual* and *PA-RISC 2.0 Architecture*.

The *operands* field follows the opcode field, separated by a blank or tab. Operands are separated by commas. The meaning of the operands depends on the specific statement type, determined by the opcode.

The number of operands permitted or required depends upon the specific instruction.

The *comments* field is introduced with a semicolon, and causes the Assembler to ignore the remainder of the source line. A comment can appear on a line by itself.

The following listing contains several assembly language statements. The headings identify the four fields.

```
Label   Opcode   Operands                Comments
JAN     .EQU     1                       ;declares a symbolic constant
SUM     .WORD    0                       ;reserve a word and set to zero
LOOP    LDW      4(%r1),%r2
        ADD      %r2,%r3,%r4
        STW      %r4,SUM-$global$(%dp)
        BL       LOOP,%r0
```

Statements are normally written on separate lines. It is sometimes useful, especially when using a macro preprocessor, to be able to write several statements on one line. This can be done by separating the statements with the "!" character. When this feature is used, a label can be placed only on the first statement of the line, and a comment can only follow the last statement on the line. The `.LABEL` directive can override this condition by providing a means for declaring a label within a multi-statement line.

Symbols and Constants

Both addresses and constants can be represented symbolically. Labels represent a symbolic address except when the label is on an `.EQU`, `.REG`, or `.MACRO` directive. If the label is on an `.EQU` or `.REG` directive, the label represents a symbolic constant. If the label is the `.MACRO` directive, the label represents a macro name.

Symbols are composed of uppercase and lowercase letters (`A-Z` and `a-z`), decimal digits (`0-9`), dollar signs (`$`), periods (`.`), ampersands (`&`), pound signs (`#`), and underscores (`_`). A symbol can begin with a letter, digit, underscore, or dollar sign. If a symbol begins with a digit it must contain a non-digit character. (The predefined register symbols begin with a percent sign (`%`).)

The Assembler considers uppercase and lowercase letters in symbols to be distinct. The mnemonics for operation codes, directives, and pseudo-operations can be written in either case. There is no explicit limit on the length of a symbol. The following are examples of legal symbols:

```
$START$   _start    PROGRAM   M$3       $global$
$$mulI    main      P_WRITE   loop1     1st_time
```

The following are examples of illegal symbols:

`LOOP|1`	*Contains an illegal character*
`&st_time`	*Begins with &*
`123`	*Does not contain a nondigit*

Integer constants can be written in decimal, octal, or hexadecimal notation, as in the C language. “Integer Constants” on page 22 lists the ranges of these integer constants.

Table 2-1 Integer Constants

	Signed	Unsigned
Decimal	-2147483648 through 2147483647	0 through 4294967295
Octal	020000000000 through 017777777777	0 through 037777777777
Hexadecimal	0x80000000 through 0x7FFFFFFF	0 through 0xFFFFFFFF

The period (.) is a special symbol reserved to denote the current offset of the location counter. It is useful in address expressions to refer to a location relative to the current instruction or data word. This symbol is considered relocatable, and can be used anywhere a relocatable symbol can be used, with the exception of the label field.

The period cannot be used in an expression involving another label, such as *sym*`+.`, *sym*`-.`, `.+`*sym*, or `.-`*sym*. It can be used in an expression that has only a constant, such as `.+8` or `.-8`.

Registers and Register Mnemonics

PA-RISC processors have four sets of registers:

- General
- Floating-point
- Space
- Control

Data is loaded from memory into general or floating-point registers and stored into memory from general or floating-point registers. Arithmetic and logical operations are performed on the contents of the general registers. On PA-RISC 1.0 or 1.1 each general register is 32 bits wide. On PA-RISC 2.0 each general register is 64 bits wide. On PA-RISC 2.0W (true 64-bit environment) each general register is 64 bits wide.

There are 32 general registers, denoted as `%r0` through `%r31`. General register `%r0` is special because "writes" into it are ignored, and it always reads as zero. The remaining general registers can be used normally, with the caution that `%r1` is the implicit target register for the `ADDIL` instruction, `%r31` is the implicit link register for the `BLE` instruction, and for PA-RISC 2.0 only, `%r2` is the implicit link register for the BLVE instruction. Certain general registers also have predefined conventional uses. Refer to "Register Procedure Calling Conventions" on page 28. You can find detailed information on both 32-bit and 64-bit runtime architecture under the topic PA-RISC Architecture at http://www.software.hp.com/STK/.

PA-RISC 1.0 machines have 16 floating-point registers; PA-RISC 1.1, 2.0, and 2.0W (true 64-bit environment) machines have 32 floating-point registers. Each register is capable of holding either a single- or double-precision floating-point number in IEEE format. These registers are denoted `%fr0` through `%fr15` for PA-RISC 1.0 and `%fr0` through `%fr31` for PA-RISC 1.1, 2.0, and 2.0W.

Registers `%fr1`, `%fr2`, and `%fr3` are exception registers and are not available to the programmer. Floating-point register `%fr0` contains a permanent floating-point zero when used in an arithmetic operation; when written or read with floating-point loads or stores, the floating-point status register is actually accessed.

In addition, on PA-RISC 1.1, 2.0. and 2.0W the left and right halves of the floating-point registers can be accessed as separate single-precision registers by using an `L` or `R` suffix.

For example, `%fr8R` accesses the right-most 32 bits of `%fr8` as a single-precision number.

The `L` or `R` suffixes can only be used on the predefined floating-point registers in the form `%fr`*nn*, where *nn* is the register number. It is not legal to use `L` or `R` with an integer value. For example, `%fr8R` is legal; `8R` is not legal.

The space registers form the basis of the virtual memory system. Each of the eight space registers can hold a 16- or 32-bit space identifier, depending on the hardware model. The space registers are denoted as `%sr0` through `%sr7`. Space register `%sr0` is set implicitly by the `BLE` instruction, and space registers `%sr5` through `%sr7` cannot be modified except by code running at the most privileged level.

The control registers contain system-state information. There are 25 control registers, denoted as `%cr0` and `%cr8` through `%cr31`. Of these registers, only `%cr11` (`%sar`), the shift amount register, and `%cr16` (`%itmt`), the interval timer, are normally accessible to the user-level programmer. The other registers are accessed only by code running at the most privileged level.

Register operands are denoted by register-typed constants because the Assembler needs to be able to differentiate between general registers, space registers, floating point registers, and ordinary integer constants.

To make assembly code more readable, you can use the `.REG` directive to declare a symbolic name as an alias for a predefined register. The predefined registers have a register type associated with them. The Assembler enforces register type checking and issues a warning message if the wrong kind of register is used within an operand. A warning is also issued when an integer constant or absolute expression is found where a register is expected. You must use the `.REG` directive to define symbolic register names. If a symbolic name defined in an `.EQU` directive is used where a register symbol is expected, the Assembler issues a warning message, because it considers an `.EQU` defined symbol to be a simple integer constant.

NOTE

If an absolute expression is used instead of a register or register-typed symbol name, the Assembler issues warning message number 41.

This warning can be suppressed with the `-w41` command-line option. Future versions of the Assembler may not always allow an absolute expression where a register is expected.

The following example demonstrates the correct usage of the `.REG` directive:

```
tblptr    .REG   %r20
aka_tbl   .REG   tblptr
```

Predefined registers are shown in the following tables. All of the mnemonics begin with the % character, so they do not conflict with any programmer-defined symbols.

Table 2-2 General Registers

%r0	%r8	%r16	%r24
%r1	%r9	%r17	%r25
%r2	%r10	%r18	%r26
%r3	%r11	%r19	%r27
%r4	%r12	%r20	%r28
%r5	%r13	%r21	%r29
%r6	%r14	%r22	%r30
%r7	%r15	%r23	%r31

Table 2-3 Single-Precision Floating-Point Registers

%fr0L	%fr8L	%fr16L	%fr24L
%fr1L	%fr9L	%fr17L	%fr25L
%fr2L	%fr10L	%fr18L	%fr26L
%fr3L	%fr11L	%fr19L	%fr27L
%fr4L	%fr12L	%fr20L	%fr28L
%fr5L	%fr13L	%fr21L	%fr29L
%fr6L	%fr14L	%fr22L	%fr30L
%fr7L	%fr15L	%fr23L	%fr31L
%fr0R	%fr8R	%fr16R	%fr24R
%fr1R	%fr9R	%fr17R	%fr25R
%fr2R	%fr10R	%fr18R	%fr26R
%fr3R	%fr11R	%fr19R	%fr27R
%fr4R	%fr12R	%fr20R	%fr28R
%fr5R	%fr13R	%fr21R	%fr29R
%fr6R	%fr14R	%fr22R	%fr30R
%fr7R	%fr15R	%fr23R	%fr31R
Accessing the right half of floating-point registers separately is possible only on PA-RISC 1.1 or later architectures. Registers %fr16L through %fr31L and %fr16R through %fr31R are available only on PA-RISC 1.1 or later architectures.			

Table 2-4 Double-Precision Floating-Point Registers

%fr0	%fr8	%fr16	%fr24
%fr1	%fr9	%fr17	%fr25
%fr2	%fr10	%fr18	%fr26
%fr3	%fr11	%fr19	%fr27
%fr4	%fr12	%fr20	%fr28
%fr5	%fr13	%fr21	%fr29
%fr6	%fr14	%fr22	%fr30
%fr7	%fr15	%fr23	%fr31
Registers %fr16 through %fr31 are available only on PA-RISC 1.1 or later architectures.			

Table 2-5 Space Registers

%sr0	%sr2	%sr4	%sr6
%sr1	%sr3	%sr5	%sr7

Table 2-6 Control Registers

Registers	Synonyms	Registers	Synonyms
%cr0	%rctr	%cr20	%isr
%cr8	%pidr1	%cr21	%ior
%cr9	%pidr2	%cr22	%ipsw
%cr10	%ccr	%cr23	%eirr
%cr11	%sar	%cr24	%tr0 %ppda
%cr12	%pidr3	%cr25	%tr1 %hta
%cr13	%pidr4	%cr26	%tr2
%cr14	%iva	%cr27	%tr3
%cr15	%eiem	%cr28	%tr4
%cr16	%itmr	%cr29	%tr5
%cr17	%pcsq	%cr30	%tr6
%cr18	%pcoq	%cr31	%tr7
%cr19	%iir		

Some additional predefined register mnemonics are provided in “Register Procedure Calling Conventions” on page 28 to match the standard procedure-calling convention. This is discussed briefly in “HP-UX Architecture Conventions” on page 39. You can find detailed information on both 32-bit and 64-bit calling conventions under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/.

Table 2-7 Register Procedure Calling Conventions

Register	Synonyms	Description
%fr4	%farg0 %fret	Floating argument, return value
%fr5	%farg1	Second floating argument
%fr6	%farg2	Third floating argument
%fr7	%farg3	Fourth floating argument
%r2	%rp	Return link
%r19	%t4	Fourth temporary register
%r20	%t3	Third temporary register
%r21	%t2	Second temporary register
%r22	%t1	First temporary register
%r23	%arg3	Argument word 3
%r24	%arg2	Argument word 2
%r25	%arg1	Argument word 1
%r26	%arg0	Argument word 0
%r27	%dp	Data pointer
%r28	%ret0	Return value
%r29	%ret1 %sl	Return value, static link
%r30	%sp	Stack pointer
%r31	%mrp	Millicode return link
%sr1	%sret %sarg	Return value, argument

In addition, there is a special register mnemonic defined as %previous_sp, that allows access to the previous value of the stack pointer.

%previous_sp must be used in the position of a base register; it can be used only between .ENTER and .LEAVE pseudo-operations. %previous_sp is the same as %sp unless the current .PROC has a large

frame (that is, `.CALLINFO` specified `FRAME > 8191`) or `.CALLINFO` specified `.ALLOCA_FRAME`. In those two cases, `%previous_sp` is the same as `%r3`, and `%r3` is set up by the `.ENTER` pseudo-operation.

Expressions

Arithmetic expressions are often valuable in writing assembly code. The Assembler allows expressions involving integer constants, symbolic constants, and symbolic addresses. These terms can be combined with the standard arithmetic operators shown in “Standard Arithmetic Operators” on page 29 or with bit-wise operators shown in “Bit-Wise Operators” on page 29.

Table 2-8 Standard Arithmetic Operators

Operator	Operation
+	Integer addition
-	Integer subtraction
*	Integer multiplication
/	Integer division (result is truncated)

The multiplication and division operators have *precedence* over addition and subtraction. That is, multiplications and divisions are performed first from left to right, then additions and subtractions are performed from left to right. Therefore, the expression `2+3*4` evaluates to `14`.

Table 2-9 Bit-Wise Operators

Operator	Operation
|	Logical OR
&	Logical AND
~	Unary logical complement (tilde)

Expressions produce either an absolute or a relocatable result. Any operation involving only absolute terms yields an absolute result. Relocatable terms are allowed only for the + and - operators. The legal combinations involving relocatable terms are shown in “Legal Combinations For Relocatable Terms” on page 30.

Table 2-10 Legal Combinations For Relocatable Terms

Operation	Result
Absolute + Relocatable	Relocatable
Relocatable + Absolute	Relocatable
Relocatable - Absolute	Relocatable
Relocatable - Relocatable (defined locally)	Absolute

For more information on the term *relocatable*, refer to “Assembler Features” on page 15.

NOTE The combination “relocatable-relocatable+relocatable” is not permitted.

For example, assume the symbols `MONTH` and `YEAR` are relocatable, and `JANUARY` and `FEBRUARY` are absolute. The expressions `MONTH+JANUARY` and `MONTH+FEBRUARY-4` are relocatable, while the expressions `YEAR-MONTH` and `FEBRUARY-4` are absolute. The expression `MONTH+JANUARY*4` is also legal and produces a relocatable result, because `JANUARY*4` is evaluated first, producing an absolute intermediate result that is added to `MONTH`. The expression `MONTH+YEAR` is illegal, because the sum of two relocatable terms is not permitted.

Because all instructions are a single word in length, it is not possible to form a complete 32-bit address in a single instruction. Therefore, it is likely that the Assembler (or linker) may not be able to insert the final address of a symbol into the instruction as desired. For example, to load the contents of a word into a register, the following instruction could be used:

```
LDW       START,%r2
```

Because `LDW` provides only 14 bits for the address of `START`, the Assembler or linker prints an error message if the address of `START` requires more than 14 bits. There are two instructions, `LDIL` and `ADDIL`, whose function is to form the left-most 21 bits of a 32-bit address. The succeeding instruction, by using the target of the `LDIL` or `ADDIL` as a

base register, needs only 11 bits for the remainder of the address. The Assembler provides special operators, called *field selectors*, that extract the appropriate bits from the result of an expression. With the field selectors `L'` and `R'`, the previous example can be recoded as follows:

```
LDIL      L'START,%r1           ;put left part into r1
LDW       R'START(%r1),%r2      ;add r1 and right part
```

The field selectors are always applied to the final result of the expression. They cannot be used in the interior of an expression. "Available Field Selectors" on page 31 shows all the available field selectors and their meanings.

Table 2-11 Available Field Selectors

Field Selector	Meaning
`F'` or `F%`	Full 32 bits (default).
`L'` or `L%`	Right-justified, high-order 21 bits.
`R'` or `R%`	Low-order 11 bits.
`LS'` or `LS%`	High-order 21 bits after rounding to nearest multiple of 2048.
`RS'` or `RS%`	Low-order 11 bits, sign extended.
`LD'` or `LD%`	Right-justified, high-order 21 bits after rounding to next multiple of 2048.
`RD'` or `RD%`	Low-order 11 bits, with negative sign.
`LR'` or `LR%`	`L%` value with constant rounded to nearest multiple of 8192.
`RR'` or `RR%`	`R%` value with constant rounded to nearest multiple of 8192, plus the difference of the constant and the rounded constant.
`T'` or `T%`	`F%` value offset of data linkage table slots from linkage table pointer. In 32-bit mode, the linkage table pointer is `%r19`. In 64-bit mode, the linkage table pointer is `%r27`.

Field Selector	Meaning
LT' or LT%	LR% value offset of data linkage table slots from linkage table pointer. In 32-bit mode, the linkage table pointer is %r19. In 64-bit mode, the linkage table pointer is %r27.
RT' or RT%	RR% value offset of data linkage table slots from linkage table pointer. In 32-bit mode, the linkage table pointer is %r19. In 64-bit mode, the linkage table pointer is %r27.
Q' or Q%	F% value offset of procedure linkage table slots from linkage table pointer. In 32-bit mode, the linkage table pointer is %r19. In 64-bit mode, the linkage table pointer is %r27.
LRQ' or LRQ%	LR% value offset of procedure linkage table slots from linkage table pointer. In 32-bit mode, the linkage table pointer is %r19. In 64-bit mode, the linkage table pointer is %r27.
RRQ' or RRQ%	RR% value offset of procedure linkage table slots from linkage table pointer. In 32-bit mode, the linkage table pointer is %r19. In 64-bit mode, the linkage table pointer is %r27.
P' or P%	Data procedure label (plabel) constructor.
LP' or LP%	Code procedure label (plabel) constructor used in LDIL instruction.
RP' or RP%	Code procedure label (plabel) constructor used in LD0 instruction.
N' or N%	A null field selector, which is applied to an LDO instruction to allow a three-instruction sequence.
NL' or NL%	Right-justified, high-order 21 bits; allows a three-instruction sequence.

Field Selector	Meaning
NLD' or NLD%	Right-justified, high-order 21 bits after rounding to next multiple of 2048; allows a three-instruction sequence.
NLR' or NLR%	L% value with constant rounded to nearest multiple of 8192; allows a three-instruction sequence.
NLS' or NLS%	High-order 21 bits after rounding to nearest multiple of 2048; allows a three-instruction sequence.

On PA-RISC 1.0, the page size is 2048 bytes long; on PA-RISC 1.1, 2.0, and 2.0W the page size is 4096. The selectors L', LS', and LD' modulate by 2048, and the corresponding selectors R', RS', and RD' extract the offset relative to that address.

The distinction is whether the offset is always positive and between 0 and 0x7ff (L'-R'), always negative and between -0x800 and -1 (LD'-RD'), or between -0x400 and 0x3ff (LS'-RS'). This distinction is only important when using short addressing near a quadrant boundary, because only the left part is used to select a space register. Each pair is designed to work together just as L' and R' do in the previous example. See “Spaces” on page 39. The LR' and RR' prefixes are used for accessing different fields of a structure, allowing the sharing of the LR' computation.

For shared libraries, the field selectors T', LT', RT', Q', LRQ', and RRQ' are used in conjunction with the position-independent code options +z or +Z.

The field selectors P', LP', and RP' are used to form plabels (procedure labels) for use in dynamic calls. With position-independent code, the use of plabel values, rather than simple code addresses, is required. Refer to the *HP-UX Linker and Libraries Online User Guide* and *ELF 64 Object File Format*, http://www.software.hp.com/STK/ for more information.

For example, to get a procedure label for foo, use the following code:

```
ADDIL   LTP'foo,%r27,%r1   ;get left portion of plabel pointer.
LDO     RTP'foo(%r1),%r4   ;add right portion to form a complete
                           ;   plabel pointer.
```

The field selectors in the above example can also be written LP% and RP%.

Parenthesized Subexpressions

The constant term of an expression may contain parenthesized subexpressions that alter the order of evaluation from the precedence normally associated with arithmetic operators. For example:

```
LABEL1-LABEL2+((6765+(2048-1))/2048)*2048
```

contains a parenthesized subexpression that rounds a value up to a multiple of 2048.

Absolute symbols may be equated to constant terms containing parenthesized subexpressions as in the following sequence:

```
BASE    .EQU    0x200
N_EL    .EQU    24
SIZE    .EQU    (BASE+4)*N_EL
```

NOTE The use of parentheses to group subexpressions may cause ambiguities in statements where parenthesized register designators are also expected.

Operands and Completers

Machine instructions usually require one or more operands.

These operands tell the processor what data to use and where to store the result. Operands can identify a register, a location in memory, or an immediate constant (that is, data that is coded into the instruction itself). The operation code determines how many and what kinds of operands are required.

Registers used in operands should be either predefined register symbols (with the % prefix) or user-defined register symbols defined with the .REG directive. They can also be absolute expressions. See "Registers and Register Mnemonics" on page 23 in this chapter.

The following example shows a few machine instructions with register operands:

```
SCRATCH  .REG    %r18           ;define register SCRATCH
         ADD     %r3,%r7,%r4    ;r3 + r7 -> r4
         OR      %r7,%r3,%r8    ;inclusive or of r7,r3 -> r8
         COPY    SCRATCH,%r7    ;copy r18 to r7
         MTCTL   %r2,%sar       ;set shift amount register (cr11)
         MFSP    %sr4,%r10      ;fetch contents of sr4
```

Operands designating memory locations usually consist of an expression and a general register used as a base register. Some instructions also require a space register designation. In general, such operands are written in the form *expr*(*sr*,*gr*) or *expr*(*gr*), as in the following examples:

```
local_off   .EQU      -64
            LDW       4(%dp),%r2
            STW       %r0,local_off-4(%sp)
            LDW       0(%sr3,%r2),%r9
```

Notice that the space register can be omitted on instructions that allow short addressing, as in the STW instruction shown above.

If only one register is given, it is assumed to be the general register, and the space register field in the machine instruction is set to zero, which indicates short addressing.

The expression in a memory operand is either absolute or relocatable. Absolute expressions are meaningful when the base register contains the address of an array, record, or the stack pointer to which a constant offset

is required. Relocatable expressions are meaningful when the base register is %r0, or when the base register contains the left part of a 32-bit address as illustrated in the following example:

```
LDIL        L%glob,%r1                ;set up %r1 for STW
STW         %r9,R%glob(%r1)
```

Immediate operands provide data for the machine language instruction directly from the bits of the instruction word itself. A few instructions that use immediate operands are shown below:

```
ADDIL       L%var,%dp
LDIL        L%print,%r1
ADDI        4,%r3,%r5
SUBI        0x1C0,%r14,%ret0
```

Completers are special flags that modify an instruction's behavior. They are written in the opcode field, separated from the instruction mnemonic by a comma. The most common type of completer is a condition test. Many instructions can conditionally trap or nullify the following instruction, depending on the result of their normal operation. For example, notice the completers in the sequence below:

```
ADD,NSV     %r1,%r2,%r3
BL,N        handle_oflo,%r0
OR          %r3,%r4,%r5
```

The ,NSV in the ADD instruction nullifies the BL instruction if no overflow occurs in the addition operation, and execution proceeds with the OR instruction. If overflow does occur, the BL instruction is executed, but the ,N completer on the BL specifies that the OR instruction in its *delay slot* should not be executed.

Each class of machine instructions defines the set of completers that can be used.

These are described in the *PA-RISC 1.1 Architecture and Instruction Set Reference Manual* and in *PA-RISC 2.0 Architecture.*

Macro Processing

A macro is a user-defined word that is replaced by a sequence of instructions. Including a macro in a source program causes the sequence of instructions to be inserted into the program wherever the macro appears.

A user may define a word as a macro by using the `.MACRO` directive.

Detailed information about macro arguments, placement and redefinition of macros, nested macro definitions, and nested macro calls is in "Assembler Directives and Pseudo-Operations" on page 53.

Defining New Instructions With Macros

If you are testing new CPUs or coprocessors, you may need to use opcodes that are unknown to the Assembler. A variant of a macro definition may be used to create a mnemonic for the instruction. After being defined, the new mnemonic instruction can be invoked as easily as a standard instruction.

Opcodes, subopcodes, completers, and operands are encoded into the instruction word in a bit-intensive manner because all PA-RISC instructions are one word, or 32-bits, in length.

To write a macro, you must specify explicitly which bit fields are to contain constants and which are to contain macro arguments. The macro processor has no built-in knowledge of instruction formats. Defining new instructions through macros is only possible because a convenient way to delimit bit fields has been provided. It is up to the programmer to choose the correct bit field.

Bit positions within the 32-bit word are numbered from zero to 31, from left to right. A bit range is indicated by the starting bit position followed by the ending bit position. The two bit positions are separated by two periods and enclosed in braces. The bit field beginning at bit position 6 and ending at bit position 10 is represented as:

```
{6..10}
```

If the bit field being assigned from is bigger than the bit field being assigned to, then a warning is issued and the assigned-from bit field is truncated on the left. When no bit field is specified for the assigned-from

value, low-order bits are used until the value of the assigned-from bit field becomes the same as the width of the assigned-to bit field. The assigned-to bit field must always be specified.

No sign extension is provided by the macro assembler when bit fields are generated.

The following macro definition defines the macro PACK with four formal parameters.

```
PACK    .MACRO            BASE,GREG,SREG,OFFSET
        {0..5}=0x3E{26..31}
        {6..10}=BASE{27..31}
        {11..15}=GREG{27..31}
        {16..17}=SREG{30..31}
        {18..31}=OFFSET{18..31}
        .ENDM
```

The following explanation assumes that PACK is invoked with the statement:

```
        PACK    %sp,%r19,%sr0,-52
```

Bit Field	Description
{0..5}	Contains the six low-order bits of the new opcode 0x3E, or binary 111110, entered as a constant in the macro definition.
{6..10}	Contains general register 30, or binary 11110. These are the five low-order bits of the argument BASE in the macro definition.
{11..15}	Contains general register 19, or binary 10011. These are the five low-order bits of the argument GREG in the macro definition.
{16..17}	Contains space register 0 and represents the five low-order bits of the argument SREG in the macro definition.
{18..31}	Contains binary 11111111001100, the OFFSET value –52, which was entered as an argument to the macro definition.

3 HP-UX Architecture Conventions

The Assembler is a flexible tool for writing programs, but every operating system imposes certain conventions and restrictions on the programs that are intended to run on that system. This chapter discusses the conventions that must be understood in order to write assembly language programs and procedures for the PA-RISC instruction set on the HP 9000 Series 700 and 800 HP-UX operating system. Several Assembler directives are mentioned in this chapter to place them in a meaningful context. A full discussion of these directives is in Chapter 4, “Assembler Directives and Pseudo-Operations,” on page 53.

Spaces

Virtual addressing on PA-RISC is based on *spaces*. A virtual address is composed of a space identifier, which is either 16 or 32 bits long (depending on the hardware model), and a 32-bit offset within the space. Therefore, each space can contain up to 4 gigabytes, and there is a large supply of spaces.

NOTE

In the 64-bit mode architecture each application is provided a flat virtual address space of 2** 64 bytes, which is divided into four quadrants. Each quadrant is mapped into this global virtual address space by means of four space registers, which are under the control of the operating system.

Every program on an HP-UX system is assigned two spaces when it is loaded for execution by the operating system: one for code, and one for data. The HP-UX operating system makes the code space *read only*, so that it can be shared whenever several processes are executing the same program. The data space is writable by the new process, and is private to that process; that is, every process has a unique data space.The actual space identifiers assigned to these two spaces can vary from one execution of the program to the next; these numbers cannot be determined at compile time or link time. Generally, programmers do not need to be concerned with the space identifiers, since the operating system places them in two reserved space registers, where they remain

for the duration of program execution. The identifier of the code space is placed in space register 4 (`%sr4`) and the identifier of the data space is placed in space register 5 (`%sr5`).

When writing an assembly language program, declare a space named `$TEXT$` for executable code, and a space named `$PRIVATE$` for modifiable data. Constant data or literals that you do not plan to modify during program execution, can be placed in either space. Placing constant data in the `$TEXT$` space decreases the size of the nonsharable part of your program and improves the overall efficiency of the operating system.

The particular space registers mentioned above play an important role in virtual addressing. While many of the branching instructions, such as `BL`, `BLR`, and `BV`, are capable of branching only within the currently executing code space (called PC-*space*), two of the branching instructions, `BE` and `BLE`, require that you specify a space register as well as an offset. These instructions allow you to branch to code executing in a different space. On HP-UX systems, normally all code for a program is contained in one space, so all `BE` and `BLE` instructions should be coded to use `%sr4`.

In contrast, the memory reference instructions, such as `LDW` and `STW`, allow a choice between two forms of addressing: long and short. With long addressing, you can choose any of the space registers 1 through 3 for the space identifier part of the virtual address. The space offset is formed as the sum of an immediate displacement and the contents of a general register. With short addressing, one of the space registers between 4 through 7 is chosen automatically, based on the high-order two bits of the base register. Each space addressed by these four space registers is effectively divided into four *quadrants*, with a different quadrant of each space accessible via short addressing.

On HP-UX systems, all of a program's code is placed in quadrant zero of the `$TEXT$` space, or `%sr4`, (space offsets from `0` through `0x3FFFFFFF`). The data is placed in quadrant one of the `$PRIVATE$` space, or `%sr5` (space offsets from `0x40000000` through `0x7FFFFFFF`). Therefore, literal data in the code space and modifiable data in the data space can be addressed using the short addressing technique, without any concern for the space registers.

The identifier for shared memory segments, including shared library text, is placed into space register 6 (`%sr6`). Shared memory and shared library text are placed into quadrant two of the shared memory space (offsets `0x80000000` through `0xBFFFFFFF`). The identifier for system

code is placed into space register 7 (`%sr7`). System code is placed into quadrant three of the system space (offsets `0xC0000000` through `0xFFFFFFFF`). Table 3-1 on page 41 shows the memory layout on HP-UX.

Table 3-1 Memory Layout on HP-UX

	%sr4	%sr5	%sr6	%sr7
0x00000000	Program code			
0x40000000		Program data stack Shared library data		
0x80000000			Shared memory Shared library text	
0xC0000000				System code

You can define spaces other than `$TEXT$` and `$PRIVATE$` in a program file by declaring a special kind of space called an *unloadable space*. Unloadable spaces are treated as normal spaces by the linker, but as the name implies, are not actually loaded when a program is executed. Unloadable spaces are typically used by compilers to store extra information within a program file. The most common example of an unloadable space is `$DEBUG$`, which is used to hold symbolic debugging information.

The *sort key* attribute allows the programmer to control the placement of a space relative to the other spaces. The linker places spaces with lower sort keys in front of spaces with higher sort keys.

The `.SPACE` directive is used to declare spaces. The assembly language programmer is not required to fill one space before beginning another. When a space is first declared, the Assembler begins filling that space. The `.SPACE` directive can also be used to return to a previously declared space, and the Assembler continues to fill it as if there had been no intervening spaces.

Subspaces

While a space is a fundamental concept of the architecture, a subspace is just a logical subdivision of a space. The Assembler places the program's code and data into subspaces within spaces. Each subspace *belongs* to the space that was current when the subspace was first declared. The linker groups subspaces into spaces as it builds an executable program file. For more details see the *ld*(1) entry in the *HP-UX Reference*. When the linker combines several relocatable files, it groups the subspaces from each file by name, so that all subspaces with the same name are placed contiguously in the program.

Attributes

Subspaces have several attributes. The *alignment* attribute specifies what memory alignment (in bytes) is required in the virtual address space. The alignment can be any power of two, from 1 through 4096, inclusive. Typically, the alignment is 4 or 8 to specify that the beginning of the subspace must be word or double-word aligned. Normally, the alignment attribute is computed automatically by the Assembler from the largest `.ALIGN` directive used within the subspace.

The *quadrant* attribute assigns the subspace to one of the four quadrants of its space. On HP-UX systems, all subspaces in the code space must be in quadrant 0, and all subspaces in the data space must be in quadrant 1.

The *access rights* attribute specifies the access rights that should be given to each physical page in the subspace. On HP-UX systems, all subspaces in the code space must have access rights of `0x2C` (code page executable at any privilege level). All subspaces in the data space must have access rights of `0x1F` (data page readable and writable at all privilege levels).

The *sort key* attribute allows the programmer to control the placement of a subspace relative to the other subspaces in its space. The linker places subspaces with lower sort keys in front of subspaces with higher sort keys.

Directives

The .SUBSPA directive is used to declare a subspace and its attributes. As with spaces, the assembly language programmer can switch from one subspace to another, and the Assembler will fill each subspace independently as if the source code had been presented one complete subspace at a time. When the .SPACE directive is used to switch spaces, the Assembler remembers the current subspace in each space.

Several additional Assembler directives are provided as shorthand to declare and switch to some standard spaces and subspaces. For example, the .CODE directive switches to the $TEXT$ space and the $CODE$ subspace, and the .DATA directive switches to the $PRIVATE$ space and the $DATA$ subspace.

You can declare as many subspaces as you can use, but the sort key attribute should be used carefully, because the stack unwind mechanism reserves a range of sort keys 56 through 255 for the $TEXT$ space. Refer to “Compiler Conventions” on page 47 in this chapter. Some of the standard subspaces and sort keys used by the compilers are shown in Table 3-2 on page 43. Directives that generate commonly used spaces and subspaces are found in Table 4-3 on page 116.

Table 3-2 Standard Subspaces and Sort Keys

Space	Subspace	Sort Key	Use
$TEXT$		8	
	$CODE$	24	Normal code.
	LIT	16	Literals.
	$MILLICODE$	8	Millicode library routines.
	$SHLIB_INFO$	0	Shared library information.
	$UNWIND$	64	Unwind information.
$PRIVATE$		16	
	BSS	82	Uninitialized data and common.
	$DATA$	16	Global arrays and structures.
	DLT	39	Data linkage table.

Space	Subspace	Sort Key	Use
	$GLOBAL$	40	Global variable base address.
	$PLT	6	Procedure linkage table.
	$SHLIB_DATA$	12	Shared library data.
	$SHORTBSS$	80	Uninitialized data and common.
	$SHORTDATA$	24	Global scalar variables.
$THREAD_SPECIFIC$		16	
	$TBSS$	40	Thread local storage

Sections in 64-bit Mode

In 64-bit mode, the Executable and Linking Format (ELF) uses segments and sections rather than spaces and subspaces.

The concept of spaces maps to the ELF concept of segments, but segments do not apply to relocatable object files. Hence, the Assembler ignores the .SPACE directive for 64-bit assembly programs. Subspaces map directly to the ELF concept of sections, so the .SUBSPA directive switches to or creates a new section. The attributes of a subspace correspond to section attributes as follows:

- Subspace names listed in the table are mapped to their corresponding section name. Names not in this table are unchanged.

SUBSPACE NAME	SECTION NAME
BSS	.bss
$CODE$	.text
$DATA$	.data
$FINI$	.fini

SUBSPACE NAME	SECTION NAME
$INIT$	.init
LIT	.rodata
$MILLICODE$	.text
$PREINIT$	.preinit
$SHORTBSS$	.sbss
$SHORTDATA$	.sdata
$TBSS$	.tbss

- The assembler translates access rights into a set of read, write or execute permissions for the section.
- The assembler ignores the sort key and quadrant attributes.
- The alignment attribute maps directly to the section alignment.
- The COMMON and DUP_COMM attributes map to a COMDAT section.
- The CODE_ONLY, FIRST, and FROZEN attributes are ignored.
- The UNLOADABLE attribute maps to a non-allocated section.

For more information about ELF, see *ELF 64 Object File Format*, at URL: http://www.software.hp.com/STK/.

Location Counters

Just as spaces can be divided into subspaces, subspaces can be further divided by using location counters. You can use up to four location counters in each subspace, and the Assembler fills a separate area for each location counter. When the assembly is complete, the subspace is formed by concatenating each of these areas. All references relative to a location counter are relocated so that they are relative to the complete subspace.

Unlike subspaces, however, the use of location counters is completely local to the Assembler. Once the subspace is formed at the end of the assembly, the distinction among the individual areas built by location counters disappears. No further reordering or grouping related to location counters is performed by the linker.

This facility allows you to assemble related data into disjoint pieces of a subspace, while keeping the source code in a convenient order.

The `.LOCCT` directive is used to switch from one location counter to another. The Assembler automatically remembers the previous value of each location counter within each subspace. When the `.SUBSPA` directive is used to switch subspaces, the Assembler automatically begins using the location counter that was last in effect in the new subspace.

Compiler Conventions

In order to write assembly language procedures that can both call to and be called from high-level language procedures, it is necessary to understand the standard procedure-calling convention and other compiler conventions.

On many computer systems, each high-level language has its own calling convention. Consequently, calls from one language to another are sometimes difficult to arrange, except through assembly code. The architecture generally prescribes very few operations that must be done to effect a procedure call, and there is often a pair of machine-language instructions to call a procedure and return from one. PA-RISC architecture provides no special procedure call or return instructions.

There is, however, a standard procedure-calling convention for all high-level languages as well as the Assembler. It is tuned for the architecture, and is designed to make a procedure call with as few instructions as possible.

Besides defining a uniform call and return sequence for all languages, the calling convention is important for other reasons. In order to streamline the calling sequence, the return link is not saved on the stack unless necessary and the previous stack pointer is rarely saved on the stack. Therefore, it is not usually possible to obtain a stack trace at an arbitrary point in the program without some additional static information about each procedure's stack frame size and usage.

For example, you could not obtain a stack trace while debugging or analyzing a core dump, or using the TRY/RECOVER feature in HP Pascal/HP-UX. Obtaining a stack trace is made possible by the *stack unwind* mechanism. It uses special *unwind descriptors* that contain the exact static information needed for each procedure. These descriptors are generated automatically by the linker based on information provided by all high-level compilers as well as the Assembler.

Each descriptor contains the starting and ending address of a procedure's object code, plus that procedure's stack frame size, and a few flags indicating, among other things, whether the return link is saved on the stack. Given the current program counter and stack pointer, the stack unwind mechanism can determine the calling procedure by finding

the return link either in a register or on the stack. Also, it can determine the previous stack pointer by subtracting the current procedure's stack frame size.

The Assembler requires that you follow programming conventions to generate unwind descriptors. The beginning and end of each procedure must be noted with the `.PROC` and `.PROCEND` directives. The `.CALLINFO` directive supplies additional information about the procedure, including the stack frame size. The Assembler passes this information to the linker, which creates the unwind descriptor. It can also generate the standard entry and exit code to create and destroy the stack frame, save and restore the return link (if necessary), and save and restore any necessary registers. These code sequences are generated at the points indicated by the `.ENTER` and `.LEAVE` pseudo-operations. For a more thorough discussion of programming conventions, refer to the *64-bit Runtime Architecture for PA-RISC 2.0*, at URL: http://www.software.hp.com/STK/.

Arguments to procedures are loaded into general registers 26, 25, 24, and 23; these registers are named, respectively, `%arg0`, `%arg1`, `%arg2`, and `%arg3`. If more than four words of arguments are required, the remaining arguments are stored in the caller's stack frame in the variable argument list. The return value should be returned in general register 28, called `%ret0`. General register 29, called `%ret1`, is used for the low-order bits of a double-word return value, while `%ret0` contains the high order bits. In addition to the argument and return registers, the procedure can use registers 19 through 22 and registers 1 and 31 as scratch registers. Any other general registers must be saved before use at entry and restored before exit.

Chapter 4, “Assembler Directives and Pseudo-Operations,” on page 53 contains detailed descriptions of the Assembler directives described above. For a more thorough discussion of the procedure calling conventions, refer to the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/.

In order for an assembly language procedure to be callable from another language or another assembly language module, the name of the procedure must be *exported*. The `.EXPORT` directive does this. It also allows you to declare the *symbol type*. For procedure entry points, the symbol type should be `ENTRY`.

The Assembler and linker treat all symbols as case-sensitive, while some compilers do not. By convention, compilers that are case-insensitive uniformly convert all exported names to lower case. For example, it is

possible to declare a procedure that cannot conflict with HP Pascal/HP-UX procedure names by using uppercase letters. However, there is an *aliasing* mechanism in some compilers that allows you to declare a case-sensitive name for external use. See the appropriate language reference manual for more information.

Conversely, the `.IMPORT` directive allows you to reference a procedure name that is exported from another module, either from the Assembler or the compiler. Once a procedure name has been imported, it can be referenced exactly as if it were declared in the same module.

Data symbols can be exported and imported just like procedure names. However, not all compilers export the names of global variables, or provide a mechanism to reference data symbols exported from an assembly language module. For example, the HP Pascal/HP-UX compiler does not normally do this, while the HP C/HP-UX compiler does. HP FORTRAN 77/HP-UX named common blocks are exported, but the names of the variables within the common blocks are not.

It was mentioned before that data is allocated beginning from a virtual space offset `0x40000000`. For convenience as well as compatibility with future releases of HP-UX systems, all data in the `$PRIVATE$` space must be accessed relative to general register 27, called `%dp`. EStandard run-time start-up code, from the file `/usr/ccs/lib/crt0.o`, must be linked with every program. This start-up code declares a global symbol called `$global$` in the `$GLOBAL$` subspace. This code also loads the address of this symbol into the `%dp` register before beginning program execution. This register must not be changed during the execution of a program. Since the `%dp` register is known to contain the address of `$global$`, the following single instruction does the load as long as the displacement from `$global$` to the desired location is less than 8 kilobytes:

```
LDW      var-$global$(%dp),%r3
```

If the desired location is not known to be close enough to `$global$`, use the following sequence:

Global Symbol Usage

```
ADDIL    L'var-$global$,%dp            ;result in r1
LDW      R'var-$global$(%r1),%r3
```

For convenience, the $SHORTDATA$ and $SHORTBSS$ subspaces can be used for small scalar variables. Most scalar variables are close enough to $GLOBAL$ so that the shorter form can be used. Arrays and large structures should be defined in $DATA$ and the long form used.

To access items in the $PRIVATE$ space (global data), the following does not work:

```
LDIL      L'var,%r1                    ;wrong
LDW       R'var(%r1),%r3               ;wrong
```

This example assumes that the operating system always allocates data at the same virtual space offset 0x40000000.

Thread local storage (TLS) data is accessed relative to control register 27 (%cr27). The contents of %cr27 must first be moved to a general register by using the MFCTL instruction. A symbol, __tp, is defined, similar to $global$. The following code shows the loading of the TLS variable. Note the similarities between this example and the example "Global Symbol Usage" on page 49.

```
MFCTL     %cr27, &rx
ADDIL     L'var-__tp,%rx           ;result in r1
LDW       R'var-__tp(%r1),%r3
```

Uninitialized areas in the data space can be requested with the .COMM (common) request. These requests are always made in the BSS subspace in the $PRIVATE$ space. The BSS subspace should not be used for any initialized data. Common requests are passed on to the linker, which matches up all requests with the same name and allocates a block of storage equal in size to the largest request. If, however, an exported data symbol is found with the same name, the linker treats the common requests as if they were imports.

HP FORTRAN 77/HP-UX common blocks are naturally allocated in this way: if a BLOCK DATA subprogram initializes the common block, all common requests are linked to that initialized block. Otherwise, the linker allocates enough storage in BSS for the common block. The HP C/HP-UX compiler also allocates uninitialized global variables this way. In C, however, each uninitialized global is a separate common request.

Shared Libraries

The field selectors `T'`, `LT'`, and `RT'` are used to write position-independent code in assembly language. When you use these selectors and invoke the Assembler with the `as` command, you must use the `+z` or `+Z` compiler option on the command line.

Any assembly code that is to be used with shared libraries must follow the standard procedure call mechanism as defined in the runtime architecture documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/. Any external procedures must be exported as type `ENTRY` for the shared library interface to work correctly.

For more information on position-independent code and shared libraries, refer to the *HP-UX Linker and Libraries Online User Guide* and the *ELF 64 Object File Format*, URL: http://www.software.hp.com/STK/.

Assembly Listing

The Assembler command-line option, `-l`, causes an assembly listing to standard output. For each line of source code, the listing provides:

- line number
- the subspace offset
- the hexadecimal representation of the assembled code (possibly flagged with an asterisk (*) to indicate address relocation)
- the source text
- any comments.

The following is a line of assembly language as it appears in the source file:

```
SAVE      LDO      VAL(%r0),%r20      ;retain value
```

The above line would appear in the assembly listing as follows:

```
line no. offset   hex representation label opcode operands      comment
16       0000004c (341400A)          SAVE  LDO    VAL(%r0),%r20 ;retain value
```

The choice of line number 16 is arbitrary here. At the end of the assembly listing, a symbol table is printed showing the name and value of each symbol in the file. A type field for each symbol, indicating either absolute or relocatable, is included.

Certain types of source lines generate multiple instructions. Macro calls often expand to several instructions. The `.ENTER` and `.LEAVE` pseudo-operations can each generate more than one instruction. The predefined subspace directives, such as `.CODE` and `.DATA`, result in a space and a subspace declaration.

You have the choice of listing a section of assembled code in either the compressed or expanded form. The placement of the `.LISTON` and `.LISTOFF` directives determines which code will be expanded during listing. The directive `.LISTON` tells the Assembler to expand the listing of all subsequent source lines until a `.LISTOFF` directive is encountered. `.LISTOFF` stays in effect until the occurrence of a `.LISTON` directive.

The default is `.LISTON`.

The directives `.LISTON` and `.LISTOFF` may be placed anywhere in the source text and always go into effect immediately. The `.LISTON` and `.LISTOFF` directives can be used as often as desired.

4 Assembler Directives and Pseudo-Operations

Assembler directives and pseudo-operations allow you to take special programming actions during the assembly process. The directive and pseudo-operation names begin with a period (.) to distinguish them from machine instruction opcodes or extended opcodes.

Introduction

Table 4-1 lists the Assembler directives. Table 4-2 on page 55 lists the pseudo-operations. The directives include those that establish the procedure-calling convention, declare common, and define spaces and subspaces. The pseudo-operations reserve and initialize data areas.

The remainder of this chapter lists the Assembler directives and pseudo-operations in alphabetic order. Several of the descriptions include sample assembly code sequences. You can enter these short code sequences, assemble them using the `-l` option of the `as` command, then inspect the offsets and field values to see how that particular directive controls the assembly environment.

This chapter also includes Table 4-3 on page 116 under “Programming Aids” on page 116, which lists the predefined directives that establish standard spaces and subspaces.

Table 4-1 Assembler Directives

Directive	Function
`.ALIGN`	Forces location counter to the next largest multiple of the supplied alignment value.
`.ALLOW`	Used with a `.LEVEL` directive, it temporarily allows the use of features in the architecture specified in the `.LEVEL` directive.
`.CALL`	Specifies that the next statement is a procedure call.

Directive	Function
.CALLINFO	Provides information for generating Entry/Exit code sequences and for creating stack unwind descriptors.
.COMM	Requests common storage for a specified number of bytes.
.COPYRIGHT	Inserts a string into the object module as a copyright notice.
.END	Terminates an assembly language program.
.ENDM	Marks the end of a macro definition.
.ENTRY	Marks the entry point of the current procedure.
.EQU	Assigns an expression to an identifier.
.EXIT	Marks the return point of the current procedure.
.EXPORT	Makes a specified symbol available to other modules.
.IMPORT	Specifies that the definition of the given symbol occurs in another module.
.LABEL	Permits a label definition to appear within a sequence of directives that occur on a single line.
.LEVEL	Makes the object file a PA-RISC 1.1, 2.0, or 2.0W file.
.LISTOFF	Controls listing of expanded Assembler instructions.
.LISTON	Controls listing of expanded Assembler instructions.
.LOCCT	Selects a location counter.
.MACRO	Marks the beginning of macro definitions.
.ORIGIN	Advances the location counter to a relative location from the beginning of the current subspace.

Directive	Function
.PROC	Marks the first statement in a procedure.
.PROCEND	Marks the last statement in a procedure.
.REG	Attaches a type and number to a user-defined register name.
.SHLIB_VERSION	Inserts a date string into the object module as a shared-library version identifier.
.SPACE	Declares a new space or switches back to a previous space.
.SUBSPA	Declares a new subspace or switches back to a previous subspace.
.VERSION	Inserts the specified string into the current object module as a user-defined version identification string.

Table 4-2 Pseudo-Operations

Directive	Function
.BLOCK	Reserves a block of data storage.
.BLOCKZ	Reserves a block of data storage.
.BYTE	Reserves 8 bits (a byte) of storage and initializes it to the given value.
.DOUBLE	Initializes 64 bits (a double-word) of storage to a floating-point value.
.DWORD	Reserves 64 bits (a double word) of storage and initializes it to the given value.
.ENTER	Marks a procedure's entry point and generates standard entry code.
.FLOAT	Initializes a single-word of storage to a floating-point value.

Directive	Function
.HALF	Reserves 16 bits (a half word) of storage and initializes it to the given value.
.LEAVE	Marks a procedure's exit point and generates standard exit code.
.SPNUM	Reserves and initializes a word of storage.
.STRING	Reserves the appropriate amount of storage and initializes it to the given string.
.STRINGZ	Reserves the appropriate amount of storage and initializes it to the given string.
.WORD	Reserves 32 bits (a word) of storage and initializes it to the given value.

.ALIGN Directive

The `.ALIGN` directive advances the current location counter to the next specified "boundary."

Syntax

.ALIGN [*boundary*]

Parameters

boundary	An integer value for the byte boundary to which you want to advance the location counter. The Assembler advances the location counter to that boundary. Permissible values must be a power of 2 and can range from one to 4096. The default value is 8 (double word aligned).

Example

This sample program adds a 21 bit field to the data pointer. Then a branch is taken to the label "page" that has been page-aligned.

```
            .CODE
            ADDIL L'$WORDMARK$-$global$,%dp
            B page
            NOP
            .ALIGN 4096
page
            ADDI    1,%r1,%r1
            .DATA
$WORDMARK$
            .WORD   0x0FFF
            .IMPORT $global$,DATA
```

.ALLOW Directive

The .ALLOW directive tells the Assembler to temporarily allow PA-RISC features from a higher version level of the PA-RISC architecture. The .ALLOW directive also tells the Assembler to temporarily allow implementation-specific features in the assembly source file.

Syntax

.ALLOW 1.1

Lines of source code

.ALLOW

Parameters

1.1	Allows PA-RISC 1.1 features.
2.0	Allows PA-RISC 2.0 features.

Discussion

Use the .ALLOW directive with the .LEVEL directive. The Assembler uses the .LEVEL directive to mark the relocatable object file with the proper PA-RISC architecture version level. In the source file, the Assembler emits warning messages whenever a feature is used that is not appropriate for the specified .LEVEL directive.

Use the .ALLOW directive when it is necessary to include features or instructions from a later version of PA-RISC while leaving the relocatable object file marked as an earlier PA-RISC architecture version. For example, use the .ALLOW directive when you need to include PA-RISC 2.0 features or instructions while leaving the relocatable object file marked as a PA-RISC 1.1 architecture version.

NOTE A 2.0W parameter is *not* permitted with .ALLOW, because the code generated for 2.0W(64-bit mode) is incompatible with other levels.

When using the .ALLOW directive, a run-time check must be inserted into the assembly source code. This run-time check should insure that the code is executing on a PA-RISC processor that supports the feature or features being used after the .ALLOW directive. See the example below.

An .ALLOW directive without a parameter signals the end of the region that the previous .ALLOW directive was controlling. Control is returned to the .LEVEL specified for the file.

NOTE The .ALLOW and .LEVEL directives replace the +DA and +DS command-line compiler options.

Example

The following example shows how to set a range of memory to 0. In PA-RISC 1.1 architecture, use the stw instruction. In PA-RISC 2.0 architecture, use the more efficient std instruction.

```
        .LEVEL  1.1
;  This object file will be marked as a PA 1.1 object file

;  Check what version of PA Architecture we are linked for
        addil   LR'_SYSTEM_ID-$global$,%dp
        ldw     RR'_SYSTEM_ID-$global$(%r1),%r5
        ldi     CPU_PA_RISC1_1,%r4
        combt,<,n %r4,%r5,$00000002
;  1.1 specific code
$00000001
        addib,< 1,%r23,$00000001
        stw,ma  %r0,4(%r31)
        b,n     $00000003
;  2.0 specific code
$00000002
        .ALLOW  2.0
        addib,< 2,%r23,$00000002
        std,ma  %r0,8(%r31)
        .ALLOW
$00000003
;  General code
```

.BLOCK and .BLOCKZ Pseudo-Operations

The .BLOCK and .BLOCKZ pseudo-operations reserve a block of storage.

Syntax

.BLOCK [*num_bytes*]

.BLOCKZ [*num_bytes*]

Parameters

num_bytes	An integer value for the number of bytes you want to reserve. Permissible values range from zero to 0x3FFFFFFF. The default value is zero.

Discussion

The .BLOCK pseudo-operation reserves a data storage area but does not perform any initialization. The .BLOCKZ pseudo-operation reserves a block of storage and initializes it to zero.

When you label a .BLOCK pseudo-operation, the label refers to the first byte of the storage area.

For large blocks, it is usually better to use the .COMM directive to allocate uninitialized space. Since .COMM storage is allocated at run time, it doesn't increase the size of the object file.

NOTE

Under the present implementation of the Assembler, the .BLOCK pseudo-operation also initializes the reserved area to zero.

Example

The first example requests the Assembler to reserve 64 bytes of memory in the $CODE$ subspace. This area is then followed by a “Load Word” and “Store Word” instruction.

```
          .SPACE $TEXT$
          .SUBSPA $CODE$
          .BLOCK 64
swap      LDW 0(%r2)%r1
          STW %r1,4(%r2)
          .END
```

The second example reserves 32 bytes of memory in the $DATA$ subspace followed by one word intended as an end marker.

```
          .DATA
word0     .BLOCK     0X20
word8     .WORD      0XFFFF
```

.BYTE Pseudo-Operation

The .BYTE pseudo-operation reserves storage and initializes it to the given value.

Syntax

.BYTE [*init_value*[, *init_value*] ...]

Parameters

init_value	Either a decimal, octal, or hexadecimal number or a sequence of ASCII characters, surrounded by quotation marks. If you omit the initializing value, the Assembler initializes the area to zero.

Discussion

The .BYTE pseudo-operation requests 8 bits of storage. If the location counter is not properly aligned on a boundary for a data item of that size, the Assembler advances the location counter to the next multiple of that item's size before reserving the area.

When you label the pseudo-operation, the label refers to the first byte of the storage area. Operands separated by commas initialize successive units of storage.

Example

The first pseudo-operation allocates a byte labeled E and initializes it to the character [.

```
E     .BYTE     "["
```

.CALL Directive

The .CALL directive marks the next branch statement as a procedure call, and permits you to describe the location of arguments and the function return result.

Syntax

.CALL [*argument_description*[*argument_description*] ...]

Parameters

argument_description

Allows you to communicate to the linker the types of registers used to pass floating point arguments and receive floating point return results in the succeeding procedure call. Similarly, this information can be communicated in the .EXPORT directive.

The linker requires this information because the runtime architecture allows floating point arguments and return values to reside in either general registers or floating point registers, depending on source language convention. At link time, the linker ensures that both the caller and called procedure agree on argument location. If not, the linker may insert code to relocate the arguments (or return result) before control is transferred to the called procedure or a procedure return is completed.

You can use up to 5 *argument-descriptions* in the .CALL directive; one for each of the four arguments that may be passed in registers (arg0–arg3), and one for a return value (ret0).

NOTE

In PA-RISC 2.0W, (64-bit mode) the Assembler ignores the .CALL directive. This means that the linker does not ensure that the caller and called procedure agree on argument locations. If you do not know the prototype of the called procedure, you must pass floating point

parameters in both the corresponding general registers and corresponding floating-point registers. See the documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/.

The form of *argument-description* is:

arg=location

where *arg* can be:

ARGW0	The first word in the argument list.
ARGW1	The second word in the argument list.
ARGW2	The third word in the argument list.
ARGW3	The fourth word in the argument list.
RTNVAL	The return value for a procedure.

and *location* can be:

NO	The argument word cannot be relocated. This should be used for all nonfloating-point arguments; it is the default when an *argument-description* is omitted.
GR	The argument word occurs in a general register.
FR	The argument word occurs in a floating point register.
FU	The argument word occurs in the upper half of a floating-point register.

Example

This example shows the use of the .CALL directive in 32-bit mode.

```
;  This program calls printf() with four arguments
;  whose register locations are described in the .CALL directive.
;  The format string goes into arg0, not to be relocated.
;  The string “message” goes into arg1, specified as a general register.
;  The floating-point value 57005.57005 goes into farg2,
;  specified as a floating-point register.
;  The hexadecimal number 0xf00d goes into arg3,
;  specified as a general register.
;  The return value from printf() is not to be relocated.

        .LIT
        .ALIGN  8
        .WORD   1197387154        ; floating-point literal
        .BLOCKZ 12
fp2     .WORD   0
        .CODE
main
        .PROC
        .CALLINFO CALLER,FRAME=24,SAVE_RP
        .ENTER
        LDIL    L’fp2,%r1
        LDO     R’fp2(1),%r31   ; r31 < - floating-point literal address
        FLDWS   -16(%r31),%fr4
        LDO     -64(%sp),%r19
        FSTWS   %fr4,0(%r19)
        ADDIL   L’61453,0
        LDO     R’61453(%r1),%r20
        STW     %r20,-68(%sp)   ; end of stacking floating-point address
        ADDIL   L’string_area-$global$,%dp
        LDO     R’string_area-$global$(%r1),%r21    ; point to “message”
        STW     %r21,-60(%sp)   ; stack “message” address
        LDO     -64(%sp),%r22
        FLDWS   0(%r22),%fr5
        FCNVFF,SGL,DBL    %fr5,%fr6  ; convert floating-point value
        ADDIL   L’string_area-$global$+8,%dp
        LDO     R’string_area-$global$+8(%r1),%arg0
                                    ;point to format string
        LDW     -60(%sp),%arg1    ; load “message” argument
        FSTDS   38,-16(%sp)
        FLDWS   -12(%sp),%fr6     ; load floating-point argument
        LDWS    -16(%sp),%arg3    ; load hexadecimal argument
        LDW     -68(%sp),%r1
        STW     %r1,-52(%sp)
        .CALL   argw0=no,argw1=gr,argw2=fr,argw3=gr,rtnval=no
        BL      printf,2
        NOP
        .LEAVE
```

```
        .PROCEND
        .EXPORT main,ENTRY
        .IMPORT printf,CODE

        .DATA
string_area
        .ALIGN  8
        .STRINGZ        “message”
        .STRINGZ        “ARGS = %s,%f,%x\n”
        .IMPORT $global$,DATA
```

.CALLINFO Directive

.CALLINFO is a required directive that describes the environment of the current procedure. The information it provides is available to the .ENTER and .LEAVE pseudo-operations to control the entry and exit code sequences that they generate. Additional information is used by the Assembler to direct the creation of stack unwind descriptors.

Syntax

.CALLINFO [*parameter*[, *parameter*] ...]

where *parameter* is one of:

```
ALLOCA_FRAME
ARGS_SAVED
CALLER
CALLS
NO_CALLS
CLEANUP
ENTRY_FR=number
ENTRY_GR=number
ENTRY_SR=number
FRAME=number
HPUX_INT
MILLICODE
NO_UNWIND
SAVE_MRP
SAVE_RP
SAVE_SP
SAVE_SR0
```

Parameters

ALLOCA_FRAME — Indicates that this procedure allocates temporary storage by modifying the stack pointer (%r30). A copy of the frame pointer is normally placed in %r3. However, if this procedure also has a large frame (FRAME > 8191), then the copy of the frame pointer is placed in %r4 instead.

ARGS_SAVED — Indicates that this procedure stores the arguments into the stack frame.

CALLER or CALLS
: Indicates that this procedure calls other routines, so it requires space in the stack for a frame marker and a fixed argument list. (When a program is assembled using the `-f` option, this becomes the default case.)

  The Assembler allocates stack space when it encounters an `.ENTER` pseudo-operation and deallocates this space when it encounters a `.LEAVE` pseudo-operation. The Assembler allocates 48 bytes for the PA-RISC 32-bit mode and 80 bytes for the PA-RISC 64-bit (2.0W) mode.

  The frame marker and fixed argument list area occur at the top of the stack so you must take this space into account when locating local variables on the stack. You must allocate an area (using `FRAME=`) for a variable argument list when this area is needed.

  `CALLER` does not imply the existence of the parameter `SAVE_RP`.

  The `CALLER` and `CALLS` parameters are equivalent.

`NO_CALLS`
: Indicates that the procedure does not call other procedures and, therefore, does not require a frame marker on the stack. This is the default case unless the program is assembled using the `-f` option.

`CLEANUP`
: Indicates that this procedure requires cleanup during unwind.

`ENTRY_FR=`*register*
: Specifies the high end boundary of the Entry/Save floating-point register partition. The partition includes `%fr12` through `%fr15` for PA-RISC 1.0 and `%fr12` through `%fr21` for PA-RISC 1.1. The Assembler automatically saves these registers when it encounters an `.ENTER` pseudo-operation and restores them when it encounters a `.LEAVE` pseudo-operation.

`ENTRY_GR=`*register*
: Specifies the high end boundary of the Entry/Save register partition. The partition may extend over registers `%r3` through `%r18`. If you omit this parameter, no registers are saved.

When a procedure uses these registers, the Assembler saves their values when it encounters an .ENTER pseudo-operation and restores these values when it encounters a .LEAVE pseudo-operation. The called routine saves these registers upon entry and restores them upon exit, so values in Entry/Save registers are preserved across a procedure call.

Note: See the description of the FRAME parameter regarding the use of %r3.

ENTRY_SR=*register*

Specifies the high end boundary of the space register partition. The partition currently contains only %sr3. When the .CALLINFO directive includes this parameter, the Assembler automatically saves the Space Register when it encounters an .ENTER pseudo-operation and restores this register when it encounters a .LEAVE pseudo-operation.

FRAME=*number*

Defines the combined size (in bytes) of the local variable area and variable argument area needed by the procedure. The .ENTER pseudo-operation allocates the desired space for local variables below the frame marker and the .LEAVE pseudo-operation deallocates that space.

The *number* parameter must be a multiple of eight bytes. If a .CALLINFO directive lacks this parameter, the Assembler assumes a default frame size of zero.

The stack frame includes space for local variables and the variable argument area. The size specified for the frame should not include space for the stack frame marker or the fixed argument area. Allocation of these areas is controlled by the CALLER and NO_CALLS parameters. The inclusion of the CALLER parameter always allocates space for the stack frame marker and the fixed argument area. (See Table 4-1 on page 53)

A frame marker is required if the assembly routine calls another routine.

For PA-RISC 32-bit mode, the frame area is offset from the Stack Pointer by 48 bytes because the frame marker contains 32 bytes and the fixed argument list contains 16 bytes, when both of these areas are present.

For PA-RISC 2.0W (64-bit mode), the frame area is offset from the Stack Pointer by 80 bytes because the frame marker contains 16 bytes and the fixed argument list contains 64 bytes.

However, the Assembler does not allocate space for the frame marker and fixed argument list if the procedure does not call any other routines (see the `NO_CALLS` parameter).

If the total frame size for a procedure exceeds 8191 bytes, the Assembler uses `%r3` to locate the previous frame marker when it encounters an `.ENTER` or `.LEAVE` pseudo-operation. Under these circumstances, changing the value of `%r3` can cause serious consequences.

`HPUX_INT` Specifies that this procedure is an interrupt procedure. This is necessary for the stack unwind mechanism.

`MILLICODE` Indicates to the unwind mechanism that this is a millicode routine and it should follow the millicode calling conventions.

`NO_UNWIND` This is to be used only in the context of *stand-alone code* or any procedure that does not need to be reliably *unwound*.

`RP_IN_R31` Indicates that the return pointer has been moved to register %r31 in order to make local millicode calls. This parameter is only valid for the PA-RISC 2.0W (64-bit mode).

`SAVE_MRP` Indicates that this millicode procedure saves the Millicode Return Pointer (MRP) in its frame marker at `(SP-20)`.

`SAVE_RP` Specifies that the frame marker of the previous routine stores the value of the Return Pointer (`RP`). The Assembler automatically saves the Return Pointer when it encounters an `.ENTER` pseudo-operation, and

it restores the RP value when it encounters a .LEAVE pseudo-operation. Generally, any procedure that calls other routines should save the RP value.

SAVE_SP — Specifies that the current routine saves the value of Previous_SP in its frame marker at SP-4. Because the Assembler does not automatically save the Stack Pointer when it generates Entry/Exit code sequences, you must explicitly save this value in your program when using this key word. You can obtain the Previous_SP value from the special register %previous_sp.

Programming languages, such as HP Pascal/HP-UX, typically use this value for up-level display pointers to reference local variables.

SAVE_SR0 — Indicates that this millicode procedure saves %sr0 in its frame marker at (SP-16). This parameter is not valid for PA-RISC 2.0W (64-bit mode).

Discussion

When a program uses the .CALLINFO directive, all entry and exit code must follow the procedure calling convention described in the documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/. If you use the .ENTER and .LEAVE directives, the Assembler will automatically generate the necessary code. The parameters in the .CALLINFO directive govern the generation of the Entry/Exit code sequence (except for SAVE_SP). However, if you use the .ENTRY and .EXIT directives, your code must provide the necessary Entry/Exit code sequences.

A stack frame consists of a pointer to the top of the frame, a frame marker, a fixed argument list, and a variable argument list. The following example, Stack Frames, illustrates these areas as an inverted stack for PA-RISC 1.x and 2.0.

NOTE For PA-RISC 2.0W, 64-bit mode, the stack frame is different. Refer to the documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/.

Stack Frames

```
                          Variable Arguments
. . .
SP-64:        arg word 7
SP-60:        arg word 6
SP-56:        arg word 5
SP-52:        arg word 4

                          Fixed Arguments

SP-48:        arg word 3 / ARG3
SP-44:        arg word 2 / ARG2
SP-40:        arg word 1 / ARG1
SP-36:        arg word 0 / ARG0

                          Frame Marker

SP-32:        Saved %r19 for shared library calls.
SP-28:        Reserved
SP-24:        Saved RP for shared library calls.


SP-20:        Saved RP (or SAVED_MRP).

SP-16:        Static Link (or SAVED %sr0).
SP-12:        Clean Up.
SP-8:         Extension Pointer. Calling stub RP (RP").
SP-4:         Previous SP.

                          Top of Frame

SP:           Stack Pointer.
```

Example

This example uses the C `printf()` routine (see *printf*(3S) in *HP-UX Reference*). It illustrates most of the directives to be used when assembly language programmers follow the standard procedure calling conventions described in the documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/.

```
 .CODE                          ; declare space and subspace
main
     .PROC                            ; delimit procedure entry
     .CALLINFO CALLER,FRAME=0,SAVE_RP    ; no local variables, need return
     .ENTER                           ; insert entry code sequence
     ADDIL  L'stringinit-$global$,%r27      ; point to data to be printed
     LDO    R'stringinit-$global$(%r1),%r26 ; place argument to printf
     .CALL                            ; set up for procedure call
     BL     printf,%r2                ; call printf, remembering from where
     NOP
     .LEAVE                           ; insert exit code sequence
     .PROCEND                         ; delimit procedure end

     .DATA                            ; declare space and subspace
stringinit                            ; mark use of global data subspace
     .IMPORT  $global$,DATA           ; get data reference point
```

```
.CODE                           ; re-enter code subspace
.EXPORT main,ENTRY              ; make routine known to linker
.IMPORT printf,CODE             ; external procedure declaration
.END
```

.COMM Directive

The `.COMM` directive makes a storage request for a specified number of bytes.

Syntax

label .COMM [*num_bytes*]

Parameters

label	Labels the location of the reserved storage.
num_bytes	An integer value for the number of bytes you want to reserve. The Assembler uses a default value of 4 if the `.COMM` directive lacks a *num_bytes* parameter. Permissible values range from one to `0x3FFFFFFF`.

Discussion

The `.COMM` directive declares a block of storage that can be thought of as a *common block*. You must label every `.COMM` directive. The linker associates the *label* with the subspace in which the `.COMM` directive is declared and allocates the necessary storage within that subspace. `.COMM` always allocates its space in the `$BSS$` subspace of the `$PRIVATE$` space. If the `label` of a `.COMM` directive appears in several object modules, the linker uses the maximum size specified in any module when it allocates the necessary storage in the current subspace.

Example

This example reserves 16 bytes of storage for `mydata`.

```
          .BSS
mydata    .COMM 16
```

.COPYRIGHT Directive

The `.COPYRIGHT` directive inserts a company name and date into the object module as a copyright notice.

Syntax

.COPYRIGHT "*company-name* [, *date*] "

Parameters

company-name, *date* — A sequence of ASCII characters, surrounded by quotation marks. The string can contain up to 256 characters. When a comma follows the company name, the next text is expected to be the date.

Discussion

The following is the standard copyright message placed in the copyright header of the object file:

`Copyright` *company-name*`,` *date*`. All rights reserved. No part of this program may be photocopied, reproduced, or transmitted without prior written consent of` *company-name*`.`

NOTE This directive can appear anywhere in the source file, but may appear only once.

Example

This program places a copyright notice in the object file. Once the copyright notice is in the object file, the HP-UX utility `strings` can be used to access it. See *strings*(1) in *HP-UX Reference*.

```
        .COPYRIGHT "My Company Name, 8 Nov 1994"
        .CODE
        .EXPORT main,ENTRY
main
        .PROC
        .CALLINFO
        .ENTER
        LDI     2,%r5
        ADDI    2,%r5,%r6
        .LEAVE
        .PROCEND
```

.DOUBLE Pseudo-Operation

The .DOUBLE pseudo-operation initializes a double-word to a floating-point value, calculated from the parameters provided. If the location counter, is not aligned on a double-word boundary, it is forced to the next multiple of eight. If the statement is labeled, the label refers to the first byte of the storage area.

Syntax

.DOUBLE *integer* [.*fraction*] [E [-] *power*]

.DOUBLE .*fraction* [E[-] *power*]

Parameters

integer	Specifies the whole number part of a decimal number.
fraction	Specifies the fractional part of a decimal number.
power	Specifies the power of ten to raise a decimal number. To raise the decimal number to a negative power of ten, place a minus sign (-) directly in front of the power specified.

Example

Each of the following examples initializes two words of memory to floating-point quantities: 0.00106 and 400000.0 respectively.

```
dec_val1  .DOUBLE 10.6E-4
dec_val2  .DOUBLE 0.4E6
```

.DWORD Pseudo-Operation

The .DWORD pseudo-operation reserves storage and initializes it to the given value.

Syntax

.DWORD [*init_value*[, *init_value*] ...]

Parameters

init_value — An absolute expression, a decimal, octal, or hexadecimal number, or a sequence of ASCII characters surrounded by quotation marks. If you omit the initializing value, the Assembler initializes the area to zero.

Discussion

The .DWORD pseudo-operation requests 64 bits of storage. If the location counter is not properly aligned on a boundary for a data item of that size, the Assembler advances the location counter to the next multiple of that item's size before reserving the area.

When you label the pseudo-operation, the label refers to the first byte of the storage area. Operands separated by commas initialize successive units of storage.

Example

The first pseudo-operation advances the current subspace's location counter to a double word boundary, allocates a double word of storage labeled F and initializes that double word to minus 64 (2s complement). The second pseudo-operation initializes a double word of storage to the hexadecimal number 6effffff12345678.

```
F    .DWORD    64
     .DWORD    0X6effffff12345678
```

.END Directive

The .END directive terminates an assembly language program.

Syntax

.END

Discussion

This directive is the last statement in an assembly language program. If a source file lacks an .END directive, the Assembler terminates the program when it encounters the end of the file.

Example

A file that omitted the last line of this sample program would produce identical results.

```
        .CODE
        .EXPORT double,ENTRY
        .PROC
double
        .CALLINFO
        .ENTER
        ADD    %arg0,%arg0,%ret0
        .LEAVE
        .PROCEND
        .END
```

.ENDM Directive

The .ENDM directive marks the end of a macro definition. The macro definition is entered into the macro table and the remaining source lines are read in and assembled. An .ENDM directive must always accompany a .MACRO directive.

Syntax

.ENDM

Example

This example defines the macro QUADL; it aligns the data specified in the macro parameters on quad word boundaries. The .ENDM directive delimits the end of the definition of QUADL.

```
QUADL   .MACRO  WD1,WD2,WD3,WD4
        .ALIGN  16
        .WORD   WD1
        .ALIGN  16
        .WORD   WD2
        .ALIGN  16
        .WORD   WD3
        .ALIGN  16
        .WORD   WD4
        .ENDM
```

.ENTER and .LEAVE Pseudo-Operations

The .ENTER and .LEAVE pseudo-operations mark a procedure's entry and exit points. They instruct the Assembler to generate procedure entry and exit code sequences based on the information provided in the .CALLINFO directive.

Syntax

.ENTER

Lines of code

.LEAVE

Discussion

The .ENTER pseudo-operation marks an entry point for the current procedure. Every procedure that follows the standard procedure-calling convention must contain one .ENTER pseudo-operation. The calling conventions are described in the documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/. The .LEAVE pseudo-operation marks a procedure's exit point. Every procedure that follows the procedure-calling convention must contain one .LEAVE pseudo-operation. See “.ENTRY and .EXIT Directives” on page 83 for exceptions.

When the Assembler encounters an .ENTER pseudo-operation, it generates an entry code sequence according to the parameters in the .CALLINFO directive for that procedure. Similarly, when the Assembler encounters a .LEAVE pseudo-operation, it generates an exit code sequence according to the parameters in the .CALLINFO directive for that procedure.

Example

This example shows the placement of the .ENTER and .LEAVE pseudo-operations.

```
   .SPACE $TEXT$
   .SUBSPA $CODE$
entrypt
   .PROC
   .CALLINFO
   .ENTER
   SH1ADD       %arg0,%arg1,%ret0
   .LEAVE
   .PROCEND
   .EXPORT entrypt,ENTRY
   .END
```

.ENTRY and .EXIT Directives

.ENTRY and .EXIT are compiler generated directives that mark the entry point and return point of the current procedure.

Syntax

.ENTRY

Lines of Code

.EXIT

Discussion

The .ENTRY directive signifies that the next instruction is the beginning of an entry point for the current procedure. The .EXIT directive signifies that the next instruction initiates a return from the current procedure. These directives must be used when .ENTER and .LEAVE are not present. .ENTRY and .EXIT are optional if the unwind region does not have a corresponding entry or exit. See the documents under the topic PA-RISC Architecture at URL: http://www.software.hp.com/STK/.

Example

This example shows a sequence of compiler-generated assembly code.

```
 .PROC
      .CALLINFO CALLER
      .ENTRY                                    ; proc entry code follows
      STW       %r2,-20(%sp)                    ; stack the return pointer
      LDO       48(%sp),%sp                     ; set up user stack pointer
      ADDIL     L'$THISMODULE$-$global$,%r27    ; point to printf data
      .CALL                                     ; set up for printf call
      BL        printf,2                        ; call printf thru RP
      LDO       R'$THISMODULE$-$global$(%r1),%r26 ; insert argument to
printf L$exit1                                  ; hide from linker
      LDW       -68(%sp),%r2                    ; get callee RP
      BV        0(%r2)                            ; exit thru RP
      .EXIT                                     ; end of exit sequence
      LDO       -48(%sp),%sp                    ; delete stack frame
      .PROCEND
```

.EQU Directive

The .EQU directive assigns an expression value to an identifier.

Syntax

symbolic_name .EQU value

Parameters

symbolic_name The name of the identifier to which the Assembler assigns the expression.

value An integer expression. The Assembler evaluates the expression, which must be absolute, and assigns this value to *symbolic_name*. If the expression references other identifiers, each identifier must be defined before the .EQU directive attempts to evaluate the expression.

NOTE The Assembler prohibits the use of relocatable symbols (instruction labels) and imported symbols as components of an .EQU expression.

Example

This is a valid assembly program because the definition of val1 comes before the definition of val2. Reversing the first two statements, however, produces an error condition.

```
val1 .EQU  0
val2 .EQU  val1+4
     .SPACE $TEXT$
     .SUBSPA $CODE$
     LDW   val1,%r1
     STW   %r1,val2
     .END
```

.EXPORT Directive

The .EXPORT directive allows symbols to be defined in one program and used in other programs.

Syntax

.EXPORT *symbol* [, *type*] [, *argument-description*] ...

Parameters

symbol The name of an identifier whose definition is being exported or imported.

type A linker symbol type that can take one of the following values:

ABSOLUTE	Designates an absolute symbol. In PA-RISC 2.0W (64-bit mode) ABSOLUTE symbols map to STT_NOTYPE with a section index of SHN_ABS.
DATA	Designates a data symbol. In PA-RISC 2.0W (64-bit mode) DATA symbols map to STT_OBJECT.
CODE	Designates a code location. The location can not be a procedure entry. In PA-RISC 2.0W (64-bit mode) CODE symbols map to STT_OBJECT.
ENTRY	Designates the entry point of a procedure. In PA-RISC 2.0W (64-bit mode) ENTRY symbols map to STT_FUNC.
MILLICODE	Locates code for the entry point of a millicode routine.

`MILLI_EXT`	Locates code for the entry point of an external millicode routine.
`PLABEL`	Locates a pointer to a procedure.
`PRI_PROG`	Designates the primary program entry point. The outer block of HP Pascal/HP-UX and the main program in HP FORTRAN 77/HP-UX are type `PRI_PROG`. In PA-RISC 2.0W (64-bit mode) `PRI_PROG` symbols map to `STT_FUNC`.
`SEC_PROG`	Designates a secondary program entry point. In PA-RISC 2.0W (64-bit mode) `SEC_PROG` symbols map to `STT_FUNC`.

argument-description

Allows you to communicate to the linker the types of registers used to receive floating point arguments and return floating point return results. Similarly, this information can be communicated in the `.CALL` directive.

The linker requires this information, since the Procedure Calling Convention described in the documents under the topic PA-RISC Architecture at http://www.software.hp.com/STK/ allows floating point arguments and return values to reside in either general registers or floating point registers, depending on source language convention. At link time, the linker ensures that both the caller and called procedure agree on argument location. If not, the linker may insert code to relocate the arguments (or return result) before control is transferred to the called procedure or a procedure return is completed.

The form of *argument-description* is described in See ".CALL Directive" on page 63 in this chapter.

Discussion

The .EXPORT directive uses a series of keywords to define a symbol to the linker. These keywords declare the symbol's type, and its argument relocation information if the symbol is the name of a procedure.

Example

This example makes the symbol proc available to the linker as an entry point. It also specifies that the first argument is expected in a general register.

```
.EXPORT proc,ENTRY,ARGW0=GR
```

.FLOAT Pseudo-Operation

The .FLOAT pseudo-operation initializes a single-word of storage to a floating-point value calculated from the parameters provided. If the location counter is not aligned on a word boundary, it is forced to the next multiple of four. If the statement is labeled, the label refers to the first byte of the storage area.

Syntax

.FLOAT integer [.fraction] [E [-] power]

.FLOAT .fraction [E [-] power]

Parameters

integer	Specifies the whole number part of a decimal number.
fraction	Specifies the fractional part of a decimal number.
power	Specifies the power of ten to raise a decimal number. To raise the decimal number to a negative power of ten, place a minus sign (-) directly in front of the power specified.

Example

Each of the following examples initializes one word of memory to floating-point quantities: 0.00096 and 3400000.0, respectively.

```
factor1  .FLOAT  9.6E-4
factor2  .FLOAT  3.4E6
```

.HALF Pseudo-Operation

The .HALF pseudo-operation reserves storage and initializes it to the given value.

Syntax

.HALF [*init_value* [, *init_value*] ...]

Parameters

init_value — Either a decimal, octal, or hexadecimal number or a sequence of ASCII characters, surrounded by quotation marks. If you omit the initializing value, the Assembler initializes the area to zero.

Discussion

The .HALF pseudo-operation requests 16 bits of storage. If the location counter is not properly aligned on a boundary for a data item of that size, the Assembler advances the location counter to the next multiple of that item's size before reserving the area.

When you label the pseudo-operation, the label refers to the first byte of the storage area. Operands separated by commas initialize successive units of storage.

Example

This example allocates two half-words, initializing them to 50 and 100. The label B refers to the first half-word allocated.

```
B   .HALF   50,100
```

.IMPORT Directive

The .IMPORT directive allows symbols to be defined in one program but used in other programs.

Syntax

.IMPORT *symbol* [, *type*] [, TSPECIFIC]

Parameters

symbol The name of an identifier whose definition is being imported.

type A linker symbol type that can take one of the following values:

ABSOLUTE	Designates an absolute symbol.
DATA	Designates a data symbol.
CODE	Designates a code location. The location can not be a procedure entry.
ENTRY	Designates the entry point of a procedure.
MILLICODE	Locates code for the entry point of a millicode routine.
MILLI_EXT	Locates code for the entry point of an external millicode routine.
PLABEL	Locates a pointer to a procedure.
PRI_PROG	Designates the primary program entry point. The outer block of HP Pascal/HP-UX and the main program in HP FORTRAN 77/HP-UX are type PRI_PROG.
SEC_PROG	Designates a secondary program entry point.

`TSPECIFIC` The `TSPECIFIC` keyword indicates that this is a thread local storage symbol.

Discussion

The `.IMPORT` directive uses a series of keywords to define a symbol to the linker. These keywords declare the symbol's type. Because the `.IMPORT` directive specifies that another object module contains this symbol's formal definition, the Assembler does not associate an imported symbol with any particular subspace. When an `.IMPORT` directive lacks a *type* parameter, the Assembler assigns the type of the current subspace (either `$CODE$` or `$DATA$`) to the symbol.

Example

The `.IMPORT` directive lets the Assembler access `symname` as a recognized symbol, even though it is actually defined elsewhere. The linker resolves the difference.

```
.IMPORT symname,CODE           ;import symname as a CODE symbol.
.CODE                          ;begin CODE subspace
LDIL    L'symname,%r1
BLE,n   R'symname(%sr4,%r1)    ;call the procedure symname in %sr4
space.
NOP
.END
```

.LABEL Directive

The .LABEL directive permits a label definition to appear within a sequence of instructions that occur on a single line.

Syntax

.LABEL *label_id*

Parameters

label_id Names the label identifier.

NOTE The .LABEL directive is especially useful when using the M4 macro processor or the C preprocessor (cpp). You would normally use this directive in a DEFINE macro that includes multiple instructions.

Example

This example defines a cpp macro named Loop.

```
#define Loop(xx) LDO xx(%r0),%r1 ! .LABEL Loop ! ADDI,=-1,%r1,%r1 \
! BL Loop,%r0  ! NOP  ! LDI 1,%ret0 ; macro
          .CODE
step_ten
          .PROC
          .CALLINFO
          .ENTER
          Loop(10)
          .LEAVE
          .PROCEND
          .EXPORT step_ten,ENTRY
```

.LEVEL Directive

The `.LEVEL` directive tells the Assembler which version level of the PA-RISC architecture to accept while assembling the source file. The `.LEVEL` directive also tells the Assembler which implementations-specific features are used in the assembly source file.

Syntax

$$.\text{LEVEL} \left\{ \begin{array}{l} 1.0 \\ 1.1 \\ 2.0 \\ 2.0W \end{array} \right\}$$

Parameters

`1.0`	Enables PA-RISC 1.0 features. This is the default.
`1.1`	Enables PA-RISC 1.1 features.
`2.0`	Enables PA-RISC 2.0 features.
`2.0W`	Enables PA-RISC 2.0W features and assembles the source for a 64-bit machine.

Discussion

The Assembler marks the relocatable object file to indicate the minimum PA-RISC architecture version level required when executing the object code corresponding to the source file. The linker marks the program file with the highest version level required by any of the object files linked into the program.

The Assembler uses the `.LEVEL` directive to mark the relocatable object file with the proper PA-RISC architecture version level. For example, if the code is expected to run only on PA-RISC 1.1 architectures, a .LEVEL 1.1 should be inserted at the beginning of the source file.

To assemble a source file for a PA-RISC 64-bit system, use a .LEVEL 2.0W directive as the first directive in the source file.

In the source file, the Assembler emits warning messages whenever a feature is used that is not appropriate for the specified .LEVEL directive. The default is to produce a PA-RISC 1.0 relocatable object file. If the default is used, any use of PA-RISC 1.1 or 2.0 features in the assembly source file generates a warning messages.

If the code is expected to run on more than one level of PA-RISC architecture, a run-time check should be used with a .ALLOW directive. See ".ALLOW Directive" on page 58 in this chapter for an example of a run-time check.

The .LEVEL directive is also used to indicate any implementation-specific extensions that the source file depends on. The Assembler marks the relocatable object file with information that indicates any implementation-specific extensions that were specified in the .LEVEL directive. The default for an assembly source file is no implementation-specific extensions; the Assembler generates warning messages if an implementation-specific extension is used.

.LISTOFF and .LISTON Directives

The .LISTOFF and .LISTON directives control the expansion of instructions for all macro invocations, all predefined subspace declarations, and the .ENTER and .LEAVE pseudo-operations. .LISTOFF causes the Assembler to cease listing expanded instructions until a .LISTON directive is encountered. .LISTON causes the Assembler to list expanded instructions until a .LISTOFF directive is encountered.

The default is .LISTON.

Syntax

.LISTOFF

.LISTON

Example

The following is the definition of the macro DECR. It is referred to in the assembly listing generated when .LISTON was used with a procedure containing the macro invocation.

```
DECR      .MACRO            LAB,VAL
SKF       ADDIL       L'VAL-$global$,%dp
          LDW         R'VAL-$global$(%r1),%r20
LAB       ADDIBF,=,N  -1,%r20,LAB
          .ENDM

          .CODE
          .IMPORT $global$
          .IMPORT mark
          .IMPORT count
          .PROC
call_DECR
          .CALLINFO   FRAME=0, SAVE_RP
          .ENTER
          DECR        mark,count
          .LEAVE
          .PROCEND
```

If .LISTOFF had been used in the above example, the macro invocation DECR, and the directives .CODE, .DATA, .ENTER, and .LEAVE, would not have been expanded in the assembly listing.

```
line offset   hexcode  label    opcode            operands (comment)
1                               .LISTON
2                               .CODE
                                .SPACE $TEXT$,    SPNUM=0,SORT=0
                                .SUBSPA $CODE$,   QUAD=0,ALIGN=8,ACCESS=0x2c
3                               .PROC
4                     call_DECR                  ;proc label
5                               .CALLINFO         FRAME=0,SAVE_RP
6                               .ENTER
    00000000 (6BC23FD9)         STW               2,-0x14(0,0x1E)
    00000004 (37DE0060)         LDO               0x30(0x1E),0x1E
7   00000008 (2B600000)         ADDIL             L'count-$global$,%dp
8   0000000C (683A0000)         STW               %arg0,R'count-$global$(%r1)
9                               DECR              mark,count;
                                                  macro invocation
    00000010 (2B600000)         ADDIL             L'VAL-$global$,%dp
    00000014 (48340000)         LDW               R'VAL-$global$(%r1),%r20
                      LAB
    00000018 (AE9F3FF5)         ADDIBF,=          -1,%r20,LAB
    0000001C (08000240)         NOP
10                              .LEAVE
    00000020 (4BC23F79)         LDW               -0x44(0,0x1E),2
    00000024 (E840C000)         BV                0(2)
    00000028 (37C03FA1)         LDO               -0x30(0x1E),0
11                              .PROCEND
12                              .EXPORT           call_DECR,ENTRY

13                              DATA
                                .SPACE $PRIVATE$, SPNUM=1,SORT=16
                                .SUBSPA $DATA$,   QUAD=1,ALIGN=8
                                                  ACCESS=0x1f
14                              .IMPORT           $global$
15  40000000 (00000000) count   .WORD             0
16                              .LISTOFF
```

.LOCCT Directive

The .LOCCT directive specifies where subsequent code should occur in one of the four location counters of the current subspace.

Syntax

.LOCCT [*loc_number*]

Parameters

loc_number A location-counter number of the current subspace. The permissible values are 0, 1, 2, and 3. The default is zero.

NOTE The .LOCCT directive is not permitted within a procedure and cannot be used to produce unwindable code.

Example

This example uses two location counters to separate code from data. In the assembled code, everything under location counter 0 comes first, followed by everything under location counter 1, and so on.

```
        .CODE
        .LOCCT  0
ldval1
        LDIL    L'val1,%r19
        LDO     R'val1(%r19),%r19
        .LOCCT  1
val1    .WORD   57005
        .LOCCT  0
ldval2
        LDIL    L'val2,%r20
        LDO     R'val2(%r20),%r20
        .LOCCT  1
val2    .WORD   61453
```

.MACRO Directive

The .MACRO directive marks the beginning of a macro definition. An .ENDM directive must be used to end the macro definition.

Syntax

label .MACRO [*formal_parameter*[,*formal_parameter*]...]

Parameters

label	The name of the macro.
formal_parameter	Specifies a string of characters treated as a positional parameter. The *i*th actual parameter in a macro invocation is substituted for the *i*th formal parameter in the macro declaration wherever the formal parameter appears in the body of the macro definition.

Discussion

Normal Assembler syntax is observed within macro definitions, except that text substitution is assumed for formal parameters. The following line is an example of a macro declaration:

```
DECR    .MACRO LAB,VAL
```

LAB and VAL are formal parameters. Their actual values are determined by the first and second parameters on any invocation of the macro DECR. On the macro invocation, the parameters are delimited by commas. Successive commas indicate a null parameter, causing the expanded macro to substitute null for one of its formal parameters. When the number of formal parameters exceeds the number of actual parameters, null parameters are inserted for the excess parameter positions. When the number of actual parameters exceeds the number of formal parameters, a warning is issued and the excess parameters are ignored.

NOTE Although there is no upper limit on the number of parameters or arguments in a macro definition, no single macro parameter may exceed 200 characters.

Macro definitions may appear wherever and as often as necessary within source code. Macro definitions may occur inside or outside of spaces, subspaces, and procedures.

Because the Assembler always uses the most recently encountered definition, macros may be redefined as often as desired.

NOTE A macro cannot be defined within the body of another macro definition.

Although nested macro definitions are not allowed, nested macro calls are. A nested macro call occurs when one macro is invoked within the definition of another macro. A macro may not be invoked within its own definition. Macros can only be invoked after being defined.

Examples

The macro definition defines a simple counter or timer called DECR.

```
DECR    .MACRO    LAB,VAL
SETP    ADDIL     L'VAL-$global$,%dp
        LDW       R'VAL-$global$(%r1),%r20
LAB
        ADDIBF,=  -1,%r20,LAB
        NOP
        .ENDM
```

The following is an invocation of DECR:

```
        DECR LOOP,COUNT
```

LOOP and COUNT are the actual parameters that are specific to this particular invocation of the macro DECR.

During macro expansion, textual substitution for positional parameters is performed in the body of the macro definition. Substitution is performed on strings of characters that are delimited by blanks, tabs, commas, or semicolons. If the string matches one of the formal parameters, it is replaced with the corresponding actual parameter.

When a macro definition contains a label, the expanded form of the macro adds a unique suffix to the label for each instance the macro is invoked. This unique suffix prevents duplicate symbols from occurring

and prevents the label from being referenced from outside the body of the macro definition. This suffix also contains a number that is used as a counter by the Assembler.

The following example defines the macro PRINT, which calls the `printf()` function (see *printf*(3S) in *HP-UX Reference*). The macro parameter DATA_ADDR is used to set up the argument to be passed to `printf()`.

```
PRINT   .MACRO   DATA_ADDR
        ADDIL    L'DATA_ADDR,%dp
        .CALL
        BL       printf,%rp
        LDO      R'DATA_ADDR(%r1),%arg0
        .ENDM
```

The next example defines the macro STORE. STORE places the contents of the register REG, the first macro parameter, into the memory address LOC, the second parameter.

```
STORE   .MACRO   REG,LOC
        LDIL     L'LOC-$global$,%r1
        STW      REG,R'LOC-$global$(%r1)
        .ENDM
```

.ORIGIN Directive

The `.ORIGIN` directive advances the location counter to the specified location.

Syntax

.ORIGIN [*location*]

Parameters

location — The integer value used to advance the location counter to that absolute location. The location counter value may not decrease during this process; that is, the value specified cannot be less than the value of the current location counter.

The default value is zero.

Discussion

When the Assembler encounters an `.ORIGIN` directive, it issues a `.BLOCK` pseudo-operation of a size calculated to advance the location counter to the requested origin. See ".BLOCK and .BLOCKZ Pseudo-Operations" on page 60 in this chapter.

Example

This sample program performs an exclusive `OR`, advances the location counter to 64 bytes, and branches to the label `idx`.

```
     .CODE
     XOR     %r21,%r22,%r23
     B  idx
     NOP
     .ORIGIN 64
idx  LDWX    %r23(%sr0,%sr0),%r3
    .END
```

.PROC and .PROCEND Directives

The .PROC and .PROCEND directives bracket the instructions within a procedure.

Syntax

.PROC

Lines of Code

.PROCEND

Discussion

The .PROC directive signifies that the next instruction is the first instruction of a procedure. The .PROCEND directive signifies that the previous instruction was the last instruction of the procedure. Switching spaces or subspaces within a procedure is not permitted.

Every procedure must contain a .CALLINFO directive and normally contains an .ENTER and .LEAVE pseudo-operation. The only exception to the latter rule occurs in procedures that are either compiler-generated or created by programmers who are writing their own entry and exit code sequences. In this case, you must use the .ENTRY and .EXIT compiler directives.

NOTE Because the .ENTER and .LEAVE pseudo-operations guarantee that the stack unwind process works correctly, you should consistently use these directives rather than writing your own entry and exit code sequences.

Example

This template shows a procedure that follows the procedure-calling convention.

```
     .CODE
test
     .PROC
     .CALLINFO
     .ENTER
     COMCLR,=     %arg0,%arg1,%ret0
     LDI          1,%ret0
     .LEAVE
     .PROCEND
     .EXPORT test
```

.REG Directive

The `.REG` directive assigns a predefined or user-defined typed-register to a symbol, which becomes a synonym for the typed-register.

Syntax

label .REG [*typed_register*]

Parameters

label	A user-defined register name.
typed_register	Must be one of the predefined Assembler registers or a previously defined user-defined register name All predefined Assembler registers begin with %.

Example

This example defines the register `shift` as a synonym for control register eleven. `%sar` is a predefined synonym for control register eleven, the shift-amount register.

```
shift   .REG %sar
```

.SHLIB_VERSION Directive

The `.SHLIB_VERSION` directive marks the object file with a version string that the shared library understands.

Syntax

.SHLIB_VERSION " *mm*/*yyyy*"

Parameters

mm	The one- or two-digit number of the month.
yyyy	The four-digit number of the year.

Example

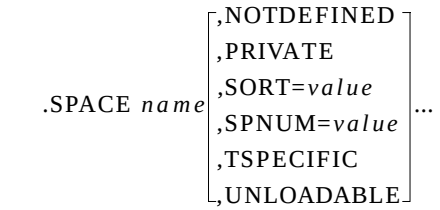
The following pseudo-operation places the date September 1994 in the object file.

```
.SHLIB_VERSION "9/1994"
```

.SPACE Directive

The .SPACE directive starts a new space or switches back to an old space. The Assembler ignores the .SPACE directive for 64-bit assembly programs. For more information, see “Sections in 64-bit Mode” on page 44.

Syntax



Parameters

name	An identifier that names the new space.
NOTDEFINED	Specifies that the definition for this space occurs in another object module.
PRIVATE	Specifies that other programs cannot *share* the data in this space. The enforcement of this directive depends on the operating system.
SORT=*value*	Provides an integer value for the sort key. The linker orders the spaces in the output object module according to this key. It is suggested that the number “8” be used for space $TEXT$ and the number “16” be used for $PRIVATE$.
SPNUM=*value*	A space number constant that provides a specific number for the current space. Its use is currently optional and is ignored by the linker. If the first parameter of the .SPACE directive is an integer, it will be interpreted as the space number and any remaining parameters will be ignored.

TSPECIFIC	Indicates that this space contains thread local storage data.
UNLOADABLE	Specifies that the space resides on disk and is not loadable into main memory. Debugger data is a typical example of an unloadable space.

Discussion

The first time the Assembler encounters a .SPACE directive with a new *name*, it uses that name to declare a new space. As this is the defining occurrence of that space, additional keywords can describe attributes for that space.

If the Assembler encounters subsequent .SPACE directives with that *name*, it continues that space. In this case, where the program is re-entering a previously defined space, the .SPACE directive can only contain the space name; other keywords to describe the space are illegal.

A space can contain from one to four discrete quadrants (See the QUAD parameter of the .SUBSPA directive.) When you divide a space into multiple quadrants, you must define all the subspaces within each quadrant as a group. If subspaces for a quadrant are defined individually, program operation is unpredictable. The Assembler, however, does not check for this condition.

Example

This example shows some of the standard “space” definitions in a typical assembly language program.

```
.SPACE  $TEXT$,     SPNUM=0,SORT=8

.SPACE  $PRIVATE$, SPNUM=1,PRIVATE,SORT=16

.SPACE  $myspace$, SPNUM=7,UNLOADABLE

.SPACE  $THREAD_SPECIFIC$, PRIVATE, TSPECIFIC, SORT=32
```

.SPNUM Pseudo-Operation

The .SPNUM pseudo-operation reserves a word of storage and initializes it with the space number of the space named by the operand. Only one operand is allowed and any label present is offset at the first byte of the storage just initialized.

Syntax

.SPNUM *name*

Parameters

name	Specifies the name of a space whose space number is used to initialize a word of storage.

NOTE Space numbers are ignored by the linker.

Example

In this example, the space number of $PRIVATE$, 1, is stored as the address of the symbol LOG by the .SPNUM pseudo-operation.

```
        .SPACE    $PRIVATE$,SPNUM=1   SORT=16
        .SUBSPA   $DATA$,QUAD=1,      ALIGN=8,ACCESS=0x1f   SORT=24
data_ref
        .WORD                         0xFFFF
LOG     .SPNUM                        $PRIVATE$
```

.STRING and .STRINGZ Pseudo-Operations

The `.STRING` pseudo-operation reserves storage for a data area and initializes it to ASCII values. The `.STRINGZ` pseudo-operation reserves storage the same as `.STRING`, but appends a zero byte to the data. This creates a C-language-type string. If the statement is labeled, the label refers to the first byte of the storage area.

Syntax

.STRING "*init_value*"

.STRINGZ "*init_value*"

Parameters

init_value A sequence of ASCII characters, surrounded by quotation marks. A string can contain up to 256 characters. The enclosing quotation marks are not stored.

The following escape sequences can be used to represent characters:

`\"`	Quotation mark
`\0`	Null (=`\x00`; ASCII NUL)
`\\`	Backslash
`\b`	Backspace (=`\x08`; ASCII BS)
`\f`	Form feed (=`\x0C`; ASCII FF)
`\n`	Newline (=`\x0A`; ASCII LF)
`\r`	Carriage return (=`\x0D`; ASCII CR)
`\t`	Tab (=`\x09`; ASCII HT)
`\x`*hh* or `\X`*hh*	Any 8-bit character; *hh* is two hexadecimal digits.

Discussion

The `.STRING` pseudo-operation requests the required number of bytes to store the string (where each character is stored in a byte). The `.STRINGZ` pseudo-operation also requests the required storage for the quoted string but then appends a zero byte for compatibility with C language strings.

When you label one of these pseudo-operations, the label refers to the first byte of the storage area.

Examples

This pseudo-operation allocates eight bytes, the first of which is labeled `G`. Then it initializes this area with the characters: `A`, *space*, `S`, `T`, `R`, `I`, `N`, and `G`.

```
G   .STRING "A STRING"
```

This pseudo-operation allocates eight bytes to hold `A STRING`, allocates an additional byte for the appended zero, and associates the label `G` with the first byte of the storage area.

```
G   .STRINGZ  "A STRING"
```

.SUBSPA Directive

The .SUBSPA directive declares a new subspace or switches back to an old subspace. In 64-bit assembly programs subspaces map directly to the ELF concept of sections, so the .SUBSPA directive switches to or creates a new section. For more information, see “Sections in 64-bit Mode” on page 44.

Syntax

```
                  ┌,ACCESS=value┐
                  │,ALIGN=value │
                  │,CODE_ONLY   │
                  │,COMMON      │
                  │,DUP_COMM    │
                  │,FIRST       │
.SUBSPA name      │,FROZEN      │ ...
                  │,LOCK        │
                  │,QUAD=value  │
                  │,SORT=value  │
                  │,TSPECIFIC   │
                  │,UNLOADABLE  │
                  └,ZERO        ┘
```

Parameters

name	An identifier that names the current subspace.
ACCESS=*value*	Specifies the 7-bit value for the access rights field in the PDIR (Physical Page Directory for virtual address mapping). Must be 0X2C for code, and 0X1F for data subspaces.
ALIGN=*value*	Specifies a value (which must be a power of 2) on which the Assembler should align the beginning of the subspace. The default value is the largest alignment requested within that subspace, or one if no alignment requests exist.

CODE_ONLY	Specifies that this subspace contains only code.
COMMON	Specifies that this subspace is a common block.
DUP_COMM	Specifies that the initialized data symbols within this subspace can have duplicate names. When you include this parameter, multiple occurrences of a universal data symbol can exist and the linker does not report a "Duplicate Definition" error.
FIRST	Specifies that the subspace must be allocated exactly at the beginning of the specified space.
FROZEN	If set, the subspace is locked into physical memory when the subspace goes into execution.
LOCK	If set, the subspace is locked into physical memory when the operating system is booted.
QUAD=*value*	Specifies the quadrant (0 through 3) in which the Assembler should place this subspace. The default value is zero.
SORT=*value*	Provides an integer value for the primary sort key. The linker orders the subspaces in the output object module according to this primary key. If several subspaces share the same primary key value, the linker lists these subspaces in the order in which it processes them. It is suggested that 24 be used for both code and data subspaces.
TSPECIFIC	Indicates that this space contains thread local storage data.
UNLOADABLE	Specifies that this subspace is not loadable into memory. Loadable subspaces must reside in loadable spaces, and unloadable subspaces must reside in unloadable spaces.
ZERO	Specifies that this subspace contains all zeros and no data appears in the output file.

Discussion

The first time the Assembler encounters a .SUBSPA directive with a new *name*, it uses that name to declare a new subspace. As this is the defining occurrence of that subspace, optional keywords describe attributes of that subspace.

When the Assembler encounters additional .SUBSPA directives with that *name*, it continues that subspace. In this case, the .SUBSPA directive can only contain the subspace name; other keywords to describe the subspace are illegal.

Example

This example shows some of the standard "subspace" definitions in a typical assembly language program.

```
.SUBSPA $CODE$,     QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=24,CODE_ONLY

.SUBSPA $DATA$,     QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=16

.SUBSPA $TBSS$,     QUAD=1,ALIGN=8,ACCESS=0x1f,ZERO, TSPECIFIC, SORT=40
```

.VERSION Directive

The `.VERSION` directive places the designated string in the current object module for version identification.

Syntax

.VERSION "*info_string*"

Parameters

info_string A sequence of ASCII characters, surrounded by quotation marks. The string can contain up to 256 characters.

Discussion

The Assembler places this string in the current object module. A program can contain multiple `.VERSION` directives.

Once the version information is in the object file, the HP-UX utility `strings` can be used to access it. See *strings*(1) in *HP-UX Reference*.

NOTE This directive can appear anywhere in the source file, and multiple occurrences are permitted.

Example

This program inserts version information into the object module, and performs subtract and deposit operations.

```
.CODE
.VERSION "Version 1 of This Simple Sample Program"
SUB      %r19,%r20,%r19
DEP      %r19,14,5,%r22
.END
```

.WORD Pseudo-Operation

The .WORD pseudo-operation reserves storage and initializes it to the given value.

Syntax

.WORD [*init_value*[, *init_value*] ...]

Parameters

init_value — A relocatable or absolute expression, a decimal, octal, or hexadecimal number, or a sequence of ASCII characters surrounded by quotation marks. If you omit the initializing value, the Assembler initializes the area to zero.

Discussion

The .WORD pseudo-operation requests 32 bits of storage. If the location counter is not properly aligned on a boundary for a data item of that size, the Assembler advances the location counter to the next multiple of that item's size before reserving the area.

When you label the pseudo-operation, the label refers to the first byte of the storage area. Operands separated by commas initialize successive units of storage.

Example

The first pseudo-operation advances the current subspace's location counter to a word boundary, allocates a word of storage labeled F and initializes that word to minus 32 (2's complement). The second pseudo-operation initializes a word of storage to the hexadecimal number 6EFF1234.

```
F     .WORD     -32
      .WORD     0X6eff1234
```

Programming Aids

The Assembler provides a series of standard space and subspace definitions that you can use to simplify the writing of an assembly program. These definitions are duplicated in the system file `/usr/lib/pcc_prefix.s`. Because this file is relatively large and may change with new releases of the Assembler, you can view the most recent version of the file on your terminal screen by typing the command:

```
more /usr/lib/pcc_prefix.s
```

Table 4-3 on page 116 lists the predefined directives for establishing standard spaces and subspaces.

Table 4-3 Predefined Subspace Directives

Directive	Space Name	Default Parameters
.BSS	.space $PRIVATE$,'' .subspa BSS,	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x1f, SORT=82,ZERO
.CODE	.space $TEXT$,'' .subspa $CODE$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=24
.DATA	.space $PRIVATE$,'' .subspa $DATA$,	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=24
.FIRST	.space $TEXT$,'' .subspa $FIRST$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=2048,ACCESS=0x2c, SORT=4,FIRST
.GATE	.space $TEXT$,'' .subspa $GATE$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=8,ACCESS=0x4c, SORT=84,CODE_ONLY
.GLOBAL	.space $PRIVATE$,'' .subspa $GLOBAL$, .IMPORT $global$	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=40
.GNTT	.space $DEBUG$,'' .subspa $GNTT$,	SPNUM=2,PRIVATE,UNLOADABLE,SORT=80 ALIGN=4,ACCESS=0,UNLOADABLE
.HEADER	.space $DEBUG$,'' .subspa $HEADER$,	SPNUM=2,PRIVATE,UNLOADABLE,SORT=80 ALIGN=4,ACCESS=0,UNLOADABLE,FIRST
.HEAP	.space $PRIVATE$,'' .subspa $HEAP$,	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=82
.LIT	.space $TEXT$,'' .subspa LIT,	SPNUM=0,SORT=8 QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=16

Directive	Space Name	Default Parameters
.LNTT	.space $DEBUG$,'' .subspa $LNTT$,	SPNUM=2,PRIVATE,UNLOADABLE,SORT=80 ALIGN=4,ACCESS=0,UNLOADABLE
.MILLICODE	.space $TEXT$,'' .subspa $MILLICODE$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=8
.PCB	.space $PRIVATE$,'' .subspa PCB,	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x10,SORT=82
.REAL	.space $TEXT$,'' .subspa $REAL$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=8,ACCESS=0x2c, SORT=4,FIRST,LOCK
.RECOVER	.space $TEXT$,'' .subspa $RECOVER$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=80
.RESERVED	.space $TEXT$,'' .subspa $RESERVED$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=8,ACCESS=0x73,SORT=82
.SHORTDATA	.space $PRIVATE$,'' .subspa $SHORTDATA$,	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=16
.SLT	.space $DEBUG$,'' .subspa SLT,	SPNUM=2,PRIVATE,UNLOADABLE,SORT=80 ALIGN=4,ACCESS=0,UNLOADABLE
.STACK	.space $PRIVATE$,'' .subspa $STACK$,	PRIVATE,SPNUM=1,SORT=16 QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=82
.UNWIND	.space $TEXT$,'' .subspa $UNWIND$,	SPNUM=0,SORT=8 QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=64
.VT	.space $DEBUG$,'' .subspa VT,	SPNUM=2,PRIVATE,UNLOADABLE,SORT=80 ALIGN=4,ACCESS=0,UNLOADABLE

5 Pseudo-Instruction Set

In addition to the PA-RISC instruction set, which is described in *PA-RISC 1.1 Architecture and Instruction Set Reference Manual* and *PA-RISC 2.0 Architecture*, the Assembler provides a number of pseudo-instructions that perform commonly used forms of the basic instructions. These pseudo-instructions are listed with their standard-instruction format in Table 5-1 on page 120.

NOTE

When coding branch instructions, including those with nullification specified, pay attention to the instruction that follows the branch in the source code. All branch instructions consider this *following* instruction to be in their *delay slot*. You can use a `NOP` pseudo-instruction to fill the delay slot when there is no other useful work to be performed. This delay slot is usually executed.

Table 5-1 Pseudo-Instructions

Pseudo-Instruction Format		Standard Instruction Format	
ADDB,cond,n[1, 2]	r1,r2,target	ADDBT,cond,n ADDBF,cond,n	r1,r2,target r1,r2,target
ADDIB,cond,n[1, 2]	r1,r2,target	ADDIBT,cond,n ADDIBF,cond,n	r1,r2,target r1,r2,target
B	w	BL	w, %r0
COMB,cond,n[1, 2]	r1,r2,target	COMBF,cond,n COMBT,cond,n	r1,r2,target r1,r2,target
COMIB,cond,n[1, 2]	r1,r2,target	COMIBF,cond,n COMIBT,cond,n	r1,r2,target r1,r2,target
COPY	r,t	LDO	0(r),t
LDI	i,t	LDO	i(%r0),t
MTSAR	r	MTCTL	r,%cr11
NOP		OR	%r0,%r0,%r0

1. The cond completer determines the actual instruction that the Assembler uses in the conditional branch. The T form is used with nonnegated completers. The F form is used with negated completers. See Table 5-2 on page 121 and Table 5-3 on page 122 for details.
2. n indicates an optional nullification completer.

Table 5-2 Compare and Branch Conditions (COMB and COMIB)

cond	Description	
	never	Nonnegated
=	opd1 is equal to opd2	
<	opd1 is less than opd2 (signed)	
<=	opd1 is less than or equal to opd2 (signed)	
<<	opd1 is less than opd2 (unsigned)	
<<=	opd1 is less than or equal to opd2 (unsigned)	
SV	opd1 minus opd2 results in overflow (signed)	
OD	result of opd1 minus opd2 is odd	
TR	always	Negated
<>	opd1 is less than or greater than opd2	
>=	opd1 is greater than or equal to opd2 (signed)	
>	opd1 is greater than opd2 (signed)	
>>=	opd1 is greater than or equal to opd2 (unsigned)	
>>	opd1 is greater than opd2 (unsigned)	
NSV	opd1 minus opd2 results in no overflow (signed)	
EV	result of opd1 minus opd2 is even	

Table 5-3 Add and Branch Conditions (ADDB and ADDIB)

cond	Description	
	never	Nonnegated
=	opd1 is equal to -opd2	
<	opd1 is less than -opd2 (signed)	
<=	opd1 is less than or equal to -opd2 (signed)	
NUV	opd1 + opd2 < 2^{32} (no unsigned overflow)	
ZNV	opd1 + opd2 < 2^{32} or opd1 + opd2 = 0	
SV	opd1 plus opd2 results in overflow (signed)	
OD	result of opd1 plus opd2 is odd	
TR	always	Negated
<>	opd1 is not equal to -opd2	
>=	opd1 is greater than or equal to -opd2 (signed)	
>	opd1 is greater than -opd2 (signed)	
UV	opd1 + opd2 > = 2^{32} (unsigned overflow)	
VNZ	opd1 + opd2 > 2^{32} and opd1 + opd2 not = 0	
NSV	opd1 plus opd2 results in no overflow (signed)	
EV	result of opd1 plus opd2 is even	

6 Assembling Your Program

This chapter describes two different ways you can invoke the Assembler and the various command line options controlling its behavior. It also contains a brief description of the interface between the Assembler and linker, and things you should remember to facilitate the running of an assembly program.

Invoking the Assembler

You can invoke the Assembler directly by using the `as` command. Or, you can invoke the Assembler through the `cc` command, which processes the assembly source using the C preprocessor. The next two sections describe these pathways.

Using the as Command

The `as` command is the standard command for invoking the Assembler on PA-RISC systems running on HP-UX. See *as*(1) in *HP-UX Reference* for complete details.

If no files are specified, the Assembler reads source text from standard input, which must be a command-line pipe or a FIFO. It cannot be a device file, such as a terminal.

The Assembler produces a single output file (see the `-o` option). If the source text is read from standard input, the object file is written to standard output and the `-o` option is ignored.

The `as` command resides in the `/usr/ccs/bin` directory.

If your programming environment does not establish a path to this directory, you must include the path name as the first part of the `as` command. For example:

```
/usr/ccs/bin/as -l line.s box.s draw.s
```

Syntax

as [[*option*] ...[*file*] ...] ...

Parameters

file — The name of an input file. The name must include the suffix `.s`. If you specify multiple input files, they are concatenated in order.

option — A flag telling the Assembler to take some special action. All options affect all input files. The `as` command supports the following options.

`+DAarch.` — Assemble code for the architecture

	specified. The use of this option is discouraged. The preferred method for selecting the architecture is to use a `.LEVEL` directive in the assembly source file. The target architecture specified with the `.LEVEL` directive takes precedence over the architecture specified with the `+DA` option.
`-e`	Specify that the Assembler should tolerate one million errors before terminating the assembly process. Without this option, the Assembler terminates a program after 100 errors.
`-f`	Specify that procedures call other procedures as the default condition. Normally, the Assembler assumes that procedures do not call other procedures. (See the `CALLS` and `NO_CALLS` parameters for `.CALLINFO` directive.).
`-l`	List the assembled program on standard output. This listing shows instruction offsets and the values stored in each field.
`-o` *filename*	Assign the specified name to the output file. The default name for the output file is the name of the last input file with the suffix changed to `.o`.
`-p` *level*	Specify the privilege level of running capability. *level* must be in the range zero to three, with three being the least privileged (normal user).
`-s`	Set the output file suffix to `.ss` instead of `.o`. The file will have a format suitable for conversion to the ROM burning programs.

`-u`	Prevent the Assembler from creating stack unwind descriptors. This option precludes the use of the `.ENTER` and `.LEAVE` directives within a program.
`-v` *filename*	Name a file to which the Assembler writes cross-reference information; this includes the source file and the line number for each appearance of all symbols.
`-V`	Print the version number of the Assembler program to standard error before assembling the source text.
`-w`*[number]*	Either suppress all warning messages if no number is supplied or suppress just the warning number provided. You can use multiple `-w`*number* options to suppress additional warning messages.
`+z`	Create position-independent code suitable for inclusion in a shared library. Use this option for small linkage tables.
`+Z`	Create position-independent code suitable for inclusion in a shared library. Use this option for large linkage tables. For more information about linkage tables, see *HP-UX Linker and Libraries Online User Guide*.

Using the cc Command

You can also use the `cc` command to run the Assembler on files that have a `.s` suffix. See *cc*(1) man page for the HP C/HP-UX ANSI C compiler, if installed. The `cc` command inserts the system file

`/usr/lib/pcc_prefix.s`

in front of the `.s` file and pipes the file through the C preprocessor (see *cpp*(1) in *HP-UX Reference*) before passing the file to the Assembler. `pcc_prefix.s` is a concatenation of the following header files in the directory `/usr/include`:

`hard_reg.h`	Set of `.REG`s for hardware registers.
`soft_reg.h`	Set of register definitions that follows the Procedure Calling Convention.
`std_space.h`	Set of space and subspace definitions that most Assembler programs use.

NOTE

If you are using the HP C/HP-UX ANSI C compiler, you can suppress the `pcc_prefix.s` file with the `cc` option `+a`.

Passing Arguments to the Assembler

The `cc` command normally strips all `as` command options from the command line, writing a warning to standard error. Therefore, when you want to retain one of these options, you must include the `-Wa` command-line option

-Wa, ,*as-argument* [*as-argument*] ...

as-argument names an Assembler argument you want to preserve. For example, to specify a cross-reference file, you could use:

```
-Wa,-v,myxreffile
```

Similarly, you can pass options to the C preprocessor (`cpp`) or the linker (`ld`) with `-Wp` and `-Wl`, respectively.

cpp Preprocessor

You can use the C preprocessor (cpp) with assembly language programs to include C-type macros, including directives. You can use an exclamation point (!) as a statement terminator to include multiple statements in the body of one macro definition. Furthermore, you can use the .LABEL directive to declare labels within a macro definition.

NOTE If you use cpp, C-style comments should only be used on separate lines.

7 Programming Examples

This chapter consists of five programming examples in assembly language. The first three examples show typical assembly language code sequences; the last two examples show the correspondence between C, a higher-level programming language, and assembly language.

Example 1	Calculates the highest bit position set in a passed parameter. A binary search is used to enhance performance.
Example 2	Copies bytes from a source location to a destination location. Both locations and the number of bytes to copy are passed in as parameters.
Example 3	Uses Divide Step to divide a 64-bit signed dividend by a 32-bit signed divisor.
Example 4	Uses a procedure call from a C program to the Assembler to verify that the program is passing the correct argument.
Example 5	Shows a C program that generates assembly code to call `printf()`.

1. Binary Search for Highest Bit Position

The Shift Double and Extract Unsigned instructions are used to implement a binary search. Bits shifted into general register 0 are effectively discarded.

```
 .CODE
       .EXPORT post
;
; This procedure calculates the highest bit position
; set in the word passed in as the first argument.
; If passed parameter is non-zero, the algorithm
; starts by assuming it is one.
; A binary search for a set bit is then used
; to enhance performance.
;
; The calculated bit position is returned to the caller.
;
       .PROC
post
       .CALLINFO SAVE_RP
       .ENTER
       COMB,=,N     %r0,%arg0,all_zeros    ; No bits set
       LDI          31,%ret0               ; assume 2 to the 0 power
;
; if extracted bits non-zero, fall thru to change assumption
; else set up 16 low order bits and keep assumption
;
       EXTRU,<>     %arg0,15,16,%r0        ; check 16 high order bits
       SHD,TR       %arg0,%r0,16,%arg0     ; left shift arg0 16 bits
       ADDI         -16,%ret0,%ret0        ; assume 2 to the 16 power
;
; if extracted bits non-zero, fall thru to change assumption
; else set up 8 low order bits and keep assumption
;
       EXTRU,<>     %arg0,7,8,%r0          ; check next 8 high order bits
       SHD,TR       %arg0,%r0,24,%arg0     ; left shift arg0 8 bits
       ADDI         -8,%ret0,%ret0         ; assume 8 higher power of 2
;
; if extracted bits non-zero, fall thru to change assumption
; else set up 4 low order bits and keep assumption
;
       EXTRU,<>     %arg0,3,4,%r0          ; check next 4 high order bits
       SHD,TR       %arg0,%r0,28,%arg0     ; left shift arg0 4 bits
       ADDI         -4,%ret0,%ret0         ; assume 4 higher power of 2
;
; if extracted bits non-zero, fall thru to change assumption
; else set up 2 low order bits and keep assumption
;
       EXTRU,<>     %arg0,1,2,%r0          ; check next 2 high order bits
       SHD,TR       %arg0,%r0,30,%arg0     ; left shift arg0 2 bits
       ADDI         -2,%ret0,%ret0         ; assume 2 higher power of 2
```

```
;
; if extracted bit is zero, fall thru and keep assumption
; else make conclusion
;
       EXTRU,=      %arg0,0,1,%r0          ; check next bit
       ADDI         -1,%ret0,%ret0         ; next higher power of 2
       B,N          tally

all_zeros
       LDI          -1,%ret0

tally
       .LEAVE
       .PROCEND
```

2. Copying a String

This example contains a section of assembly code that moves a byte string of arbitrary length to an arbitrary byte address.

```
; The routine reflect copies bytes from the source location
; to the destination location.
;
; The first parameter is the source address and the second
; parameter is the destination address.
;
; The third parameter is the number of bytes to copy.
;
; For performance, larger chunks of bytes are handled differently.
;
       .CODE
       .EXPORT     reflect,ENTRY

reflect
       .PROC
       .CALLINFO   ENTRY_GR=6,SAVE_RP
       .ENTER
       COMB,=,N    %arg2,%r0,fallout    ; done, count is zero
       COMB,<,N    %arg2,%r0,choke      ; caller error, neg count
       OR          %arg0,%arg1,%r6      ; source and dest
       OR          %r6,%arg2,%r6        ; count
       EXTRU,=     %r6,31,2,%r0         ; 2 low order bits = 0?
       B,N         onebyte              ; yes, skip this branch
       ADDIBT,<,N  -16,%arg2,chekchunk  ; no, skip chunkify if count<0

chunkify
       LDWM        16(%arg0),%r6        ; word 1- > temp1
                                        ; point ahead 4 words  in source
       LDW         -12(%arg0),%r5       ; place mark 3 wds back- >temp2
       LDW         -8(%arg0),%r4        ; place mark 2 wds back- >temp3
       LDW         -4(%arg0),%r3        ; place mark 1 wds back- >temp4
       STW         %r5,4(%arg1)         ; dest wd 2 <-temp2
       STWM        %r6,16(%arg1)        ; dest wd 1 <-temp1
                                        ; point ahead 4 words in dest
       STW         %r4,-8(%arg1)        ; dest wd 3 <-temp3
       ADDIBF,<    -16,%arg2,chunkify   ; loop if count > 0
       STW         %r3,-4(%arg1)        ; dest wd 2 <-temp1

chekchunk
       ADDIBT,<    12,%arg2,exeunt      ; go if count < -12
       COPY        %r0,%ret0            ; clear rtnval

subchunk
       LDWS,MA     4(%arg0),%r6         ; word- >temp1
                                        ; point ahead 4 bytes in source
       ADDIBF,<    -4,%arg2,subchunk    ; go if count<4
       STWS,MA     %r6,4(%arg1)         ; dest< -temp1
                                        ; point ahead 4 bytes in dest
```

```
        B           exeunt              ; all done
        COPY        %r0,%ret0           ; clear rtnval

onebyte
        LDBS,MA     1(%arg0),%r6        ; temp1 < -byte,bump src pointer

onemore
        STBS,MA     %r6,1(%arg1)        ; dest<-temp1,bump dest pointer
        ADDIBF,=,N  -1,%arg2,onemore    ; decrement count
                                        ; compare for 0.
        LDBS,MA     1(%arg0),%r6        ; delay slot
                                        ; temp1 <-byte,bump src pointer
fallout
        B           exeunt
        COPY        %r0,%ret0

choke
        LDI         14,%ret0

exeunt
        .LEAVE
        .PROCEND
```

3. Dividing a Double-Word Dividend

This example contains the code sequence to divide a 64-bit signed dividend by a 32-bit signed divisor using the DS (Divide Step) instruction. Table 7-1 on page 135 lists the registers that this program uses.

```
start
            MOVB,>=         dvdu,rem,check_mag  ; Move upper dividend
                                                ;   check for &< 0
            ADD             0,dvdl,quo          ; Move lower dividend always
            SUB             0,quo,quo           ; Get absolute value of
            SUBB            0,rem,rem           ;   the dividend in rem,quo
check_mag
            SUBT,=          0,dvr,tp            ; Check 0, clear carry,
                                                ;   negate the divisor
                                                ;   and trap if dvr = 0
            DS              0,tp,0;             ; Set V-bit to the complement
                                                ;   of the divisor sign
            ADD             quo,quo,quo         ; Shift msb bit into carry
            DS,&<<           rem,dvr,rem         ; 1st divide step, if carry
                                                ;   out msb of quotient = 0
            B,n             min_ovfl            ; Abs(quotient) > 2**31
                                                ;   deal with elsewhere
            ADDC            quo,quo,quo         ; Shift quo with/into carry
            DS              rem,dvr,rem         ; 2nd divide step
            ; ...
            ;repeat divide step sequence
            ; ...
            ADDC            quo,quo,quo         ; Shift quo with/into carry
            DS              rem,dvr,rem         ; 31st divide step
            ADDC            quo,quo,quo         ; Shift quo with/into carry
            DS              rem,dvr,rem         ; 32nd divide step,
            ADDC            quo,quo,quo         ; Shift last quo bit into quo
            ADDB,>=,n       rem,0,finish        ; Branch if pos. rem
            ADD,&<           dvr,0,0             ; If dvr > 0, add dvr
            ADD,tr          rem,dvr,rem         ;   for correcting rem.
            ADDL            rem,tp,rem          ; Else add absolute value dvr
finish
            ADD,>=          dvdu,0,0            ; Set sign of rem
            SUB             0,rem,rem           ;   to sign of dividend
            XOR,>=          dvdu,dvr,0          ; Get correct sign of quo
            SUB             0,quo,quo           ;   based on operand signs
```

Table 7-1 Register Designations

Register Designations	Purpose
`dvr`	Register holding divisor.
`dvdu dvd1`	Pair of registers holding dividend.
`tp`	Temporary register.
`quo`	Register holding quotient.
`rem`	Register holding remainder.

4. Demonstrating the Procedure Calling Convention

A C program calls an assembly language program to test if .ENTER and .LEAVE are working correctly. The assembly language program checks to see if the C program has passed the value zero in arg0. The assembly language program then returns the value -9 in ret0 to the calling program.

You need to compile this assembly listing using cc. The registers ret0 and arg0 are declared within /usr/lib/pcc_prefix.s, which is automatically included when you give the C compiler an assembly file.

To remove the dependency on pcc_prefix.s, replace all occurrences of ret0 with %r28 and arg0 with %r26.

C Program Listing

```
#include <stdio.h>
int errorcount = 0;
main ()
{
     int toterr = 0;
     printf("TESTING FEATURE  000");
     fflush(stdout);
     if( feat000(000) != -9 ) ++errorcount;
     printf("         %d errors\\n",errorcount);
     toterr += errorcount;
     errorcount = 0;
}
```

Assembly Program Listing

```
; Assembler Module that passes results back to C driver module
myfeat   .EQU    000
success  .EQU    -9

         .CODE
         .IMPORT errorcount,DATA
         .SUBSPA $CODE$
         .EXPORT feat000,ENTRY

         .PROC
         .CALLINFO
feat000 .ENTER
         LDI       0,ret0
         COMIB,<>  myfeat,arg0,exit
  NOP
         LDI       success,ret0
exit     .LEAVE
         .PROCEND
         .END
```

5. Output of the cc -S Command

This example shows how a simple C program generates assembly language code. The program calls the `printf()` routine. To run the assembled code, you need to link the file `/usr/ccs/lib/crt0.o` and the C library file. Remember that the `ld` command requires that you link the `crt0.o` file first in 32-bit mode only. You do not need to link `/usr/ccs/lib/crt0.o` in 64-bit mode..

C Program Listing

```
main ()
{
    printf ("Hello World\n");
}
```

Assembly Program Listing From the C Compiler

```
.LEVEL  1.0
        .SPACE  $TEXT$,SORT=8
        .SUBSPA $CODE$,QUAD=0,ALIGN=4,ACCESS=44,CODE_ONLY,SORT=24
main
        .PROC
        .CALLINFO CALLER,FRAME=0,SAVE_RP
        .ENTRY
        STW     %r2,-20(0,%r30) ;offset 0x0
        LDO     48(%r30),%r30   ;offset 0x4
        ADDIL   LR'$THIS_DATA$-$global$,%r27    ;offset 0x8
        .CALL   ARGW0=GR        ;in=26;
        BL      printf,%r2      ;offset 0xc
        LDO     RR'$THIS_DATA$-$global$(%r1),%r26 ;offset 0x10
L$exit1
        LDW     -68(0,%r30),%r2 ;offset 0x14
        BV      %r0(%r2)        ;offset 0x18
        .EXIT
        LDO     -48(%r30),%r30  ;offset 0x1c
        .PROCEND ;


        .SPACE  $TEXT$
        .SUBSPA $LIT$,QUAD=0,ALIGN=8,ACCESS=44,SORT=16
        .SUBSPA $CODE$
        .SPACE  $PRIVATE$,SORT=16
        .SUBSPA $DATA$,QUAD=1,ALIGN=8,ACCESS=31,SORT=16
$THIS_DATA$
        .ALIGN  4
        .STRINGZ "Hello World\n"

        .SUBSPA $SHORTDATA$,QUAD=1,ALIGN=8,ACCESS=31,SORT=24
```

```
$THIS_SHORTDATA$

        .SUBSPA $BSS$,QUAD=1,ALIGN=8,ACCESS=31,ZERO,SORT=82
$THIS_BSS$

        .SUBSPA $SHORTBSS$,QUAD=1,ALIGN=8,ACCESS=31,ZERO,SORT=80
$THIS_SHORTBSS$

        .SUBSPA $STATICDATA$,QUAD=1,ALIGN=8,ACCESS=31,SORT=16
$STATIC_DATA$

        .SUBSPA $SHORTSTATICDATA$,QUAD=1,ALIGN=8,ACCESS=31,SORT=24
$SHORT_STATIC_DATA$

        .IMPORT $global$,DATA
        .SPACE  $TEXT$
        .SUBSPA $CODE$
        .EXPORT main,ENTRY,PRIV_LEV=3,RTNVAL=GR
        .IMPORT printf,CODE
        .END
```

5. Output of the cc -S Command

8 Diagnostic Messages

This appendix lists all error messages that originate from the PA-RISC Assembler.

The Assembler error messages are divided into the following categories:

Warning Messages	Conditions that cause errors in program execution.
Error Messages	Conditions that cause the Assembler to terminate abnormally.
Panic Messages	Conditions that cause the Assembler to abort immediately.
User Warnings	Conditions that cause the Assembler to produce an object file and possibly to take a specified corrective action.
Limit Errors	Conditions caused by running into Assembler limits or running out of memory.
Branching Errors	Conditions that prevent the Assembler from creating an object file.

Message descriptions use symbols in the form *&<operand>* to designate Assembler source elements that are the subject of the error. When a message is printed during the assembly operation, the *&<operand>* symbol is replaced by the appropriate source element.

The text for the Assembler messages is stored in a file with the path name:

`/usr/lib/nls/msg/$LANG/as.cat`

The default value for the localization environment variable `LANG` is `C`.

Warning Messages

The following messages describe compiler warnings that prevent the Assembler from creating an object file. You must correct these errors to assemble your program.

1	**MESSAGE**	`Use of old style opcode, “%s”`
	CAUSE	Attempt to use an opcode that has been renamed for PA2.0.
	ACTION	Consult the PA-RISC Architecture manual for the new form of the opcode.
2	**MESSAGE**	`Unknown option “%s” ignored.`
	CAUSE	An unknown or invalid command-line option was passed to the assembler.
	ACTION	Remove the invalid option from the command-line.
3	**MESSAGE**	`Argument is missing for "%s"`
	CAUSE	Missing argument for command-line option <*operand*>.
	ACTION	Add an argument to the command-line option.
4	**MESSAGE**	`Illegal argument for option “%s”`
	CAUSE	Invalid value for command-line option <*operand*>
	ACTION	Supply a valid value for the command-line option.
5	**MESSAGE**	`Usage of field selector "%s" with instruction "%s" may be incorrect`
	CAUSE	Using an improper field selector for the instruction.
	ACTION	Change the field selector.

7	**MESSAGE**	`Space characteristics may not be changed after first declaration`
	CAUSE	Attempt to change the values assigned to keywords for a space previously declared with a `.SPACE` directive. The first declaration of the space may be in the file `pcc_prefix.s`.
	ACTION	Use desired values for keywords on first declaration of space. Specify keyword values on first declaration of space only.
8	**MESSAGE**	`Subspace characteristics may not be changed after first definition`
	CAUSE	Attempt to change the values assigned to keywords for a subspace previously declared with a `.SUBSPACE` directive. The first declaration of the subspace may be in the file `pcc_prefix.s`.
	ACTION	Use desired values for keywords on first declaration of subspace. Specify keyword values on first declaration of subspace only.
10	**MESSAGE**	`Alignment omitted - 8 assumed`
	CAUSE	Missing argument for `.ALIGN` directive.
	ACTION	Use a valid power of two integer argument with `.ALIGN`
11	**MESSAGE**	`Missing value - zero assumed`
	CAUSE	Missing argument for `.ORIGIN` or `.EQU` directive
	ACTION	Use a valid integer argument.
12	**MESSAGE**	`Size omitted - 4 assumed`

	CAUSE	Missing argument for `.COMM` directive.
	ACTION	Specify the actual number of bytes to reserve.
13	**MESSAGE**	`Modification of %r3 with a frame size larger than 8191 bytes violates .ENTER/.LEAVE convention`
	CAUSE	General register 3 used as a temporary register within a procedure where the frame size was set by the `FRAME` keyword to a size larger than 8191 bytes. Note: `%r3` is predefined as a frame pointer for procedures with large frames.
	ACTION	Don't use `%r3` as a temporary register in a procedure that has a large frame.
14	**MESSAGE**	`KEEP should not be in force for this statement`
	CAUSE	`.KEEP` directive used outside of a procedure
	ACTION	Remove the `.KEEP` directive.
15	**MESSAGE**	`Procedure makes calls but is not flagged as CALLER in CALLINFO`
	CAUSE	Missing `CALLER` keyword in `.CALLINFO` directive for this procedure.
	ACTION	Add `CALLER` keyword to `.CALLINFO` for this procedure.
16	**MESSAGE**	`Redefinition of symbol`
	CAUSE	Symbol used in label definition is already defined.

	ACTION	Use a different name in the label part to avoid overwriting the previous definition.
17	**MESSAGE**	`Existing register name, number, and type are being overwritten`
	CAUSE	Name (label) used with `.REG` was previously defined.
	ACTION	Use a different name in the label part to avoid overwriting previous definition.
18	**MESSAGE**	`The "%s" error message catalog cannot be located`
	CAUSE	Error message catalog for `LANG` <*operand*> cannot be accessed.
	ACTION	Insure that your `NLSPATH` variable is set correctly. Also insure that the default error message catalog for the assembler is accessible in `/usr/lib/nls/msg/C/as.cat`
19	**MESSAGE**	`Defining register missing or defining register has no type`
	CAUSE	Parameter to `.REG` is not one of the predefined assembler registers, nor is it a previously defined (by another `.REG` directive) register.
	ACTION	Either use one of the predefined assembler register names or a register name previously defined by a `.REG` directive.
20	**MESSAGE**	`General register expected in this field - %s`
	CAUSE	Wrong register type used.
	ACTION	Use a general register.
21	**MESSAGE**	`Space register expected in this field - %s`

	CAUSE	Wrong register type used.
	ACTION	Use a space register.
22	**MESSAGE**	`Control register expected in this field - %s`
	CAUSE	Wrong register type used.
	ACTION	Use a control register.
23	**MESSAGE**	`Floating point register expected in this field - %s`
	CAUSE	Wrong register type used.
	ACTION	Use a floating-point register.
25	**MESSAGE**	`This subspace should have no initialized data in it`
	CAUSE	Use of a directive, such as `.WORD` that allocates and initializes data, when the currently active subspace has the `ZERO` keyword associated with it, which disallows initialized data.
	ACTION	Either use the `.BLOCK` directive to allocate storage in this subspace or remove the `ZERO` keyword from the `.SUBSPACE` definition.
26	**MESSAGE**	`Output file name missing`
	CAUSE	Filename needed for `-o` command-line option.
	ACTION	Supply a valid filename for the `-o` command-line option.
27	**MESSAGE**	`XREF file name missing after -v`
	CAUSE	Filename needed for `-v` command-line option.
	ACTION	Supply a valid filename for the `-v` command-line option.
28	**MESSAGE**	`Only one copyright message permitted`

	CAUSE	More than one `.COPYRIGHT` directive encountered.
	ACTION	Remove the extra `.COPYRIGHT` directive(s).
29	**MESSAGE**	`A procedure may not be empty`
	CAUSE	Procedure with no code encountered.
	ACTION	Add at least one instruction to procedure or delete the procedure from the source file.
30	**MESSAGE**	`Procedure does not have .CALLINFO`
	CAUSE	Procedure requires a `.CALLINFO` due to use of `.ENTER`/`.LEAVE` or if there are no unwind space requirements.
	ACTION	Insert a correct `.CALLINFO` directive at the start of the procedure.
31	**MESSAGE**	`Empty source file(s)`
	CAUSE	Input source file was empty.
	ACTION	An empty source file usually indicates an error of some kind.
32	**MESSAGE**	`Missing .PROCEND`
	CAUSE	A `.PROC` was not terminated by a corresponding `.PROCEND`
	ACTION	Insert a `.PROCEND`
33	**MESSAGE**	`Cache hint may not work on some hardware`
	CAUSE	An instruction was encountered that was performing a load to `%r0`. This type of instruction is reserved as a hint to the cache system. However some of the early hardware didn't properly perform this cache hint feature.

	ACTION	Avoid using loads to `%r0` if you want your code to execute correctly on all PA-RISC machines.
34	**MESSAGE**	Missing .LEVEL directive; A .LEVEL 1.0 was inserted before .ALLOW
	CAUSE	A `.ALLOW` directive was encountered without first seeing a `.LEVEL` directive.
	ACTION	Insert a `.LEVEL` directive at the start of the source file.
35	**MESSAGE**	`Use of .ALLOW %s not meaningful for file assembled at .LEVEL %s`
	CAUSE	The `.ALLOW` directive supplied has no meaning for a file assembled at given `.LEVEL`. For example if your source file specifies `.LEVEL 1.1` then a `.ALLOW 1.0` or `.ALLOW 1.1` would not be meaningful for this source file.
	ACTION	Removed `.ALLOW` directive or change `.LEVEL`.
36	**MESSAGE**	`Use of %s is incorrect for the current %s of %s`
	CAUSE	Use of a feature that is not supported on the hardware that the assembler is targeting. The assembler is told what hardware it is targeting through the use of the `.LEVEL` and `.ALLOW` directives. Using PA1.1 features while at `.LEVEL 1.0` will generate this message.
	ACTION	Insert a `.LEVEL` or `.ALLOW` directive as appropriate, or remove the offending instruction from the source file.

37	**MESSAGE**	`Use of %s requires key bit %s to be enabled with a .LEVEL or .ALLOW`
	CAUSE	Use of a feature that requires a key bit to be set.
	ACTION	Add key bit to the `.LEVEL` or `.ALLOW` directive.
38	**MESSAGE**	`Encoding for %s requires a format that is incorrect for the current %s of %s`
	CAUSE	The instruction requires an encoding format that is not available on the hardware that the assembler is targeting. The assembler is told what hardware it is targeting through the use of the `.LEVEL` and `.ALLOW` directives. Using a PA-RISC 2.0 instruction encoding format while at `.LEVEL 1.1` will generate this message.
	ACTION	Change the instruction such that it can be properly encoded on the hardware that the assembler is targeting or change the `.LEVEL` to 2.0.
39	**MESSAGE**	`The completer specified ,%s is obsolete but will be accepted as ,%s`
	CAUSE	The use of the `,SH` completer is incorrect.
	ACTION	Replace the `,SH` completer by the `,BC` completer is the source.
40	**MESSAGE**	`Poorly formed operand, accepted as %s(%r0)`
	CAUSE	The previous assembler would silently accept poorly formed operands and add a trailing (`%r0`) to

		the operand. The new assembler will also accept these poorly formed operands and also add the trailing (`%r0`) to the operand, but it additionally flags this as a potential problem by issuing this warning.
	ACTION	Add a trailing (`%r0`) to the operand or otherwise correct the poorly formed operand.
41	**MESSAGE**	`A register typed operand is expected here - %s`
	CAUSE	The old assembler would accept integers between 0 and 31 as valid registers, or alternatively accept names that were defined using a `.EQU` to an integer. The new assembler performs additional type checks on the operands and wants to see either a predefined register (starting with a `%`) or a register name that was previously defined by the `.REG` directive. The file `/usr/lib/pcc_prefix.s` is typically included when the assembler is invoked through `cc(1)` and this file defines many register names that are typically used in assembly programs.
	ACTION	Inspect the source file and replace the integer with the appropriate predefined register, or for a name, find and replace the `.EQU` directive with a correct `.REG` directive. Alternatively the `w41` command-line option may be used to suppress all occurrences of this warning message. Note that future versions of the assembler may require proper register typing of operands in order

for it to be able to disambiguate between immediates and registers for certain opcodes. Thus in future versions of the assembler this message may be a non-suppressible error instead of a warning.

42 **MESSAGE** `Use of %s is incorrect for the current %s of %s`

CAUSE Use of a cbit in a FTEST or FCMP instruction, with a `.LEVEL` of 1.1 or 1.0. The cbit feature of FCMP and FTEST is only available for `.LEVEL 2.0`.

ACTION Insert a `.LEVEL` or `.ALLOW` directive as appropriate, or remove the offending instruction from the source file.

44 **MESSAGE** `Value for ACCESS was not specified for this new .SUBSPA directive.`

CAUSE A new subspace is being defined by the this `.SUBSPA` directive and a value of the `ACCESS` keyword is not supplied. You must always give a value for `ACCESS` when defining a new subspace.

ACTION If the subspace that you are referencing is a predefined subspace then make sure that the header file `/usr/lib/pcc_prefix.s` is being included. You must add the header file to the command-line if you are invoking `as(1)` directly. The header file will typically be included for you if you invoke the assembler using `cc(1)`

If you are declaring a new subspace then add the proper `ACCESS` definition to the `.SUBSPA` directive.

		The value `ACCESS=0x2c` should be used for all code or read-only subspaces and the value `ACCESS=0x1f` should be used for all data or read-write subspaces.
45	**MESSAGE**	`Previous value for .SHLIB is being changed to this value`
	CAUSE	More than one `.SHLIB` directive was encountered.
	ACTION	Remove the extra `.SHLIB` directive(s).
46	**MESSAGE**	`The +DA option conflicts with the .LEVEL directive, using .LEVEL %s.`
	CAUSE	The assembly source file contained a `.LEVEL` directive which conflicted with the command-line `+DA` option. The assembler always honors the `.LEVEL` directive found in the source file. The command-line `+DA` was ignored.
	ACTION	Remove `+DA` from the command-line used to invoke the assembler.
47	**MESSAGE**	`The behavior of instruction %s is undefined with the operands and completers supplied.`
	CAUSE	The behavior of the instruction used is undefined with the operands supplied.
	ACTION	Read the PA-RISC Architecture manual entry for the instruction being used, paying attention to the cases in which the behavior of the instruction is undefined. Recode the operands for the instruction so that the operands don't cause the instruction to be undefined.

48 **MESSAGE** `Expression encountered while expecting a register; Register %s substituted for expression.`

CAUSE An expression was encountered in a location where a predefined register (starting with a % or a register name that was previously defined by the `.REG` directive was expected. (Also see warning 41).

ACTION Replace expression with a predefined register or a register name that was previously defined by the `.REG` directive.

49 **MESSAGE** `Number is too large. The value -1 will be used instead.`

CAUSE A number was encountered that was too large to fit in a 64-bit integer.

ACTION Replace the number with a smaller value.

Error Messages

The following messages describe compilation errors that prevent the Assembler from creating an object file. You must correct these errors to assemble your program.

1000	**MESSAGE**	`Unterminated quoted string`
	CAUSE	String specified was missing the trailing double quote. Strings literals can not span multiple lines.
	ACTION	Add trailing double quote to string.
1001	**MESSAGE**	`Undefined register symbol`
	CAUSE	Name specified is not a predefined or `.REG` defined register symbol
	ACTION	Correct spelling of name or add `.REG` directive to define name.
1002	**MESSAGE**	`Undefined completer`
	CAUSE	Invalid value used in completer field.
	ACTION	Use a proper completer as specified in *PA-RISC Architecture and Instruction Set Reference Manual*.
1003	**MESSAGE**	`Improper completer ,%s specified for opcode %s`
	CAUSE	The completer used is not a valid completer for the instruction.
	ACTION	Consult the *PA-RISC Architecture and Instruction Set Reference Manual* for the list of valid completers for this instruction.
1004	**MESSAGE**	`Illegal completer combination specified for opcode %s`
	CAUSE	The combination of completers used is not valid for the instruction.

	ACTION	Consult the *PA-RISC Architecture and Instruction Set Reference Manual*, for the list of valid completer combinations for this instruction.
1005	**MESSAGE**	`Unable to open xref file: %s`
	CAUSE	Assembler could not create or access the file specified with the `-v` command-line option.
	ACTION	Insure that the directory is writable.
1007	**MESSAGE**	`Label not allowed here in this expr`
	CAUSE	Assembler will not allow a label here.
	ACTION	Expressions must be in the form *label1[[-label2]+constant_exp]* Reorder expression to be in the proper form.
1008	**MESSAGE**	`Illegal symbol in expression`
	CAUSE	An expression contains a sequence other than *label operator term* or *term operator term*
	ACTION	Place operators `+`, `-`, between a label and a term, or place operators `+`, `-`, `*`, `/` between a term and term. Note that a term means a constant expression.
1009	**MESSAGE**	`Field selector not allowed in pc-relative expression`
	CAUSE	Field selector, such as `L'` or `R'` used on a expression that is a branch target.
	ACTION	Omit field selectors from branch target expression.
1010	**MESSAGE**	`String not allowed in pc_relative expression`
	CAUSE	String used for branch target expression.

	ACTION	Replace with an expression beginning with a label or “.”
1011	**MESSAGE**	`"." allowed in pc_rel expression only`
	CAUSE	A period (.) used as an operand in a non-branch context, or used as a target in external branch or vectored branch.
	ACTION	Use “.” only for pc-relative branches, not in branch external or branch vectored.
1012	**MESSAGE**	`PC-relative expression must begin with . or label`
	CAUSE	Branch target is poorly formed.
	ACTION	Use a label or “.” as the first term of a branch expression
1013	**MESSAGE**	`Second label not allowed in pc_relative expression`
	CAUSE	Branch target is poorly formed: *label operator label*
	ACTION	Use an offset in place of the second label.
1014	**MESSAGE**	`Labels may not be added, they may only be subtracted`
	CAUSE	Attempt to form the sum of two labels.
	ACTION	Use an offset in place of the second label.
1015	**MESSAGE**	`Unexpected end of expression`
	CAUSE	Nothing follows a +, -, /, or * in an expression.
	ACTION	Place meaningful terms, integers or labels after operator.

1016	**MESSAGE**	`General register %s is out of range`
	CAUSE	Register number specified greater than 31 or less than 0.
	ACTION	Use a valid general register number between 0 and 31.
1017	**MESSAGE**	`Value of %s for space register not in %sr0..%sr3`
	CAUSE	Space register specified was not in the legal range.
	ACTION	Use a space register in the valid range 0 to 3.
1018	**MESSAGE**	`Value of %s for space register not in %sr0..%sr7`
	CAUSE	Space register number specified greater than 7 or less than 0
	ACTION	Use a valid space register number between 0 and 7.
1019	**MESSAGE**	`Opcode %s not defined`
	CAUSE	Characters in the opcode field do not comprise a legal machine instruction or directive.
	ACTION	Starting in column 2, use only valid opcodes and directives as specified in *PA-RISC Architecture and Instruction Set Reference Manual*.
1020	**MESSAGE**	`Number required for keyword value`
	CAUSE	A `.CALLINFO` keyword was assigned a non-numeric argument.
	ACTION	Ensure that `.CALLINFO` keywords are assigned numeric or register values.
1021	**MESSAGE**	`Unrecognized value for keyword`

	CAUSE	Illegal assignment for ARGW or RTNVAL keyword in .CALL or .EXPORT directive
	ACTION	Use NO, GR, FR, or FU as appropriate.
1022	**MESSAGE**	`This directive must occur within a declared subspace: .%s`
	CAUSE	The directive used must appear inside of a .SUBSPA. The directive was place outside of a subspace.
	ACTION	Insert a .SUBSPA before issuing this directive.
1023	**MESSAGE**	`Directive .%s not allowed inside a procedure`
	CAUSE	Use of this directive must occur outside of a .PROC The .LOCCT, .SPACE or .SUBSPA directives must occur outside of a .PROC
	ACTION	Do not attempt to change the location counter, space or subspace within a procedure.
1024	**MESSAGE**	`Space name required`
	CAUSE	.SPACE directive is not followed by a valid name.
	ACTION	Follow .SPACE directive with a valid name.
1025	**MESSAGE**	`Unrecognized keyword`
	CAUSE	Directive, such as .SPACE, .SUBSPA, or .CALLINFO followed by a keyword not specified in the Assembler manual.
	ACTION	Follow directives with legal keywords separated by commas.
1026	**MESSAGE**	`Identifier %s previously defined`

	CAUSE	The name being defined already has a definition. Each identifier can only have one legal meaning. You can't define both a space and a subspace with the same name.
	ACTION	Change the name used by one of the definitions to a unique name.
1027	**MESSAGE**	`This item must be declared within a space`
	CAUSE	A directive such as `.SUBSPA`, is used before the first `.SPACE` directive.
	ACTION	Insert a valid `.SPACE` directive prior to the offending directive.
1028	**MESSAGE**	`Subspace name required`
	CAUSE	`.SUBSPA` directive is not followed by a valid name.
	ACTION	Follow `.SUBSP` directive with a valid name.
1029	**MESSAGE**	`Directive .%s must occur within a procedure`
	CAUSE	Directive such as `.CALLINFO`, `.ENTER` or `.LEAVE` is used outside of a procedure. A procedure is defined by a matching pair of `.PROC`, `.PROCEND` directives.
	ACTION	Move the offending directive inside a procedure or correct the location of the `.PROC` and `.PROCEND` directives for this procedure.
1030	**MESSAGE**	`Only one .CALLINFO per procedure`
	CAUSE	Multiple `.CALLINFO` directives were found within a procedure. A procedure is defined by a matching pair of `.PROC`, `.PROCEND` directives.

	ACTION	Remove the duplicate `.CALLINFO` directive or correct the location of the `.PROC` and `.PROCEND` directives for this procedure.
1031	**MESSAGE**	`Value for %s must be >=0`
	CAUSE	1. In a `.CALLINFO` directive the parameter `FRAME` is assigned a negative value. 2. In `.BLOCK` or `.BLOCKZ` directive the parameter is a negative value.
	ACTION	Supply a non-negative value.
1032	**MESSAGE**	`Value for %s must be in range %r3..%r18`
	CAUSE	In a `.CALLINFO` directive the parameter `ENTRY_GR` is assigned an invalid general register.
	ACTION	Use a general register in the range `%r3` to `%r18` when assigning to the parameter `ENTRY_GR`.
1033	**MESSAGE**	`Value for %s must be in range %fr12..%fr21`
	CAUSE	In a `.CALLINFO` directive the parameter `ENTRY_FR` is assigned an invalid floating-point register.
	ACTION	Use a floating-point register in the range `%fr12` to `%fr21` when assigning to the parameter `ENTRY_FR`.
1034	**MESSAGE**	`ENTRY_SR must be %sr3 or not specified`
	CAUSE	In a `.CALLINFO` directive the parameter `ENTRY_SR` specifies an invalid space register.

	ACTION	Only `%sr3` is saved using the PA-RISC calling convention. Either specify `%sr3` or omit the `ENTRY_SR` keyword.
1035	**MESSAGE**	`Instructions must occur within a declared subspace: %s`
	CAUSE	Instructions present before `.SUBSPA` directive
	ACTION	Use `.SUBSPA` directive before issuing instructions
1036	**MESSAGE**	`Illegal use of %previous_sp, must be used as a base register`
	CAUSE	The pseudo register `%previous_sp` is being used in an instruction as a source or destination register. This special register can only be used as a base register.
	ACTION	Use `%previous_sp` as the base register in a Load or Store instruction.
1037	**MESSAGE**	`nested .PROC`
	CAUSE	A second `.PROC` directive was encountered before a `.PROCEND` directive
	ACTION	Insert `.PROCEND` directive before the second `.PROC` directive, or remove unnecessary `.PROC` directive.
1038	**MESSAGE**	`Label name required for %s`
	CAUSE	Directive, such as `.COMM`, `.REG`, `.EQU` or `.MACRO` requires that a label be present.
	ACTION	Add a label starting in column 1 to use as the name being defined by this directive.

1039	**MESSAGE**	`Missing string constant`
	CAUSE	Directive, such as `.STRING`, `.STRINGZ`, `.VERSION`, or `.COPYRIGHT` is present without a string operand.
	ACTION	Add missing quoted string after directive.
1041	**MESSAGE**	`Name required for %s`
	CAUSE	Directive, such as `.IMPORT`, `.EXPORT`, `.SPACE` or `.SUBSPA` is not followed by an valid identifier.
	ACTION	Follow directive with a legal identifier.
1044	**MESSAGE**	`Name required for label definition`
	CAUSE	`.LABEL` directive is not followed by a legal identifier
	ACTION	Add missing identifier after `.LABEL` directive.
1045	**MESSAGE**	`Name to be defined by .LABEL must appear as operand.`
	CAUSE	The `.LABEL` directive cannot have an identifier in column one.
	ACTION	Place identifier after `.LABEL` directive, not before it.
1046	**MESSAGE**	`Duplicate definition of symbol`
	CAUSE	The same identifier appeared more than once in column one, or was defined more than one time with a `.LABEL` directive.
	ACTION	Rename one of the labels.
1047	**MESSAGE**	`Unmatched .PROCEND`

	CAUSE	Two `.PROCEND` directives were encountered without a `.PROC` directive in between.
	ACTION	Each procedure should begin with a single `.PROC` and end with a single `.PROCEND`.
1048	**MESSAGE**	`Comma expected`
	CAUSE	A directive which expects two or more operands was missing a comma between it's operands.
	ACTION	Insert comma between operands.
1050	**MESSAGE**	`Illegal symbol in label position`
	CAUSE	Illegal character present in identifier which begins in column one.
	ACTION	Use only legal identifiers in label field.
1051	**MESSAGE**	`Illegal symbol in opcode position`
	CAUSE	A sequence of characters starting in column two or beyond does not begin with a alphabetic character or period.
	ACTION	Use only valid opcodes and directives starting in column two or beyond.
1052	**MESSAGE**	`Directive name not recognized`
	CAUSE	A sequence of characters starting in column two or beyond, beginning with a period, does not correspond to a legal directive.
	ACTION	Check spelling of directive. Use only legal directive names starting in column two or beyond.
1053	**MESSAGE**	`Displacement must be a constant expression`

	CAUSE	The displacement for this instruction must be a constant expression.
	ACTION	Rewrite the instruction so that it uses a constant expression.
1054	**MESSAGE**	`Unexpected items at end of line`
	CAUSE	Legal operands are followed by trailing characters or operators.
	ACTION	Examine entire sequence of operations for syntactic integrity. Possibly insert a ";" to denote a comment after legal operands.
1055	**MESSAGE**	`Label must be defined within a declared subspace`
	CAUSE	Label is present before a `.SUBSPA` directive.
	ACTION	Place label after issuing `.SUBSPA` directive.
1056	**MESSAGE**	`Poorly formed .DWORD argument`
	CAUSE	The syntax for this .DWORD argument is invalid.
	ACTION	Consult the Assembler manual for the valid syntax.
1057	**MESSAGE**	`Unexpected register symbol %s found in a constant expression`
	CAUSE	A predefined register or a name defined by a `.REG` directive was encountered in a location where only an integer constant, a name defined by a `.EQU` directive, may occur.
	ACTION	Replace the predefined register or a name defined by a `.REG` directive by a constant, or change the `.REG` directive into a `.EQU` directive.

1059	**MESSAGE**	`Divide by zero`
	CAUSE	Attempt to perform division with a zero divisor.
	ACTION	Examine definition of divisor, ensure that it is not zero.
1060	**MESSAGE**	`Argument 0 or 2 in FARG upper`
	CAUSE	Using the `FU` value with `ARGW0` or `ARGW2` keywords.
	ACTION	Only use the `FU` value with `ARGW0` or `ARGW2` keywords.
1061	**MESSAGE**	`Closing parenthesis is missing in expression`
	CAUSE	Mismatched parenthesis.
	ACTION	Insert closing parenthesis in the expression.
1062	**MESSAGE**	`Macro parameters must be separated by commas`
	CAUSE	Formal parameters to `.MACRO` or actual parameters to a macro invocation are not separated by commas.
	ACTION	Insert commas between parameters.
1063	**MESSAGE**	`Unterminated macro definition`
	CAUSE	A `.MACRO` directive is not matched with a `.ENDM` directive.
	ACTION	Terminate macro definition with `.ENDM`.
1064	**MESSAGE**	`Poorly formed macro parameter`
	CAUSE	Formal parameter to the macro definition is not in the format accepted by the Assembler.
	ACTION	Change the form of the formal parameter to an acceptable form.

1065	**MESSAGE**	`Poorly formed .FLOAT or .DOUBLE argument`
	CAUSE	The floating-point number that was used as the argument to `.FLOAT` or `.DOUBLE` is not in the right format.
	ACTION	Use a properly formatted floating-point constant for the argument.
1066	**MESSAGE**	`Poorly formed bit field specifier`
	CAUSE	Bit field is not specified in the form {*x*..*y*} where *x* and *y* are non-negative integers.
	ACTION	Specify bit fields in the correct format.
1067	**MESSAGE**	`Bit field too wide for instruction field`
	CAUSE	Mismatched bit field declaration and usage.
	ACTION	Use the same length bit field for the bit field being assigned to and the bit field being assigned from.
1068	**MESSAGE**	`Brace outside of macro definition`
	CAUSE	Opening brace ({) or closing brace (}) used outside a macro definition. These symbols can only be used with a macro definition. They are used to form a bit field within a macro definition.
	ACTION	Remove opening or closing brace and ensure that they are only used within a macro definition.
1069	**MESSAGE**	`Equal sign required in bit field assignment`

	CAUSE	Missing assignment operator = for assigning one bit field to another.
	ACTION	Insert assignment operator = for bit field assignment.
1070	**MESSAGE**	`Bit range must be within {0..31}`
	CAUSE	Range specified in bit field is not in the legal range.
	ACTION	Ensure bit field range is within the range 0 to 31.
1071	**MESSAGE**	`Opening brace expected in bit range designator`
	CAUSE	Missing opening brace to specify bit field
	ACTION	Use correct format for bit field specification.
1072	**MESSAGE**	`Ending brace expected in bit range designator`
	CAUSE	Missing closing brace to specify bit field
	ACTION	Use correct format for bit field specification.
1073	**MESSAGE**	`Unmatched .ENDM`
	CAUSE	No `.MACRO` directive was recognized as corresponding to the `.ENDM` directive.
	ACTION	Either remove the unmatched `.ENDM` directive or insert a `.MACRO` directive in an appropriate position preceding the `.ENDM` directive.
1074	**MESSAGE**	`Illegal expression type for plabel`
	CAUSE	More than one label was found in a plabel expression.

	ACTION	Use only one label in a plabel expression.
1075	**MESSAGE**	`Undefined field selector`
	CAUSE	Illegal field selector is being used.
	ACTION	Use correct field selector.
1076	**MESSAGE**	`Recursive macro expansion for %s`
	CAUSE	Recursive macro expansion not permitted.
	ACTION	Change macro definition to not be recursive.
1077	**MESSAGE**	`A .CALLINFO may specify either CALLS or NO_CALLS but not both`
	CAUSE	A `.CALLINFO` directive contained both the `CALLS` and `NO_CALLS` operands.
	ACTION	Remove either `CALLS` or `NO_CALLS` from the `.CALLINFO` directive.
1078	**MESSAGE**	`Only one architecture revision level can be specified with .LEVEL`
	CAUSE	More than one `.LEVEL` directive was encountered and they specified different architecture levels.
	ACTION	Remove the inappropriate `.LEVEL` directive.
1079	**MESSAGE**	`Missing "=" for parameter %s`
	CAUSE	An operand to a directive is expecting a value to be supplied. For example, the `FRAME` keyword to the `.CALLINFO` directive expects an argument to be associated like this: `FRAME=32`

	ACTION	Supply the missing value to be associated with the keyword using the format *keyword=value*.
1080	**MESSAGE**	`Missing integer for parameter %s`
	CAUSE	An operand to a directive is expecting a value to be supplied. For example, the `FRAME` keyword to the `.CALLINFO` directive expects an argument to be associated like this: `FRAME=32`
	ACTION	Supply the missing value to be associated with the keyword using the format `keyword=integer`.
1081	**MESSAGE**	`Missing register for parameter %s`
	CAUSE	An operand to a directive is expecting a value to be supplied. For example the `ENTRY_GR` keyword to the `.CALLINFO` directive expects an argument to be associated like this: `ENTRY_GR=%r6`
	ACTION	Supply the missing value to be associated with the keyword using the format `keyword=register`.
1082	**MESSAGE**	`Wrong kind of register for parameter %s`
	CAUSE	An operand to a directive is expecting a different register class to be supplied. For example the `ENTRY_GR` keyword to the `.CALLINFO` directive expects a general purpose register to be associated; supplying a floating-point register to `ENTRY_GR` would produce this error message.
	ACTION	Use a register of the expected class for the keyword.

1083	**MESSAGE**	`Floating point register %s is out of range`
	CAUSE	The value supplied does not correspond to a legal floating-point register number.
	ACTION	Supply a valid floating-point register number.
1084	**MESSAGE**	`Control register %s is out of range`
	CAUSE	The value supplied does not correspond to a legal control register number.
	ACTION	Supply a valid control register number.
1085	**MESSAGE**	`Illegal value for alignment`
	CAUSE	The value supplied for alignment is not a valid alignment value. Valid values are powers of 2 that are greater than zero and less than or equal to 4096.
	ACTION	Change alignment value to a legal value.
1086	**MESSAGE**	`Only one type can be specified for a symbol with .EXPORT`
	CAUSE	More than one symbol type was given for the `.EXPORT` directive.
	ACTION	Remove the extra type from the `.EXPORT` directive.
1087	**MESSAGE**	`Bad value for .SHLIB parameter, format is "mm/yyyy"`
	CAUSE	The parameter to the `.SHLIB` directive was not in the proper format. The format must be *mm/yyyy*, when *mm* is the integer

		value for the month, (Jan=1,...Dec=12) and *yyyy* is the year.
	ACTION	Change the parameter to `.SHLIB` to a valid value.
1088	**MESSAGE**	`Floating point register %s is out of range for %s,SGL`
	CAUSE	The floating-point register used is not valid for this opcode. The multiops `FMPYADD,SGL` and `FMPYSUB,SGL` require that the operands be single precision floating-point registers in the range `%fr16L,%fr16R` .. `%fr31L,%fr31R`. Specifying a register below `%fr16` will result in this error message.
	ACTION	You must use single precision floating-point registers in the range `%fr16L,%fr16R .. %fr31L,%fr31R` when using single precision `FMPYADD` or `FMPYSUB`.
1089	**MESSAGE**	`Revision level must be specified for .LEVEL directive`
	CAUSE	A `.LEVEL` directive was missing an architecture level value.
	ACTION	You must specify a valid architecture level of 1.0, 1.1, or 2.0.
1090	**MESSAGE**	`Value of %1s must be in the range [%2s..%3s]`
	CAUSE	The immediate value %1s is constrained to be in the range %2s..%3s for the current instruction.
	ACTION	Use a different instruction that allows for a larger range, or use a register to hold the value %1s.

1091	**MESSAGE**	`Incorrect register %s used with %s optional target register must be %s.`
	CAUSE	This opcode takes an optional register operand as specified. The register you used for this operand was incorrect.
	ACTION	Use either the correct operand or no operand.
1094	**MESSAGE**	`Value for %s must be in range 0..3`
	CAUSE	The value supplied for the privilege level was outside the legal range of 0 to 3.
	ACTION	Supply a valid value in the range 0 to 3 for the privilege level.
1095	**MESSAGE**	`Not enough operands for instruction %s`
	CAUSE	While parsing the operands for the current instruction <inst>, the assembler encountered the end of the line while it was still expecting one or more operands for the instruction.
	ACTION	Supply the missing operand(s).
1096	**MESSAGE**	`Missing completer for opcode %s`
	CAUSE	The instruction <inst> requires a completer. For example the instruction BB always requires a completer (either < or >=); omitting this completer will cause the assembler to generate this error message.
	ACTION	Inspect the current instruction for missing completers and add the appropriate completer.

1097	**MESSAGE**	`A "(" was expected while parsing the operands of instruction %s`
	CAUSE	The operands for the current instruction do not have a “(“ in the correct location.
	ACTION	Inspect the current instruction and change the operands to the instruction so that the are valid.
1098	**MESSAGE**	`A ")" was expected while parsing the operands of instruction %s`
	CAUSE	The operands for the current instruction do not have a “)” in the correct location.
	ACTION	Inspect the current instruction and change the operands to the instruction so that the are valid.
1099	**MESSAGE**	`A register was expected while parsing the operands of instruction %s`
	CAUSE	The operands for the current instruction do not have a register in the correct location.
	ACTION	Inspect the current instruction and change the operands to the instruction so that the are valid.
1100	**MESSAGE**	`A "," was expected while parsing the operands of instruction %s`
	CAUSE	The operands for the current instruction do not have a comma (,) in the correct location.
	ACTION	Inspect the current instruction and change the operands to the instruction so that the are valid.

1101	**MESSAGE**	`Standard input must be a pipe or FIFO, not a TTY or device file.`
	CAUSE	The assembler was invoked without any input files on the command-line. For this situation the assembler will then attempt to use the standard input of a UNIX pipe command. The object file will be written to standard output for this case. However, before assembling the standard input, the assembler will attempt to discover if the standard input file is associated with a TTY or terminal. If the assembler determines that standard input is associated with a TTY or terminal then it prints this error message and exits.
	ACTION	Supply a filename when invoking the assembler, or use a UNIX pipe to provide an input file for the assembler.
1102	**MESSAGE**	`Displacement of %s must be multiple of four`
	CAUSE	The displacement in this instruction must be a multiple of four.
	ACTION	Use a displacement that is a multiple of four.
1103	**MESSAGE**	`Displacement of %s must be zero with ,O`
	CAUSE	The displacement must be zero when using the `,O` completer.
	ACTION	Use a displacement of zero.
1104	**MESSAGE**	`Displacement can't be zero with ,MA`
	CAUSE	The displacement cannot be zero when using the `,MA` completer.

	ACTION	Use a non-zero displacement.
1105	**MESSAGE**	`Displacement of %s must be multiple of eight`
	CAUSE	The displacement in this instruction must be a multiple of eight.
	ACTION	Use a displacement that is a multiple of eight.

Panic Messages

The following messages describe panic errors that cause the Assembler to terminate immediately and prevent it from creating an object file. You must correct these errors to assemble your program.

2000	**MESSAGE**	`Exceeded maximum error count`
	CAUSE	More than 100 errors were detected and the `-e` option was not used.
	ACTION	Use the `-e` option to permit up to a million errors.
2002	**MESSAGE**	`Unable to open input file: %s`
	CAUSE	The input file is either nonexistent or unreadable.
	ACTION	Check for presence of requested input file and examine the read permission for the file.
2003	**MESSAGE**	`Unable to open output file: %s`
	CAUSE	One of the following: 1. Output file exists and is not writable. 2. Directory is not writable 3. File system is not writable. 4. File system full 5. File system error.
	ACTION	Perform the corresponding action: 1. Delete output file or make output file writable. 2. Make directory writable. 3. Use a read/write file system for the output file. 4. Contact your HP-UX system administrator 5. Contact your HP-UX system administrator
2004	**MESSAGE**	`Free storage exhausted`
	CAUSE	Assembler cannot allocate memory for it's internal structures.

	ACTION	Break up the program into smaller modules. If this does not work contact your HP-UX system administrator.
2005	**MESSAGE**	`Internal instruction parsing error on %s`
	CAUSE	Assembler has an internal defect.
	ACTION	Have your HP-UX system administrator contact HP Technical Support.
2006	**MESSAGE**	`Unable to regain access to source file for listing`
	CAUSE	Not able to access source file for reading, while formatting the assembly listing file.
	ACTION	Check for existence of source file and permission to read it.
2007	**MESSAGE**	`Unable to access temporary file to build listing`
	CAUSE	Not able to write to the temporary listing file. Could be a file system error.
	ACTION	Contact your HP-UX system administrator.
2008	**MESSAGE**	`Unterminated macro definition`
	CAUSE	Macro definition is not complete until a `.ENDM` is encountered.
	ACTION	Insert a `.ENDM` at the end of the macro definition.

User Warning Messages

The following messages are user warnings. The Assembler will proceed, and produce an object file, in some cases taking the corrective action described.

7000 **MESSAGE** `Model number is unknown; will default to arch-rev code generation.`

CAUSE The model number given on a +DA option is not known to the compiler.

ACTION The default code generation is as specified in the warning. If this is not the desired target architecture revision, specify the version using an architecture revision (e.g., 1.1) instead of a model number on the +DA option.

7001 **MESSAGE** `Architecture version is unknown; will default to` *arch-rev* `code generation.`

CAUSE The architecture revision given on a +DA option is not known to the compiler.

ACTION The default code generation is as specified in the warning. If this is not what is desired, an alternate architecture revision may be specified.

7002 **MESSAGE** `Cannot open sched.models. (7002)`

CAUSE The file `sched.models` does not exist or cannot be opened for reading.

	ACTION	Check protections on `/opt/langtools/lib/sched.models` and `/usr/lib/sched.models`. If neither file exists, contact your HP Service Representative.
7003	**MESSAGE**	`Improper argument to +DA option. (7003)`
	CAUSE	An improper argument was given to the `+DA` or `+DS` option.
	ACTION	The `+DA`*model* is either a model number (such as 877 or I50, or one of the PA-RISC architecture designations 1.0 or 1.1. The `+DS`*model* is either a model number (such as 877 or I50), or one of the PA-RISC processor names (such as PA7100). See the `/opt/langtools/lib/sched.models` file for model numbers, architectures, and processor names.
7004	**MESSAGE**	`Debug information may be corrupt: %1s unresolvable reference %2s (7004)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7005	**MESSAGE**	`Unrecognized opcode %1s (7005)`
	CAUSE	The opcode specified in an inline assembly call was invalid.
	ACTION	Check the architecture instruction set specification to determine valid opcode names.
7006	**MESSAGE**	`Improper completer ,%1s given for opcode %2s (7006)`

	CAUSE	The completer specified in an inline assembly call was invalid for the opcode given.
	ACTION	Check the architecture instruction set specification to determine valid completers.
7100	**MESSAGE**	`code subspace has no unwind subspace (7100)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7101	**MESSAGE**	`Improper completer` *,completer* `given for opcode` *opcode*
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7102	**MESSAGE**	`Immediate value of` *value* `for 5-bit-field in` *opcode* not in [0..31]
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7103	**MESSAGE**	Extract/deposit of *value* for field size in *opcode* not in [1..32]
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7104	**MESSAGE**	`Immediate value of` *value* `for` *opcode* `is less than -16 (set to -16)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.

7105	**MESSAGE**	`Immediate value of` *value* `for` *opcode* `is greater than 15 (set to 15)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7106	**MESSAGE**	`DSR value of %1s for %2s not in [0..3] - truncated (7106)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7107	**MESSAGE**	`CSR value of` *value* `for` *opcode* `not in [0..7] - truncated`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7108	**MESSAGE**	The value *hex-value* did not fit into a signed *number* bit field at offset 0x*instruction-offset* (op code - *op-number*)
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7109	**MESSAGE**	`Tried to define value of non-absolute symbol %1s (7109)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7110	**MESSAGE**	`Instruction bypassed low-level manip (7110)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.

7111	**MESSAGE**	`Bad annotation (7111)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7112	**MESSAGE**	`Mandatory completer missing for opcode %1s (7112)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.

Limit Error Messages

The following messages describe limit errors that cause the Assembler to terminate immediately and prevent it from creating an object file. you may be able to work around these errors. They involve running into Assembler limits or running out of memory.

7200 **MESSAGE** `start/new_pool: out of memory. (7200)`

CAUSE The compiler attempted to allocate some dynamic memory, and the system was unable to provide the memory.

ACTION The easiest workaround is to break your compilation unit into two or more pieces and compile them separately.

On HP-UX, this error may also be produced if the system runs out of swap space. You can increase the amount of swap space available to the system (see your HP-UX system administrator). However, this should only be a last-resort.

7201 **MESSAGE** `new_slc_block: out of memory. (7201)`

CAUSE The compiler attempted to allocate some dynamic memory, and the system was unable to provide the memory.

ACTION See message 7200. Check the system limits because other processes might be running that also allocate dynamic memory.

Break up your compilation module into smaller pieces, and compile them separately.

		Increase the system swap area.
7202	**MESSAGE**	`init_link: out of memory. (7202)`
	CAUSE	Compiler ran out of virtual memory. The compiler attempted to allocate some dynamic memory, and the system was unable to provide the memory.
	ACTION	See message 7200. Check the system limits because other processes might be running that also allocate dynamic memory.
		Break up your compilation module into smaller pieces, and compile them separately.
		Increase the system swap area.
7203	**MESSAGE**	`allocate_bytes: out of memory. (7203)`
	CAUSE	Compiler ran out of virtual memory. The compiler attempted to allocate some dynamic memory, and the system was unable to provide the memory.
	ACTION	See message 7200. Check the system limits because other processes might be running that also allocate dynamic memory.
		Break up your compilation module into smaller pieces, and compile them separately.
		Increase the system swap area.
7204	**MESSAGE**	`error in writing to output file. (7204)`
	CAUSE	I/O error writing to object file.

	ACTION	Check for full file system (HPUX-MPE/iX) or too small object file (MPE/iX).
7205	**MESSAGE**	`unable to allocate space for object in RL. (7205)`
	CAUSE	I/O error writing to RL.
	ACTION	Check for too small RL file (MPE/iX).
7206	**MESSAGE**	`unable to add object to RL. (7206)`
	CAUSE	I/O error writing to RL.
	ACTION	Check for too small RL file or write permission (MPE/iX).
7207	**MESSAGE**	`object is too big to fit into RL. (7207)`
	CAUSE	Object size is too large for the RL requested.
	ACTION	Check for too small RL file or split object up (MPE/iX).
7208	**MESSAGE**	`Internal error while reading %1s (7208)`
	CAUSE	An error condition was returned while attempting to open or read data from an object file.
	ACTION	Check status of the object files used to build this program. You might also try recompiling the source file.
7209	**MESSAGE**	`Out of memory while reading %1s (7209)`
	CAUSE	Compiler ran out of virtual memory while reading ISOM file.
	ACTION	See message 7200.
7210	**MESSAGE**	`Internal error while writing %1s (7210)`

	CAUSE	An error condition was returned while attempting to open or write data from an object file.
	ACTION	Check file permissions and the status of object files being written by the compiler.
7211	**MESSAGE**	`Out of memory while writing %1s (7211)`
	CAUSE	Compiler ran out of virtual memory while writing ISOM file.
	ACTION	See message 7200.
7212	**MESSAGE**	`get_m_heap: out of memory. (7212)`
	CAUSE	Compiler ran out of virtual memory.
	ACTION	See message 7200.
7213	**MESSAGE**	`OUTPUT_byte: out of memory. (7213)`
	CAUSE	Compiler ran out of virtual memory.
	ACTION	See message 7200.
7214	**MESSAGE**	`Out of memory while writing ELF file. (7214)`
	CAUSE	Compiler ran out of virtual memory.
	ACTION	See message 7200.

Branching Error Messages

The following messages describe branching errors that prevent the Assembler from creating an object file. You must correct these errors to assemble your program.

7400	**MESSAGE**	`Procedure number %1s has no label known to linker (7400)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7401	**MESSAGE**	`Attempt to set location counter backward with .ORIGIN value \ of %1s (7401)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7402	**MESSAGE**	`Procedure call to non entry point: %1s (7402)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7403	**MESSAGE**	`undefined label - %1s (7403)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7404	**MESSAGE**	`branch target %1s unresolvable, instruction number %2s (7404)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.

7405	**MESSAGE**	`branch target %1s unresolvable, instruction number %2s (7405)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative
7406	**MESSAGE**	`label known to linker deleted (7406)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7407	**MESSAGE**	`Corrupt or unrecognized intermediate code in %1s (7407)`
	CAUSE	The ucode in the ISOM file is not recognizable.
	ACTION	Report error to your HP Service Representative.
7408	**MESSAGE**	`File I/O error while reading %1s (7408)`
	CAUSE	A file operation on the ISOM file failed.
	ACTION	Check the reasons for why the file was not readable by user.
7800	**MESSAGE**	`deletion of instruction has removed a target at %1s (7800)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7801	**MESSAGE**	`attempt to delete non-existent instruction (7801)`

	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7802	**MESSAGE**	`attempt to insert non-existent inst. (7802)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7203	**MESSAGE**	`attempt to insert labeled instruction (7803)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7804	**MESSAGE**	`set_inst : attempt to set preg field of an instruction (7804)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7805	**MESSAGE**	`internal instruction parsing error (7805)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7806	**MESSAGE**	`re_init_sllic : output file not open (7806)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7807	**MESSAGE**	`re_init_sllic : i/o error (7807)`
	CAUSE	Internal compiler error.

	ACTION	Report error to your HP Service Representative.
7808	**MESSAGE**	`re_init_sllic : file position out of alignment (7808)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7809	**MESSAGE**	`Data size not equal to subspace length. (7809)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7810	**MESSAGE**	`push_mappings: Stack overflow. (7810)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7811	**MESSAGE**	`pop_mappings: Stack underflow. (7811)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7812	**MESSAGE**	`enter_VT: String too long ( > 8K-12 bytes). (7812)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7813	**MESSAGE**	`fixup_DNTT_entry: no graph entry for symbol %1s. (7813)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.

7814	**MESSAGE**	`fixup_DNTT_entry: can't find procedure end for symbol %1s. (7814)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7815	**MESSAGE**	`Malloc: underflow detected in free(). (7815)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7816	**MESSAGE**	`Malloc: overflow detected in free(). (7816)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7817	**MESSAGE**	Malloc: Item being freed is not in use. (7817)
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7818	**MESSAGE**	`Malloc: Item being freed is of wrong size. (7818)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7819	**MESSAGE**	`Disasm: Attempt to print NIL expression. (7819)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7820	**MESSAGE**	`Disasm: Bad format in format string: %s (7820)`

	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7821	**MESSAGE**	`after: only one graph entry allowed for repeated inits. (7821)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7822	**MESSAGE**	`newfixup: invalid fixup. (7822)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7823	**MESSAGE**	`xdb_sup: XT entry out of order. (7823)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7824	**MESSAGE**	`inst: Illegal use of pseudo AP register. (7824)`
	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative.
7825	**MESSAGE**	`inst: Illegal use of floating point register. (7825)`
	CAUSE	Internal compiler error (unless using the Assembler).
	ACTION	Report error to your HP Service Representative.
7826	**MESSAGE**	`Improper format for sched.models. (7826)`

	CAUSE	Contents of the file `sched.models` were unexpected. This file should contain current mappings between machine model numbers and architecture revisions.
	ACTION	Check that `/opt/langtools/lib/sched.models` or `/usr/lib/sched.models` were installed or updated along with your current version of the operating system.
7827	**MESSAGE**	`Invalid architecture version. (7827)`
	CAUSE	The architecture revision provided in the file `sched.models` is not known to the compiler.
	ACTION	Check the format of any `+DA` option specified to the compiler. If none specified or format is correct, check that the file `sched.models` (in either `/opt/langtools/lib` or `/usr/lib`) was installed or updated along with your current version of the operating system.
7828	**MESSAGE**	`inst: Illegal displacement, low order bits must be zero.`
	CAUSE	Internal compiler error (unless using the Assembler).
	ACTION	Report error to your nearest HP Service Representative.
7834	**MESSAGE**	`Procedure limit reached. (7834)`
	CAUSE	Too many procedures.
	ACTION	Reduce the number of procedures.
7835	**MESSAGE**	`Internal error encountered while generating ELF file. (7835)`

	CAUSE	Internal compiler error.
	ACTION	Report error to your HP Service Representative
7836	**MESSAGE**	`Files with executable code must have at least one exported code symbol. (7836)`
	CAUSE	Your assembly file contains executable code but does not have any exported entry points.
	ACTION	Use the `.EXPORT` directive for one of your entry points or code symbols.
7837	**MESSAGE**	`.WORD pseudo-op cannot hold a 64-bit address. Use .DWORD instead. (7837)`
	CAUSE	Your PA2.0W assembly file contains a `.WORD` *expr* pseudo-operation, where *expr* is an address expression.
	ACTION	Change the pseudo-op to `.DWORD` *expr*

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