
The 32-bit PA-RISC Run- time Architecture Document

HP-UX 10.20 Version 3.0

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This document describes the runtime architecture for PA-RISC systems running either the HP-UX or the MPE/iX operating system. Other operating systems running on PA-RISC may also use this runtime architecture or a variant of it.

The runtime architecture defines all the conventions and formats necessary to compile, link, and execute a program on one of these operating systems. Its purpose is to ensure that object modules produced by many different compilers can be linked together into a single application, and to specify the interfaces between compilers and linker, and between linker and operating system.

The runtime architecture applies only to hardware platforms based on PA-RISC Revision 1.0, 1.1, or 2.0.

The runtime architecture does not specify the application programming interface (API), the set of services provided by the operating system to the program. Thus, observing the runtime architecture does not automatically lead to a program that will run on all PA-RISC platforms. It does, however, allow many of the development tools to be shared to a large extent among the various operating systems.

When combined with a particular API, this runtime architecture leads to an application *binary* interface (ABI). In other words, an ABI can be regarded as the composition of an API, a hardware description, and a runtime architecture for that hardware.

1.1 Target Audiences

This document is intended for a variety of readers.

If you are a systems programmer, you will find information in this document describing the format of an executable object file, the memory model and startup environment

assumed by a valid program, and the architected interface between a program and the services provided by your operating system. Chapters 5–7 will be of primary interest.

If you develop compilers or other development tools, you will find information in this document about calling conventions and other coding conventions, the object file format, interfaces to the linker, symbolic debug format, and other details important to program translation. Chapters 2–4 and 8–10 will be of primary interest; the other chapters may also contain relevant information.

If you are an application programmer, this document can help you learn about the low-level details of how programs execute on PA-RISC. If you need to write assembly code, process object files, examine the stack, or perform dynamic linking, you will find the necessary information in this document. Chapters 2, 5, 9, and 11 will be of primary interest.

1.2 Overview of the PA-RISC Runtime Architecture Document

Chapter 2 describes the coding conventions used by compilers and by assembly-language programmers. This includes details of the virtual memory model, usage of processor registers, external name conventions, addressing data, procedure calling and parameter passing, and the program startup environment.

Chapter 3 describes the format of relocatable object files, and Chapter 4 describes the format of relocatable libraries.

Chapter 5 describes the format of program files in general, while Chapters 6 and 7 cover details specific to the HP-UX and MPE/iX operating systems, respectively. These chapters also cover shared libraries and executable libraries.

Chapter 8 describes the format of the symbolic debug information generated by the HP compilers and used by the *xdb* debugger.

Chapter 9 describes the details of stack unwinding, and the interfaces to the stack unwind library provided by HP.

Chapter 10 describes the library of millicode routines provided for the use of HP compilers.

Chapter 11 describes the principles of dynamic linking—that is, dynamically loading relocatable objects into the address space of a running process.

Common Coding Conventions

2.1 Memory Model

The PA-RISC virtual memory is a set of linear spaces. Each space is four gigabytes (2^{32} bytes) in size and is divided into four equal portions of one gigabyte (2^{30} bytes each), known as quadrants. The four quadrants in a space are numbered 0,1,2, and 3, from low memory to high memory. An application can address 2^{16} spaces. Each application has its own short address space composed of these four distinct quadrants (can possibly be four distinct spaces).

2.1.1 Text Segment

The first quadrant (quadrant 0) of the short address space is mapped by space register 4 to the first quadrant of a space containing the shared text. The text is readable and executable, but not writable and must begin at a page boundary. An application must not change the contents of space register 4.

This area of memory is used to store code (machine instructions), and literals only. The text address begins at 0x00000000 and ends at 0x3FFFFFFF.

2.1.2 Initialized and Uninitialized Data Segments

The second quadrant (quadrant 1) of the short address space is mapped by space register 5 to the second quadrant of a space containing the private data of applications. The data section is readable, writable, and executable and must begin at a page boundary. The private data includes the initialized data, the uninitialized data (BSS), the heap and the user stack.

Data segments start at 0x40000000 and end at 0x7FFFFFFF.

2.1.3 Shared Memory

The third and fourth quadrant (quadrant 2 and 3) of the short address space is mapped by space register 6 and 7 to quadrants containing shared memory. Those portions of the shared memory that have been legally attached to the process via shared data memory system calls are readable and writable. The upper 256 megabytes of the fourth quadrant is not readable, writable, or executable by applications. The first page of the fourth quadrant is the Gateway page.

Shared memory starts at 0x80000000 and ends at 0xFFFFFFFF.

2.1.4 Subspaces

While a space is a fundamental concept of the architecture, a subspace is just a logical subdivision of a space. The linker groups subspaces into spaces as it builds an executable program file. 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.

2.2 Register Usage

2.2.1 Data Pointer (GR 27)

By software convention, general register GR 27 is used to point to the beginning address of global data in the data segment (\$PRIVATE space).

The start up code for each process sets up this address which is also known as the address of symbol \$global\$. Compilers and the linker then use this symbol to assign global data or to relocate data addresses.

2.2.2 Linkage Table Register (GR 19)

The general purpose caller-saves register GR 19 has a special meaning in HP-UX shared library. In an HP-UX shared library, register GR 19 is used for the *Data Linkage Table*.

Each shared library and incomplete executable contains a linkage table, which is allocated in the DATA space for the file. The linkage table is divided into two parts, the *Data Linkage Table* (DLT), and the *Procedure Linkage Table* (PLT). The PLT contains an entry for each unresolved procedure symbol referenced within the object and it is placed immediately following the DLT (if one exists).

The DLT contains an entry for each data or procedure symbol that is accessed indirectly. Each DLT entry is a single word which contains a pointer to the actual data item referenced indirectly; this pointer value is assigned by the dynamic loader, after mapping the shared library. All references to data items go directly through the DLT and GR 19 is

reserved to point to the middle of this table. The linker allocates GR 19-relative offsets for each DLT entry, and uses those offsets when applying fixups.

2.2.3 Stack Pointer (GR 30)

Because no explicit procedure call stack exists in the PA-RISC processor architecture, the stack is defined and manipulated entirely by software convention. By convention, GR 30 is used for the stack pointer.

The stack pointer always points to the first unused byte of data segment beyond the stack frame marker, and is 64-byte aligned.

When a process is initiated by the operating system, a virtual address range is allocated for that process to be used for the call stack, and the stack pointer (GR 30) is initialized to point to the low end of this range. As procedures are called, the stack pointer is incremented to allow the called procedure frame to exist at the address below the stack pointer. When procedures are exited, the stack pointer is decremented by the same amount.

2.2.4 Space Registers

The following table (table 1) summarizes the PA-RISC available space registers and their usage.

TABLE 1**Space Register Usage**

Register Name	Other Names	Usage Convention
SR 0		Caller-saves space register or millicode return space register.
SR 1	sarg sret	Space argument and return register or caller-saves space register.
SR 2		Caller-saves space register.
SR 3		Callee-saves space register.
SR 4		Code space register (stubs save and restore on inter-module calls).
SR 5		Data space register, modified only by privileged code.
SR 6		System space register, modified only by privileged code.
SR 7		System space register, modified only by privileged code.

2.2.5 User-Readable Control Registers (CR 26 and CR 27)

2.2.6 General Registers Summary

The following table (table 2) summarizes general register usage:

Common Coding Conventions

TABLE 2 General Register Usage

Register Name	Other Names	Usage Convention
GR 0		Zero value register. (Writing to this register does not affect its contents.)
GR 1		Scratch register (caller-saves). (can be destroyed by call mechanism).
GR 2	RP	Return pointer and scratch register.
GR 3 - GR 18		General purpose callee-saves registers.
GR 19		Shared Library linkage register.
GR 19 - GR 22		General purpose caller-saves registers.
GR 23	arg3	Argument register 3 or general purpose caller-saves register.
GR 24	arg2	Argument register 2 or general purpose caller-saves register.
GR 25	arg1	Argument register 1 or general purpose caller-saves register.
GR 26	arg0	Argument register 0 or general purpose caller-saves register.
GR 27	DP	Global data pointer; may not be used to hold other values. (Stubs save and restore on inter-module calls)
GR 28	ret0	Function return register on exit or function result address on entry. May also be used as a general purpose caller-saves register.
GR 29	SL ret1	Static link register (on entry), millicode function return or function return register for upper part of a 33 to 64 bit function result. May also be used as a general purpose caller-saves register.
GR 30	SP	Stack pointer, may not be used to hold other values.
GR 31		Millicode return pointer, Scratch register (caller-saves).

2.3 External Naming Conventions

The external naming conventions (commonly known as *name space pollution solution*, or *secondary definitions*) are designed to allow ANSI C, POSIX users to define their own versions of reserved symbols, while still allowing users to access the underlying system symbols if they want to.

The external naming conventions provide a secondary definition for special names (code or data) that would be specified from within the library source code by means of a pragma, for example:

```
#pragma _HP_SECONDARY_DEF _open open

{
    /* code for open */
}

open = secondary symbol
_open = primary symbol
```


Since `open` is only a secondary definition within `libc`, a primary definition of `open` provided by the user can override it. Within `libc` itself, `_open` is called directly to avoid conflicts with the user version's of `open`.

In implementing the secondary definitions, the linker makes the following assumptions:

- Secondary definitions would be used only by internal developers of `libc` and `libm`.
- The reference to a secondary definition must be seen before any definition of that symbol.
- No modules within `libc` or `libm` will make references to secondary definitions.
- Secondary symbol definitions will be ignored if there are no outstanding references to them. Secondary symbols that are not used to resolve references will not be placed to the output file, and secondary symbols that are used to resolve references will have the `secondary_def` flag cleared in the resultant output file.

2.4 Conventions for Accessing Data

This section describes the various classes of data, how they are mapped into the memory model, and how the program should address that data.

2.4.1 Static Variables

Static variables can be initialized or uninitialized, they can be small or large, and they can be local or global scope. In general, compilers allocate global variables relative to Data Pointer (DP) or GR 27, and allocate local variables relative to Stack Pointer (SP) or GR 30. Static variables are allocated in the DATA subspace of PRIVATE space. Please refer to “Symbol Table” on page 75 for details of symbol scopes and symbol types.

Local variables are managed by the compilers and are not visible in the object files.

Initialized global data are defined by symbols whose scope are *universal*.

The following code segments are used to make references to common, *NOT position independent* globals:

- To form the address of global X into register RR:

```
ADDIL    LR'X-$global$, DP
LDO      RR'X-$global$(r1), RR
```

- To load the global X into register RR

```
ADDIL    LR'X-$global$, DP
LDW      RR'X-$global$(0, r1), RR
```

LR' and RR' are representing fixups of type `R_DP_RELATIVE` emitted for global X in the above code segments.

Three aspects must be described: (1) the coding conventions to be followed by the compiler or in assembly code, (2) allocating the data to the correct segment, and (3) the responsibilities of the linker in relocating or transforming the code and allocating the data

2.4.2 C-Style Common

Uninitialized external-scope variables in C, without the *extern* keyword, are normally implemented similarly to Fortran Common blocks. The variables are treated as imported symbols, but are allocated automatically by the linker if no definition for the symbol is found in the program

2.4.3 Fortran-Style Common

Fortran Common blocks differ from C-style common only because the linker needs the ability to extend an initialized common block if an uninitialized declaration for the common block is larger than the initialized definition.

2.4.4 COBOL-Style Common

2.4.5 Pascal Outer Block Globals

Pascal has two methods for allocating global variables. In one method, the compiler allocates the global variables and assigns fixed dp-relative addresses to each symbol. Since the compiler sees the entire set of outer block declarations in each separate compilation, no link-time allocation is necessary, and the global variable names do not need to be externally visible.

In the second method, Pascal global variables are treated as in C.

2.4.6 Constants and Literals

Constant data and compiler-generated literals can be allocated in the text segment, or they can be allocated as static variables. Data allocated in the text segment must be accessed in a different fashion than data in the data segment, so there must be some support for determining which form of code generation to use when making an external reference to data whose allocation is unknown at compile time. Currently, the compiler assumes that constant data items are declared consistently at definition and reference sites.

2.4.7 Automatic Variables

Most local variables are allocated in the procedure stack frame, and are assigned fixed sp-relative offsets at compile time. These variables are not visible in the object files and no link time relocation (fixups) are needed.

Example assembly code uses to access local integer X:

```
LDW      -offset(0, R30), tmp1; to load X into register tmp1.  
                                     offset is assigned by the compiler.  
STW      tmp1, -offset(0, R30); to store X back to memory.
```

2.4.8 Position-Independence

In *position independent* compilation, the data linkage register (GR 19) and T' fixup will be used to access global variables. Depending on the size of the DLT table, short or long form code sequences will be generated.

- If the size of the DLT table is less than or equal to 16K bytes, the following code sequence will be used to form the address of a variable or to load the content of a variable, respectively:

```
LDW      T' X(0,R19), tmp1
LDO      offset(tmp1), RR;  Omit if offset = 0, RR is used instead of tmp1.
```

and

```
LDW      T' X(0,R19), tmp1
LDW      offset(0,tmp1), RR
```

Note that the 16K bytes restriction on the DLT size are imposed because the T' fixup on the LDW allows for a 14-bit signed offset only.

The T' fixup specifier should generate a DLT_REL fixup preceded by an FSEL override fixup.

- If the DLT table size is greater than the 16K bytes limit, the linker will emit an error indicating to users that this program must be recompiled with the +Z option. The +Z option produces the following long form code sequence:

To form the address of a variable:

```
ADDIL   LT' X, R19
LDW     RT' X(0, R1), tmp1
LDO     offset (tmp1), RR;  Omit if offset = 0 and RR is used instead of tmp1.
```

To load the content of a variable:

```
ADDIL   LT' X, R19
LDW     RT' X(0, R1), tmp1
LDW     offset (0, tmp1), RR;
```

2.5 Conventions for Calling Procedures

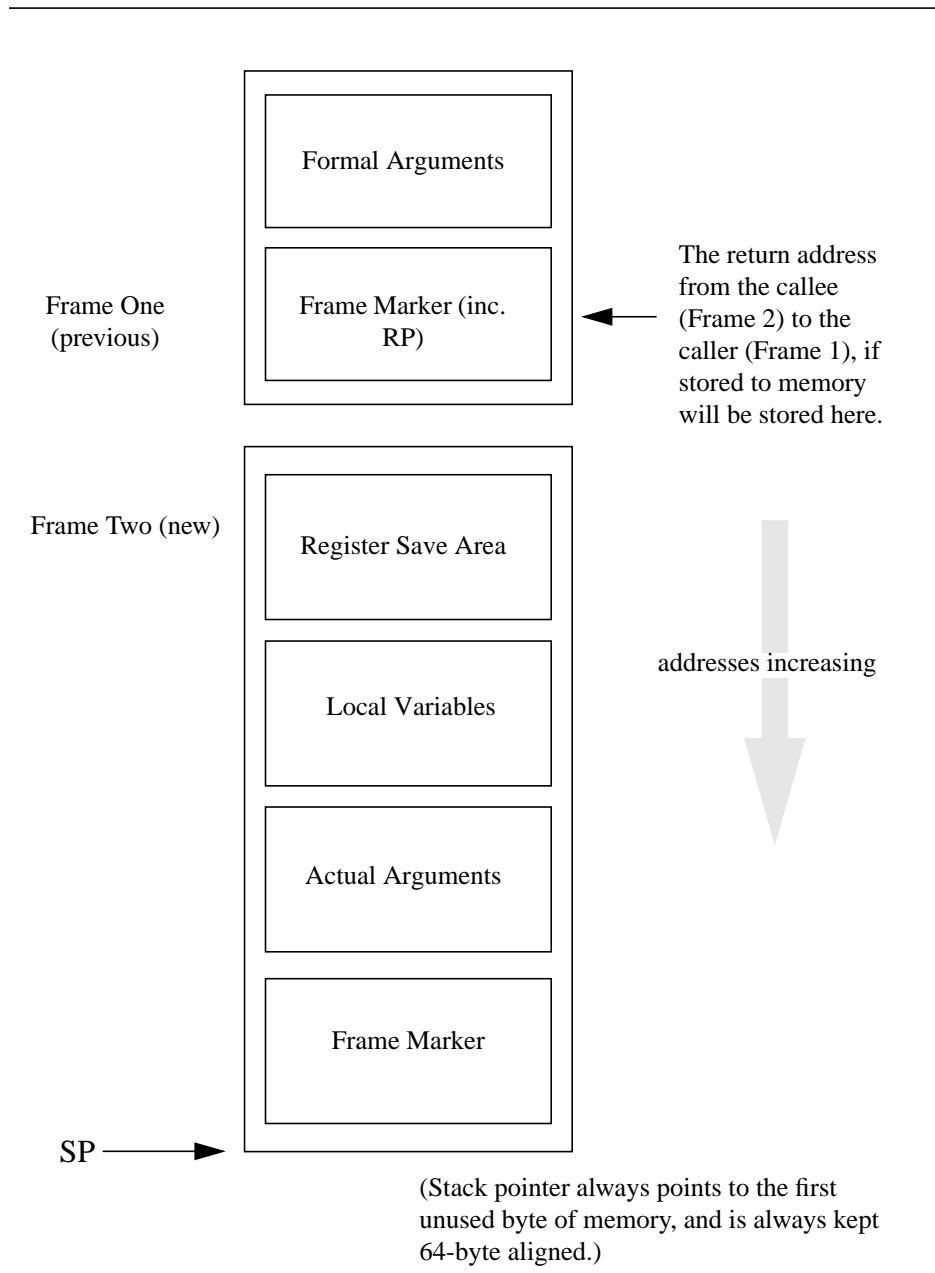
2.5.1 Stack Frame Layout and Marker

All procedures can be classified in one of two categories: leaf or non-leaf. A leaf procedure is one that makes no additional calls, while a non-leaf procedure is one that does make additional calls. Although simple, the distinction is essential because the two cases entail considerably different requirements regarding (among other things) stack allocation and usage. Every non-leaf procedure requires the allocation of an additional stack frame in order to preserve the necessary execution values and arguments. A stack

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frame is not always necessary for a leaf procedure. The recognition of a procedure as fitting into either the leaf or non-leaf category and the determination of the necessary frame size is done at compile time. It is often the case that much of a procedure's state information is saved in the caller's frame. This helps to avoid unnecessary stack usage.

A general picture of the top of the stack for one call, including the frames belonging to the caller (previous) and callee (new) is shown below:



The elements of a single stack frame that must be present in order for a procedure call to occur are shown below in Table 3. The stack addresses are all given as byte offsets from the actual SP (stack pointer) value; for example, ‘SP-36’ designates the address 36 bytes below the current SP value.

TABLE 3

Elements of Single Stack Frame Necessary for a Procedure Call

Offset	Contents	
Variable Arguments (optional; any number may be allocated)		
SP-(4*(N+9))	arg word N	
:	:	
:	:	
SP-56	arg word 5	
SP-52	arg word 4	
Fixed Arguments (must be allocated; may be unused)		
SP-48	arg word 3	
SP-44	arg word 2	
SP-40	arg word 1	
SP-36	arg word 0	
Frame Marker		
SP-32	External Data/LT Pointer (LPT)	(set before Call)
SP-28	External SR4/LT Pointer (LPT')	(set after Call)
SP-24	External/stub RP (RP')	(set after Call)
SP-20	Current RP	(set after Entry)
SP-16	Static Link	(set before Call)
SP-12	Clean Up	(set before Call)
SP- 8	Relocation Stub RP (RP'')	(set after Call)
SP- 4	Previous SP	(set before Call)
Top of Frame		
SP- 0	Stack Pointer (points to next available address)	
	< top of frame >	

The size of a stack frame is required to be a multiple of 64 bytes so that the stack pointer is always kept 64-byte aligned. Since cache-lines on PA-RISC can be no larger than 64 bytes, this requirement allows compilers to know when data structures allocated on the

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stack are cache-line aligned. Knowledge of this alignment allows the compiler to use cache hints on memory references to those structures.

Frame Marker Area

This eight-word area is allocated by any non-leaf routine prior to a call. The exact size of this area is defined because the caller uses it to locate the formal arguments from the previous frame. (Any standard procedure can identify the bottom of its own frame, and can therefore identify the formal arguments in the previous frame, because they will always reside in the region beginning with the ninth word below the top of the previous frame.)

Previous SP: Contains the old (procedure entry) value of the Stack Pointer. It is only required that this word be set if the current frame is noncontiguous with the previous frame, has a variable size or is used with the static-link.

Relocation Stub RP (RP''): Reserved for use by a relocation stub that must store a Return Pointer (RP) value, so the stub can be executed after the exit from the callee, but before return to the caller.

Clean Up: Area reserved for use by language processors; possibly for a pointer to any extra information (i.e. on the heap) that may otherwise be lost in the event of an abnormal interrupt.

Static Link: Used to communicate static scoping information to the callee that is necessary for data access. It may also be used in conjunction with the SL register, or to pass a display pointer rather than a static link, or it may remain unused.

Current RP: Reserved for use by the called procedure; this is where the current return address must be stored if the procedure uses RP (GR2) for any other purpose.

External/Stub RP (RP'), External SR4/LTP', and External DP/LTP: All three of these words are reserved for use by the inter-modular (external) calling mechanism.

Fixed Arguments Area

These four words are reserved for holding the argument registers, should the callee wish to store them back to memory so that they will be contiguous with the memory-based parameters. All four words must be allocated for a non-leaf routine, but may be unused.

Variable Arguments Area

These words are reserved to hold any arguments that can not be contained in the four argument registers. Although only a few words are shown in this area in table 3, there may actually be an unlimited number of arguments stored on the stack, continuing downward in succession (with addresses that correspond to the expression given in the diagram). Any necessary allocation in this area must be made by the caller.

2.5.2 Stack frame after dynamic memory allocation

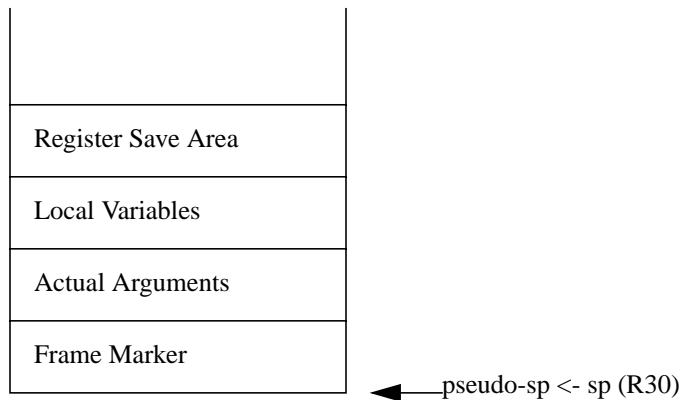
This section describes the extension of the PA-RISC Procedure Calling Convention to allow C routines to allocate memory on the stack using the built-in `alloca()` routine. `Alloca()` is a routine that works like `malloc()` except that it allocates storage from the stack instead of the heap. The storage will be freed automatically when the routine that called `alloca()` exits or returns. The following is the declaration of the `alloca()` routine:

```
char *alloca(int Size)
```

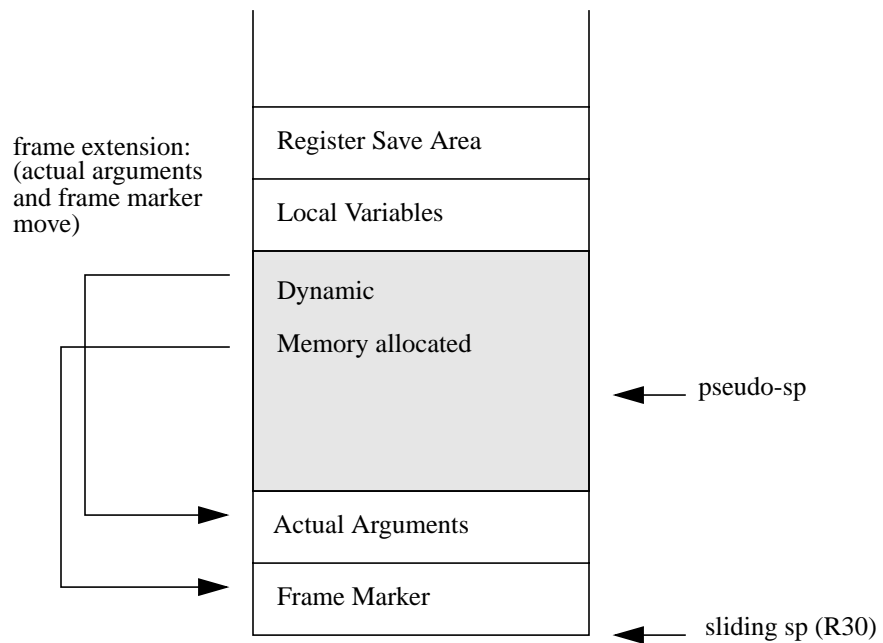
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Here is what the stack looks like as it allocates dynamic memory:

Initially:



After first `alloca()`:



Since the stack pointer, SP, is modified for each call to `alloca()`, the existing unwind mechanism needs to be enhanced. Refer to the unwind chapter for details of how the entry and exit code are changed to support the variable frame size. Also, refer to that chapter for details of how `alloca()` works on PA-RISC.

2.5.3 Parameter Passing and Return Values

The PA-RISC processor architecture does not have instructions which specify how registers should be used or how parameter lists should be built for procedure calls. Instead, the software procedure calling convention prescribes the register usage and parameter passing guidelines.

Register Partitioning

In order to reduce the number of register saves required for typical procedure calls, the PA-RISC general and floating-point register files have been divided into partitions designated as callee-saves and caller-saves. The names of these partitions indicate which procedure takes responsibility for preserving the contents of the register when a call is made.

If a procedure uses a register in the callee-saves partition, it must save the contents of that register immediately after procedure entry and restore the contents before the exit. Thus, the contents of all callee-saves registers are guaranteed to be preserved across procedure calls.

A procedure is free to use the caller-saves registers without saving their contents on entry. However, the contents of the caller-saves registers are not guaranteed to be preserved across calls. If a procedure has placed a needed value in a caller-saves register, it must be stored to memory or copied to a callee-saves register before making a call.

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GR0	Value (zero)
GR1	Scratch *
GR2	RP (Return Pointer/Address)
GR3	Callee Saves
:	
:	
GR18	
GR19	Caller Saves
:	
GR22	
GR23	Arguments *
:	
GR26	
GR27	DP (Global Data Pointer)
GR28	Return Values *
GR29	
GR30	SP (Stack Pointer)
GR31	MRP (Millicode Ret. Ptr)/Scratch *

*** May also be considered part of the caller-saves partition**

Figure 2-2: Register Partitioning

Other Register Conventions

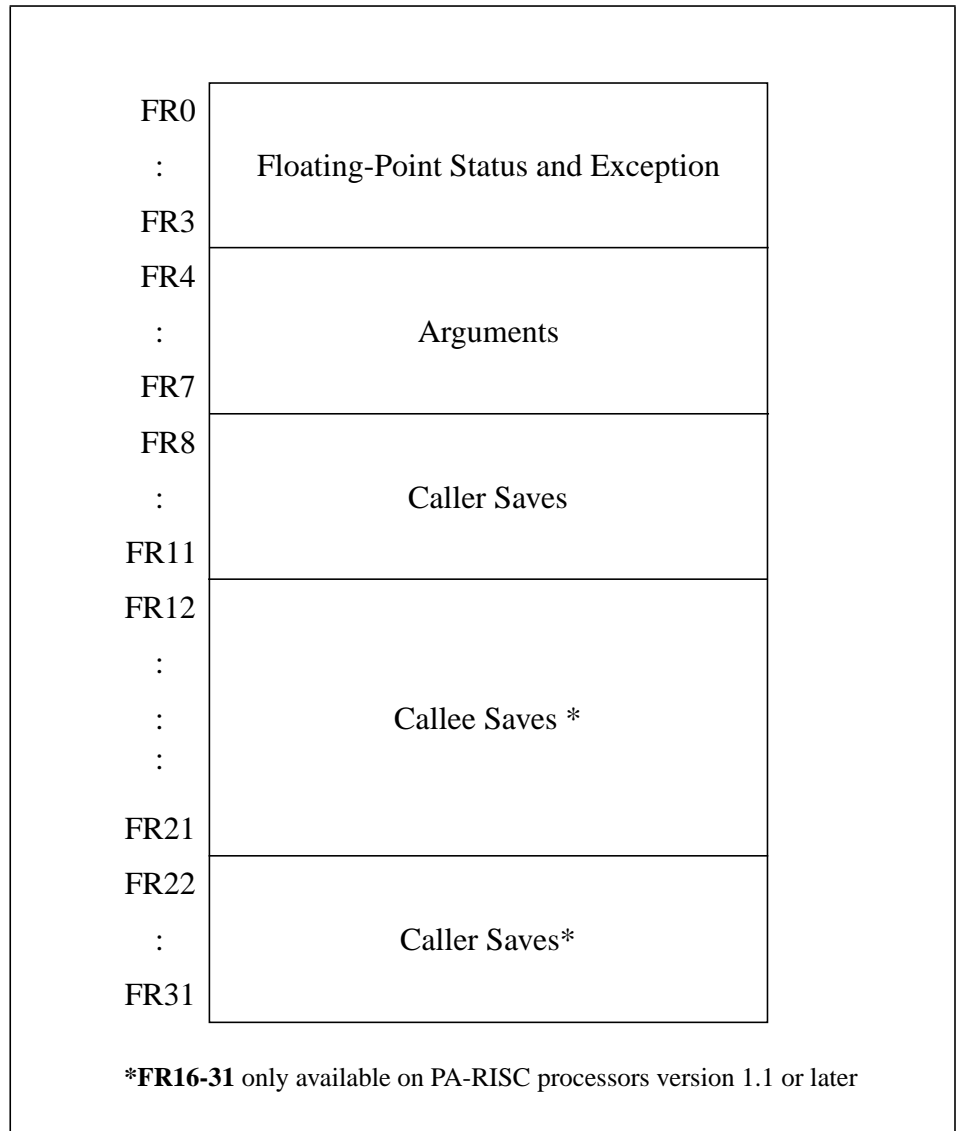


Figure 2-3: Floating-Point Registers

The following are guaranteed to be preserved across calls:

- The procedure entry value of SP.
- The value of DP.
- Space registers SR3, SR4, SR5, SR6, and SR7.
- The Processor Status Word (PSW).
- The state, including internal registers, of any special function units accessed by the architected SPOP operations.

The following is not guaranteed to be preserved across calls:

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- The shift (cr11) or any control registers that are modified by privileged software (e.g. Protection IDs).

The Floating-Point Coprocessor Status Register

Within the floating-point coprocessor status register (FR0), the state of the rounding mode (bits 21-22) and exception trap enable bits (bits 27-31) are guaranteed to be preserved across calls. An exception to this convention is made for any routine which is defined to explicitly modify the state of the rounding mode or the trap enable bits on behalf of the caller.

The states of the compare bit (bit 5), the delayed trap bit (bit 25), and the exception trap flags (bits 0-4) are not guaranteed to be preserved across calls.

Note



If the routine in question is a non-leaf routine, return pointer GR2 must be stored because subsequent calls will modify it. Once stored, it is available to be used as a scratch register by the code generators.

Although common, it is not absolutely necessary that GR2 be restored before exit; a branch (BV) using another caller-saves register is allowed.

Value Parameters

Value parameters are mapped to a sequential list of argument words with successive parameters mapping to successive argument words, except 64-bit parameters, which must be aligned on 64-bit boundaries. Irregularly sized data items should be extended to 32 or 64 bits. (The practice that has been adopted is to right-justify the value itself, and then left-extend it.) Non-standard length parameters that are signed integers are sign-extended to the left to 32 or 64 bits. This convention does not specify how 1-31, 33-63-bit data items are passed by value (except single ASCII characters).

Table 4 lists the sizes for recognized inter-language parameter data types. The form column indicates which of the forms (space ID, nonfloating-point, floating-point, or any) the data type is considered to be.

TABLE 4 **Parameter Data Types and Sizes.**

Type	Size (bits)	Form
ASCII character (in low order 8 bits)	32	Nonfloating-Pt.
Integer	32	Nonfloating-Pt. or Space ID
Short Pointer	32	Nonfloating-Pt.
Long Pointer	64	Nonfloating-Pt.
Routine Reference (see below for details of Routine Reference)	32 or 64	Routine Reference
Long Integer	64	Nonfloating-Pt.
Real (single-precision)	32	Floating-Pt.
Long Real (double-precision)	64	Floating-Pt.
Quad Precision	128	Any

Inter-Language Parameter Data Types and Sizes

- Space Identifier (SID) (32 Bits): One arg word, callee cannot assume a valid SID.
- Non-Floating-Point (32 Bits): One arg word.
- Non-Floating-Point (64 Bits): Two words, double word aligned, high order word in an odd arg word. This may create a void in the argument list (i.e. an unused register and/or an unused word on the stack.)
- Floating-Point (32 Bits, single-precision): One word, callee cannot assume a valid floating-point number.
- Floating-Point (64 Bits, double-precision): Two words, double word aligned (high order word in odd arg word). This may create a void in the argument list. 64-bit floating-point value parameters mapped to the first and second double-words of the argument list should be passed in farg1 and farg3, respectively. farg0 and farg2 are never used for 64-bit floating-point parameters. Callee cannot assume a valid floating-point number.

Note



The point is made that the callee “cannot assume a valid” value in these cases because no specifications are made in this convention that would ensure such validity.

- Any Larger Than 64 Bits: A short pointer (using SR5 - SR7) to the high-order byte of the value is passed as a nonfloating-point 32-bit value parameter. The callee must copy the accessed portion of the value parameter into a temporary area before any modification can be made to the (caller's) data. The callee may assume that this

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address will be aligned to the natural boundary for a data item of the parameter's type. It should be noted that some compilers support options which allow data structures to be aligned on non-natural boundaries. The instruction sequence used to copy the value should be consistent with the data alignment assumptions made by potential callers of that routine.

Note



The natural boundaries for data types on PA-RISC are documented in the Programmer's Guide that is available for each supported programming language.

Reference Parameters

A short pointer to the referenced data item (using SR4-SR7) is passed as a nonfloating-point 32-bit value parameter. The alignment requirements for the short pointer are the same as those mentioned for value parameters larger than 64 bits. Note that SR4 can only be used if the call is known to be local, because an external call will modify SR4.

Value-Result and Result Parameters

It is intended that language processors can use either the reference or value parameter mechanisms for value-result and result parameters. In particular, Ada uses the argument registers/parameters as output registers/parameters.

Routine References

This convention requires that routine references (i.e. procedure parameters, function pointers, external subroutines) be passed as 32-bit nonfloating-point values.

It is expected that language processors that require a static link to be passed with a routine reference (i.e. Pascal passing level 2 procedures) will pass that static link as a separate 32-bit nonfloating-point value parameter. A language processor is free to maximize the efficiency of static scope linking within the requirements, without impacting other language processors. (Pascal passes routine references as either two separate 32-bit values or as one 64-bit value.) See Chapter 5 for further details on Routine References.

Argument Register Usage Conventions

Parameters to routines are logically located in the argument list. When a call is made, the first four words of the argument list are passed in registers, depending on the usage and number of the argument. The first four words of the actual argument list on the stack are reserved as spill locations for the argument registers. These requirement simply that the minimum argument list size is 16 bytes; this space must be allocated in the frame for non-leaf procedures, but it may remain unused.

The standard argument register use conventions are shown in Table 5.

TABLE 5**Argument Register Use**

	void	SID	nonFP	FP32	FP64
arg word 0	no reg	sarg	arg0	farg0	farg1 {32..63}
arg word 1	no reg	arg1	arg1	farg1	farg1 {0..31}
arg word 2	no reg	arg2	arg2	farg2	farg3 {32..63}
arg word 3	no reg	arg3	arg3	farg3	farg3 {0..31}

definitions :

- void - arg word not used in this call
- SID - space identifier value
- nonFP - any 32-bit or 64-bit nonfloating-point
- FP32 - 32-bit floating-point (single-precision)
- FP64 - 64-bit floating-point (double-precision)

Function Return Values

Function result values are placed in registers as described in Table 6. As with value parameters, irregularly sized function results should be extended to 32 or 64 bits. (The practice that has been adopted is to right-justify the value itself, and then left-extend it.) Non-standard length function results that are signed integers are sign-extended to the left to 32 or 64 bits. This convention does not specify how 1 - 31 or 33 - 63-bit data items are returned (except single ASCII characters).

When calling functions that return results larger than 64 bits, the caller passes a short pointer (using SR5 - SR7) in GR28 (ret0) which describes the memory location for the function result. The address given should be the address for the high-order byte of the result. The function may assume that the result address will be aligned to the natural boundary for a data item of the result's type. It should be noted that some compilers support options which allow data structures to be aligned on non-natural boundaries. The instruction sequence used to store a function result should be consistent with the data alignment assumptions made by potential callers of that function.

2.5.4 Type Checking and Floating-Point Parameter Relocation

Parameter Type Checking

Some compilers may place argument descriptors in the object file which contain information about the type of each parameter passed and each formal argument expected.

Common Coding Conventions

TABLE 6**Return Values.**

Type of Return Value	Return Register
ASCII character	ret0 (GR28) - low order 8 bits
Nonfloating-Pt. (32-bit)	ret0 (GR28)
Nonfloating-Pt. (64-bit)	ret0 (GR28) - high order word ret1 (GR29) - low order word
Floating-Pt. (32-bit)	fret (FR4) ^a
Floating-Pt. (64-bit)	fret (FR4) ¹
Space Identifier (32-bit)	sret (SR1)
Any Larger Than 64-bit	result is stored to memory at location described by a short pointer passed by caller in GR28 ^b

a. Although not common, it is possible to return floating-point values in general registers, as long as the argument relocation bits in the symbol record are set correctly. (Refer to Parameter Relocation for more details.)

b. The caller may not assume that the result's address is still in GR28 on return from the function.

These descriptors are then checked by the linker for compatibility. If they do not match, a warning is generated. There is currently no mechanism available in the PA-RISC assembler to generate these argument descriptors.

Parameter Relocation

The procedure calling convention specifies that the first four words of the argument list and the function return value will be passed in registers: floating-point registers for floating-point values, general registers otherwise. However, some programming languages do not require type checking of parameters, which can lead to situations where the caller and the callee do not agree on the location of the parameters. Problems such as this occur frequently in the C language where, for example, formal and actual parameter types may be unmatched, due to the fact that no type checking occurs.

A parameter relocation mechanism alleviates this problem. The solution involves a short code sequence, called a relocation stub, which is inserted between the caller and the callee by the linker. When executed, the relocation stub moves any incorrectly located parameters to their expected location. If a procedure is called with more than one calling sequence, a relocation stub is needed for each non-matching calling sequence.

The compiler or assembler must communicate the location of the first four words of the parameter list and the location of the function return value to the linker and loader. To accomplish this, ten bits of argument location information have been added to the definitions of a symbol and a fix-up request. The following diagram shows the first word of a symbol definition record in the object file.

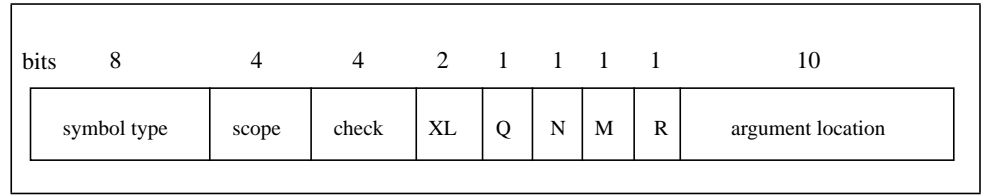


Figure 2-4: Layout of Symbol Definition Record

The argument location information is further broken down into five location values, corresponding to the first four argument words and the function return value, as shown below:

- Bits 22-23: define the location of parameter list word 0
- Bits 24-25: define the location of parameter list word 1
- Bits 26-27: define the location of parameter list word 2
- Bits 28-29: define the location of parameter list word 3
- Bits 30-31: define the location of the function value return

The value of an argument location is interpreted as follows:

- 00 Do not relocate
- 01 arg Argument register
- 10 FR Floating-point register (bits 0..31)^a
- 11 frupper Floating-point register (bits 32..63)¹

a. For return values, '10' means a single precision floating-point value, and '11' means double precision floating-point value.

When the linker resolves a procedure call, it will generate a relocation stub if the argument location bits of the fixup request do not exactly match the relocation bits of the exported symbol. One exception is where either the caller or callee specifies “do not relocate”. The relocation stub will essentially be part of the called procedure, and the linker can optionally add a symbol record for the stub so that it can be reused. The symbol record will be the same as the original export symbol record, except that the relocation bits will reflect the input of the stub. The type will be STUB and the symbol value will be the location of the relocation stub.

The execution of a relocation stub can be separated into the call path and the return path. During the call path, only the first four words of the parameter list will be relocated, while only the function return will be relocated during the return path. The control flow is shown in Figure 2-5.

If the function return does not need to be relocated, the return path can be omitted and the branch and link will be changed to a branch. The call path must always be executed, but if the first four words of the parameter list do not need to be relocated, it can be reduced to the code required to establish the return path (i.e save RP and branch and link to the callee).

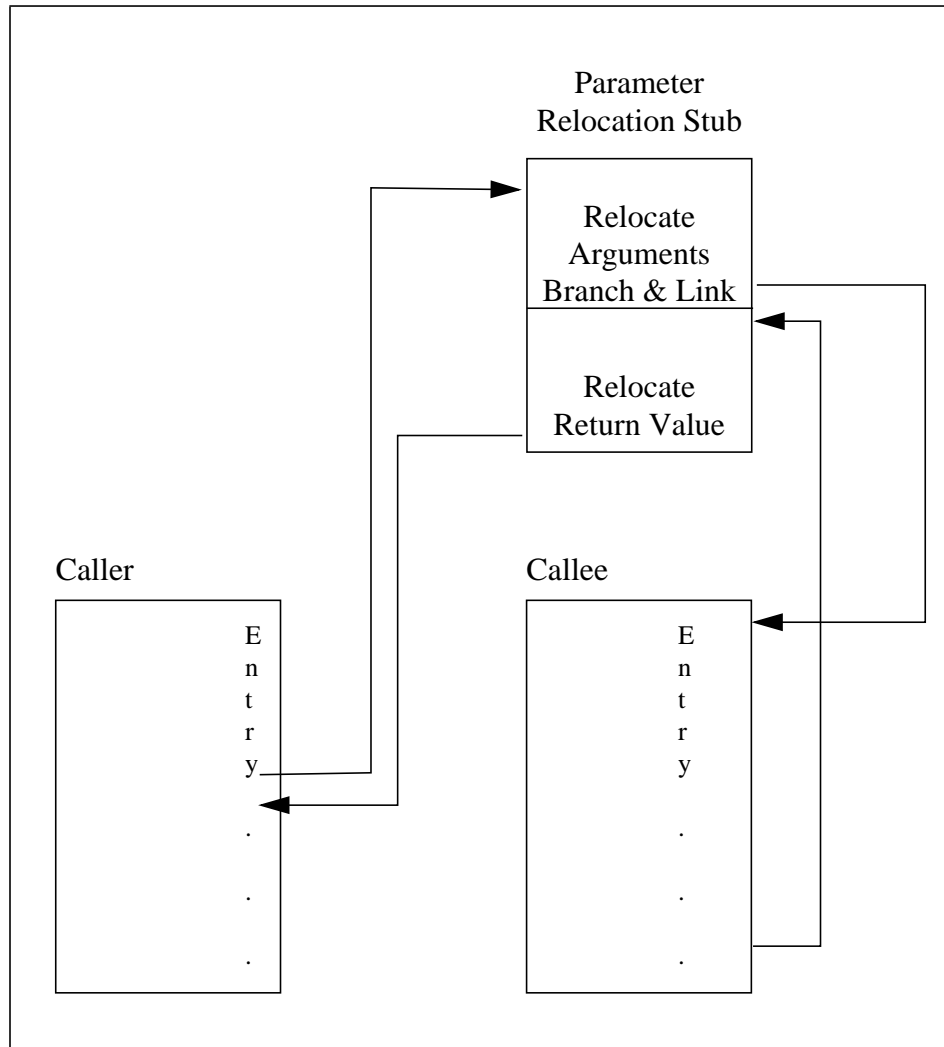


Figure 2-5: Parameter Relocation Stub.

When multiple stubs occur during a single call (e.g. calling stub and relocation stub), the stubs can be cascaded (i.e. used sequentially); in such a case, both RP' and RP'' would be used. (The relocation stub uses RP'').

The linker will generate stubs for each procedure that can be called from another load module (i.e. called dynamically). In addition, a stub will be required for each possible calling sequence. Each of these stubs will contain the code for both relocation and external return, and will be required to contain a symbol definition record. Both calling and called stubs use a standard interface: calling stubs always relocate arguments to general registers, and called stubs always assume general registers.

In order to optimize stub generation, the compilers should maximize the use of the argument location value 00 (do not relocate). A linker option may be provided, which will allow the user to turn stub generation on or off, depending on known conditions. Also, a linker option is provided to allow the user to inhibit the generation of stubs for run-time

linking. In this case, if a mismatch occurs, it will be treated as a parameter type checking error (which is totally independent of parameter relocation).

Assembly programmers can specify argument relocation information in the “.CALL” and “.EXPORT” assembler directives.

2.5.5 Standard Procedure Calls

The code generated by the compiler to perform a procedure call is the same whether the call is external or local. If the linker locates the procedure being called within the program file, it will make the call local by patching the BL instruction to directly reference the entry point of the procedure. If the linker determines that the called procedure is outside of the program file, it makes the call external by inserting an import stub (calling stub) into the calling code, and patching the BL instruction to branch to the stub. For any routine in the program file which the linker detects is called from outside of that program file, an export stub (called stub) is inserted into the program file's code.

Long Calls

Normally, the compilers generate a single-instruction call sequence using the BL instruction to perform a procedure call. However, the compilers can be forced to generate a long call sequence when the module is so large that the BL instruction is not guaranteed to reach the beginning of the subspace. For example, COBOL compilers that typically compile large applications need to make sure that the BL instruction can reach to the beginning of subspace (including an estimation of stubs that will be generated by the linker, currently HP compilers allocate 2K bytes for stubs) is within the range of 256K bytes. Otherwise, a long call sequence as show below should be generated instead of the BL branch instruction. At link phase, the linker can then insert a stub. The existing long call sequence is three instructions, using an absolute target address:

```
LDIL    L'target,%r1
BLE     R'target(%sr4,%r1)
COPY    %r1,%rp
```

External Calls

External calls occur in both shared libraries and the programs which use them. A shared library contains subroutines that are shared by all programs that use them. Shared libraries are attached to the program at run time rather than copied into the program by the linker. Since the shared library code is not copied into the program file and is shared among several programs as a separate load module, an external call mechanism is needed.

In order for the object code in a shared library to be fully sharable, it must be compiled and linked in such a way that it does not depend on its position in the virtual addressing space of any particular process. In other words, the same physical copy of the code must work correctly in each process.

Position independence is achieved by two mechanisms. First, PC-relative addressing is used wherever possible for branches within modules and for accesses to literal data. Second, indirect addressing through a per-process linkage table is used for all accesses to global variables, for inter-module procedure calls and other branches and literal accesses where PC-relative addressing cannot be used. Global variables must be accessed indirectly since they may be allocated in the main program's address space, and even the relative position of the global variables may vary from one process to another.

Position-independent code (PIC) implies that the object code contains no absolute addresses. Such code can be loaded at any address without relocation, and can be shared by several processes whose data segments are allocated uniquely. This requirement extends to DP-relative references to data. In position-independent code all references to code and data must be either PC-relative or indirect. All indirect references are collected in a single linkage table that can be initialized on a per-process basis.

The Linkage Table (LT) itself is addressed in a position-independent manner by using a dedicated register, gr19, as a pointer to the Linkage Table. The linker must generate import (calling) and export (called) stubs which set gr19 to the Linkage Table pointer value for the target routine, and handle the inter-space calls needed to branch between shared libraries.

The code in the program file itself does not need to be position independent, but it must access all external procedures through its own linkage table by using import stubs. The Linkage Table in shared libraries is accessed using a dedicated Linkage Table pointer (LTP), whereas the program file accesses the Linkage Table through the DP register.

Code which is used in a shared library must be compiled as position independent code. Refer to compiler documentation for specific instructions. Code in the program file is not PIC and the linker places the import/export stubs into the program file to handle external calls.

When building a shared library, the linker must generate import and export stubs for all procedures which can be called from outside of the shared library. Figure 2-6 below shows the control flow of an external call.

Calling Code

The calling code in program files is responsible for performing the standard procedure call steps regardless of whether the call is external or local. The linker generates an import stub to perform the additional steps required for external calls.

The import stub (calling stub) of an external call performs the following steps:

- Loads the target (export stub) address of the procedure from the Linkage Table
- Loads into gr19 the LTP (Linkage Table Pointer) value of the target load module.
- Saves the return pointer (RP'), since the export stub will overwrite RP with the return address into the export stub itself.
- Performs the interspace branch to the target export stub.

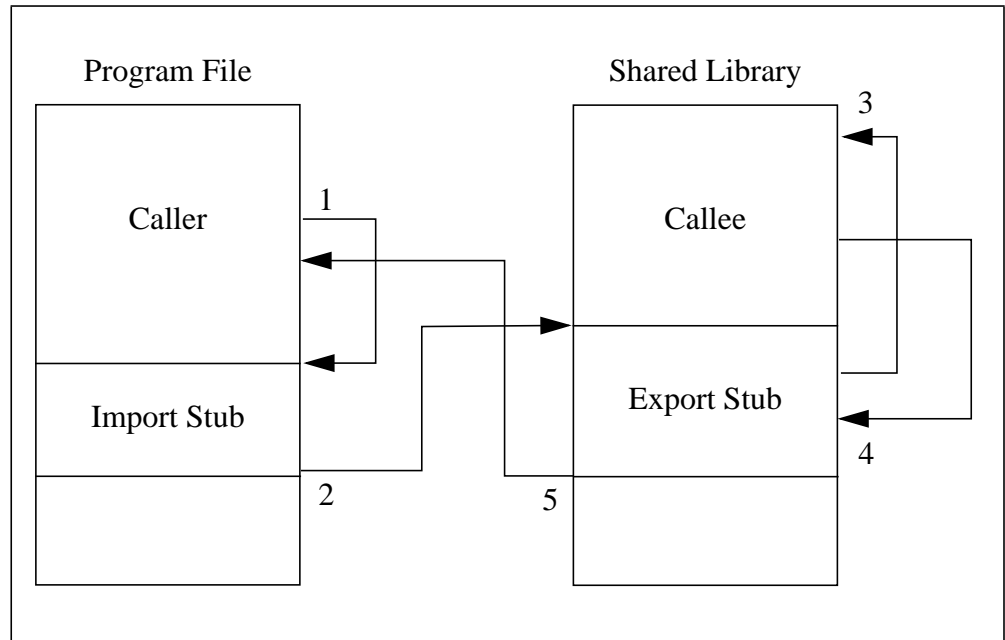


Figure 2-6: Flow of an External Procedure Call

The code sequence of the import stub used in the program file is shown below:

```

;Import Stub (Program file)
    LDW disp(0, dp), r21
    LDW disp+4(0, dp), r19
    BVE 0(r21)
    STW rp, -24(0, sp)

```

The difference between a shared library and program file import stub is that the Linkage Table is accessed using gr19 (the LTP) in a shared library, and is accessed using DP in the program file.

The code sequence of the import (calling) stub used in a shared library is shown below:

```

;Import Stub (Shared Library)

X:    LDW disp(0, r19), r21
      LDW disp+4(0, r19), r19
      BVE 0(r21)
      STW rp, -24(0, sp)

```

Called Code

The called code in shared library files is responsible for performing the standard procedure call steps regardless of whether the call is external or local.

Common Coding Conventions

The linker generates an export stub to perform the additional steps required for shared library external calls. The export stub is used to trap the return from the procedure and perform the steps necessary for an inter-space branch.

The export stub (called stub) of a shared library external call performs the following steps:

- Branches to the target procedure. The value stored in RP at this point is the return point into the export stub.
- Upon return from the procedure, restores the return pointer (RP').
- Performs an interspace branch to return to the caller.

The code sequence of the export stub is shown below:

```
X':  <optional parameter relocation code>
      BLL      <entry>
      NOP
      <optional return relocation code>
      LDW      -24(0,sp),rp          ; restore the original RP
      BVE,N    0(rp)                ; inter-space return
```

PIC Requirements for Compilers and Assembly Code

Any code which is PIC or which makes calls to PIC must follow the standard procedure call mechanism. In addition, register gr19 (the linkage table pointer register) must be stored at sp-32 by all PIC routines. This should be done once upon procedure entry. Register gr19 must also be restored upon return from each procedure call, even if gr19 is not referenced explicitly before the next procedure call. The LTP register, gr19, is used by the import stubs and must be valid at all procedure call points in position independent code. If the PIC routine makes several procedure calls, it may be wise to copy gr19 into a callee-saves register as well, to avoid a memory reference when restoring gr19 upon return from each procedure call. As with gr27 (DP), the compilers must treat gr19 as a reserved register whenever position-independent code is being generated.

2.5.6 Indirect Procedure Calls

Procedure Labels and Dynamic Calls

PA-RISC compilers must generate the code sequence required for proper handling of procedure labels and dynamic procedure calls. Assembler programmers must use the same code sequence, described below, in order to insure proper handling of procedure labels and dynamic procedure calls.

A procedure label is a specially-formatted variable that is used to link dynamic procedure calls. The format of a procedure label is shown below in Figure 2-7.

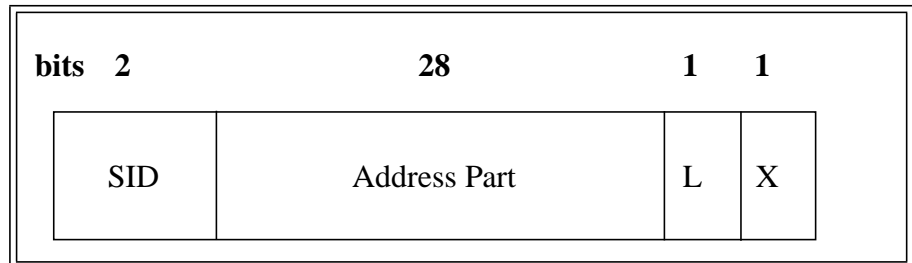


Figure 2-7: Procedure Label Layout

The X field in the address section of the procedure label is reserved. The L field is used to flag whether the procedure label is a pointer to an LT entry (L-field is on) or to the entry point of the procedure.

The label calculation produced by the compilers in both shared libraries and incomplete executables is modified by the linker, when building shared libraries and incomplete executables, to load the contents of an LT entry which is built for each symbol associated with a CODE_PLABEL fixup.

In shared libraries and incomplete executables, a label value is the address of a PLT (Procedure Linkage Table) entry for the target routine, rather than a procedure address; therefore a utility routine named \$\$dyncall must be used when calling a routine via a procedure label. The linker sets the L field (second-to-last bit) in the procedure label to flag this as a special PLT procedure label. The \$\$dyncall routine checks this field to determine which type of procedure label has been passed, and calls the target procedure accordingly. The \$\$dyncall routine assumes that the X field is always 0.

The following pseudo-code sequence shows the process used by \$\$dyncall to perform dynamic calls:

```
IF (L-field in Plabel) = 0 THEN
  Perform interspace branch using Plabel as target address;
ELSE BEGIN
  Clear L-field;
  Load new LTP value into gr19;
  Load address of target;
  Save RP';
  Perform interspace branch to target address;
END.
```

In order to generate a procedure label that can be used for shared libraries and incomplete executables, assembly code must specify that a procedure address is being taken (and that a plabel is wanted) by using the P' assembler fixup mode. For example, to generate an assembly plabel, the following sequence must be used:

; Take the address of a function

```
LDIL    LP'function,r1
LDO     RP'function(r1), r22
```

This code sequence will generate the necessary PLABEL fixups that the linker needs in order to generate the proper procedure label. The `$$dyncall` millicode routine in `/lib/milli.a` (linked in automatically by linker) must be used to call a procedure using this type of procedure label (i.e. a BL/BV will not work). For example:

; Now to call the routine using a plabel

```
BL      $$dyncall, 31          ; r22 is the input register for $$dyncall
COPY    r31, r2
```

The compilers generate the necessary code sequence required for proper handling of procedure labels.

2.5.7 Millicode Procedure Calls

Millicode is PA-RISC's simulation of complex microcoded instructions, accomplished through the creation of assembly-level subroutines that perform the desired tasks. While these subroutines perform comparably to their microcoded counterparts, they are architecturally similar to any other standard library routines, differing only in the manner in which they are accessed. As a result, millicode is portable across the entire family of PA-RISC machines, rather than being unique to a single machine (as is usually the case with traditional microcode).

Millicode routines are accessed through a mechanism similar to a procedure call, but with several significant differences. In general terms, the millicode calling convention stresses simplicity and speed, utilizing registers for all temporary argument storage and eliminating the need for the creation of excess stack frames. Thus, a great majority of the overhead expense associated with a standard procedure call is avoided, thereby reducing the cost of execution.

Making a Millicode Call

A call to a millicode routine can only be made from the assembly level. It is currently not possible to directly call a millicode function from high-level programming languages.

It is intended that the standard register usage conventions be followed, with two exceptions:

- The return address (MRP) is passed in `gr31`; and
- Function results are returned in `gr29`.

There are, however, many non-standard practices regarding millicode register usage.

Local millicode can be accessed with three different methods, depending on its location relative to currently executing code. These three methods are:

- A standard Branch and Link (BL), if the millicode is within 256K bytes of the caller,
- A BLE instruction, if the millicode is within 256K bytes of a predefined code base register, and
- The two-instruction sequence (LDIL,BLE) that can reach any address or a BL with a linker-generated stub.

2.6 Program Startup

All programs must include the start-up routine `crt0.o`. This code defines entry points, initializes program variables such as `DP`, and checks for dynamic libraries. The symbols defined by `crt0.o` are listed in Table 7, and the value of processor's registers are defined in Table 8.

Common Coding Conventions

TABLE 7 **Symbols Defined By crt0.o**

Symbol	Description
__argc_value	A variable of type int containing the number of arguments.
__argv_value	An array of character pointers to the arguments themselves.
_environ	An array of character pointers to the environment in which the program will run. This array is terminated by a null pointer.
_SYSTEM_ID	A variable of type int containing the system id value for an executable program.
\$START\$	Execution start address.
_start	A secondary start-up routine for C programs, called from \$START\$, which in turn calls main. This routine is contained in the C library rather than in the crt0.o file. For Pascal and FORTRAN programs, this symbol labels the beginning of the outer block (main program) and is generated by the compilers.
\$global\$	The initial address of the program's data pointer. The start-up code loads this address into GR 27.
\$UNWIND_START	The beginning of the stack unwind table.
\$UNWIND_END	The end of the stack unwind table.
\$RECOVER_START	The beginning of the try/recover table.
\$RECOVER_END	The end of the try/recover table.
__text_start	The beginning address of the program's text area. ^a
__data_start	The beginning address of the program's data area. ^a

a. The symbols __text_start and __data_start are defined by the linker.

TABLE 8 Register Definition at Process Initialization

Register	C Source Definition	Value
GR 24	char ** envp	array of pointers to environment strings
GR 25	char ** argv	array of pointers to arguments
GR 26	int argc	argument count
GR 30		stack pointer, set by O.S.
All Other GR's		Undefined
SR 4		address of first quadrant of virtual address space ^a
SR 5		address of second quadrant of virtual address space ^b
SR 7		address of fourth quadrant of virtual address space
SR0-SR3		Undefined
SAR (Shift Amount Register)		Undefined
All Co-processors' Registers		Undefined
CCR (Co-processor Config.. Register)		If any bits are set then the corresponding co-processor must be present and functional
PSW (Processor Status Word)		^c Bits C,D,P,Q =1; Bits B, M, N =0

- a. Space register 4 is unprivileged, but it must not be modified by a conforming application.
- b. Space registers 5 and 7 are privileged and cannot be modified by a conforming application.
- c. C=Code Addr. Translation Enable,
D=Data Addr. Translation Enable
P=Protection ID Validation Enable
Q=Interruption State Collection Enable
B=Taken Branch bit
M=High-priority machine check mask
N=Nullify bit

Common Coding Conventions

Relocatable Object Files

The SOM common object file format defined in this document is intended to be a common representation of code and data for all compilers which generate code for PA-RISC based systems. A SOM is the smallest unit which may be generated by a compiler, and it may exist as a single entity or as part of a collection.

The SOM consists of a main header record, an exec auxiliary header record, and other optional components. The location and size of the auxiliary header record and all other components are defined in the main header record. Each location is given by a byte offset (relative to the first byte of the header), and the size is given either by the number of entries (records) of the component, or the total number of bytes in the component.

The first byte of the header record is also the first byte of the SOM. It contains a 'magic' number which distinguishes the SOM from any other entity, such as a Library File or a random access archive. In addition to defining the size and location of the other components of the SOM, the header contains a time stamp and other identifying information.

Figure 3-1 below shows the general block diagram of a SOM.

Table 9 shows a suggested layout of records in a SOM.

Figure 3-8: Block Diagram of the SOM

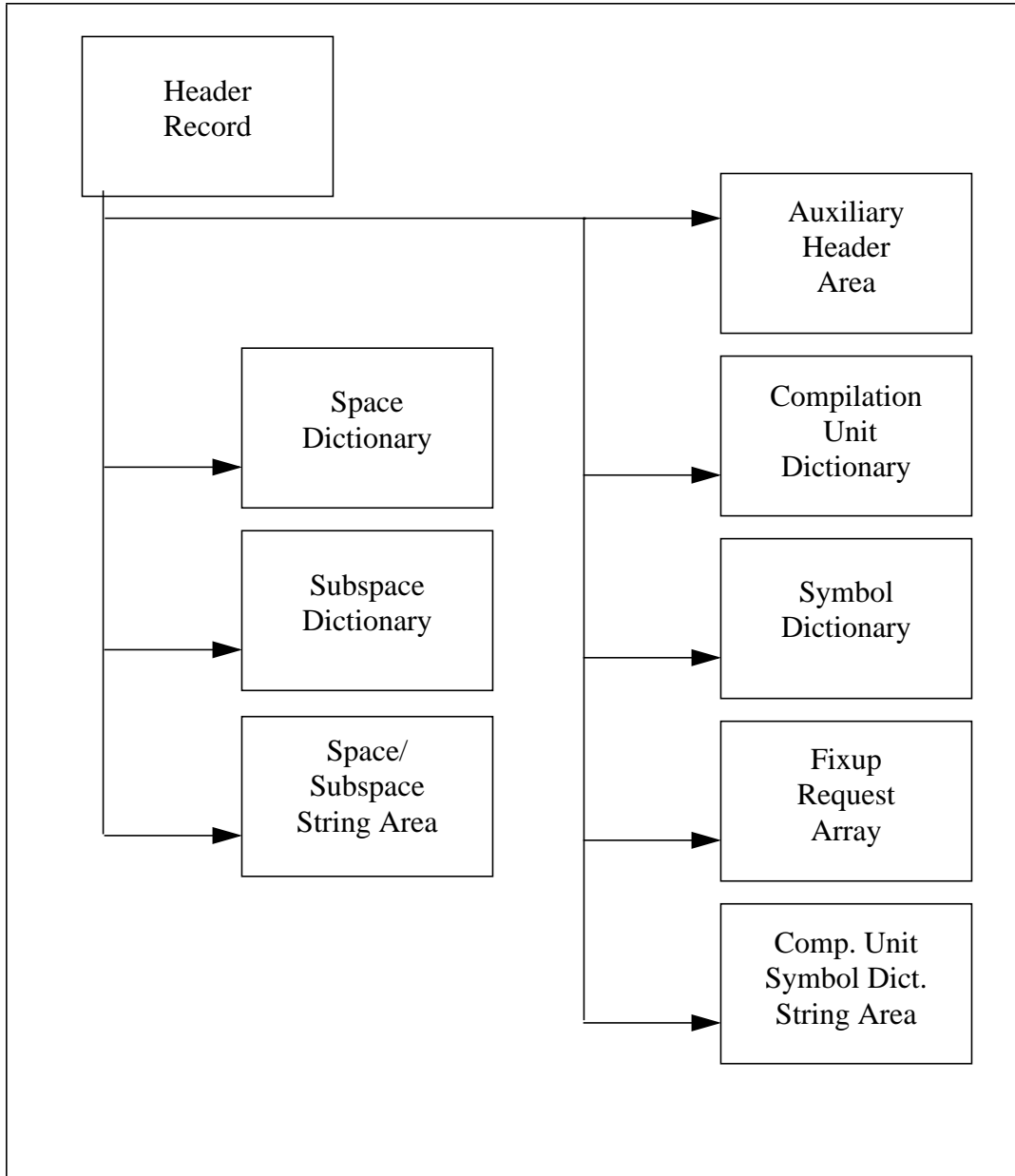


TABLE 9 Record Layout of a SOM

Header Record
Auxiliary Header Record
Space Records
Subspace Records
Loader Fixup Records
Space Strings
Symbol Records
Fixup Records
Symbol Strings
Compiler Records
Data for Loadable Spaces
Data for Unloadable Spaces

3.1 Object File Header

The first halfword of the header record contains a 'system id' number, identifying the target architecture of the SOM. The second halfword of the header record contains a 'magic number', identifying the type of this SOM. Following this, a character array will contain the version ID of the SOM format, and a time stamp specifying the time of creation of the particular SOM.

The remaining fields in the header record define the other components of the SOM. These fields provide a means to do bounds checking when there is a reference to a particular component.

The SOM header is required in any executable or relocatable object.

The C language definition of the SOM header is shown in Figure 3-9

system_id

This 2-byte field is used to identify the architecture that this object module is targeted for. The system ID for PA-RISC 1.0 systems is 20b (hexadecimal), for PA-RISC 1.1 systems is 210 (hexadecimal), and for PA-RISC 2.0 systems is 214 (hexadecimal).

a_magic

This 2-byte field is a number that indicates certain characteristics about the internal format of the object module. The magic numbers that are currently defined for use on PA-RISC systems are listed in Table 10.

Figure 3-9: Definition of SOM Header Fields

```
struct header {
    short int    system_id;        /* magic number - system */
    short int    a_magic;         /* magic number - file type */
    unsigned int version_id;      /* version id; format=YYMMDDHH */
    struct       sys_clock file_time; /* system clock- zero if unused */
    unsigned int entry_space;     /* index of space containing
                                   entry point */
    unsigned int entry_subspace;  /* index of subspace for
                                   entry point */
    unsigned int entry_offset;    /* offset of entry point */
    unsigned int aux_header_location; /* auxiliary header location */
    unsigned int aux_header_size;  /* auxiliary header size */
    unsigned int som_length;      /* length in bytes of entire som */
    unsigned int presumed_dp;     /* DP value assumed during
                                   compilation */
    unsigned int space_location;  /* location in file of space
                                   dictionary */
    unsigned int space_total;     /* number of space entries */
    unsigned int subspace_location; /* location of subspace entries */
    unsigned int subspace_total;  /* number of subspace entries */
    unsigned int loader_fixup_location; /* MPE/iX loader fixup */
    unsigned int loader_fixup_total; /* number of loader fixup records */
    unsigned int space_strings_location; /* file location of string area
                                   for space and subspace names */
    unsigned int space_strings_size; /* size of string area for space
                                   and subspace names */
    unsigned int init_array_location; /* reserved for use by system */
    unsigned int init_array_total;   /* reserved for use by system */
    unsigned int compiler_location;  /* location in file of module
                                   dictionary */
    unsigned int compiler_total;     /* number of modules */
    unsigned int symbol_location;    /* location in file of symbol
                                   dictionary */
    unsigned int symbol_total;      /* number of symbol records */
    unsigned int fixup_request_location; /* location in file of fix_up
                                   requests */
    unsigned int fixup_request_total; /* number of fixup requests */
    unsigned int symbol_strings_location; /* file location of string area
                                   for module and symbol names */
};
```


Figure 3-9: Definition of SOM Header Fields (Continued)

```

unsigned int    symbol_strings_size;    /* size of string area for
                                         module and symbol names    */
unsigned int    unloadable_sp_location; /* byte offset of first byte of
                                         data for unloadable spaces */
unsigned int    unloadable_sp_size;    /* byte length of data for
                                         unloadable spaces    */
unsigned int    checksum;
};

```

Note that the magic numbers for executable and relocatable SOM libraries indicate that the header is an LST header rather than a SOM header.

TABLE 10

Magic Number Values

Magic Number (in hexadecimal)	SOM Type
0104	Executable SOM Library
0106	Relocatable SOM
0107	Non-sharable, executable SOM
0108	Sharable, executable SOM
010B	Sharable, demand-loadable executable SOM
010D	Dynamic Load Library
010E	Shared Library
0619	Relocatable SOM Library

version_id

This is a number that is used to associate the SOM with the correct definition of its internal organization. The value of the number will be an encoding of the date the SOM version was defined.

The version ID can be interpreted by viewing it in its decimal form and separating it into character packets of YYMMDDHH, where YY is the year, MM is the month, DD is the day, and HH is the hour.

The version_id that are currently defined for use by conforming applications are 85082112 for old version ID and 87102412 for new version ID with new fixups.

file_time

Relocatable Object Files

The file time is a 64 bit value that represents the time the file was last modified. The file time is actually composed of two 32 bit quantities where the first 32 bits is the number of seconds that have elapsed since January 1, 1970 (at 0:00 GMT), and the second 32 bits is the nano second of the second (which requires 30 bits to represent).

This value is independent of any modification time maintained by other subsystems (e.g. the file system). The use of this field is optional, but if it is not used it will be set to zero.

entry_space

This is the space dictionary index of the space containing the main entry point of this particular SOM.

entry_subspace

This is the subspace dictionary index of the subspace containing the main entry point of this particular SOM.

entry_offset

This is the byte offset of the main entry point of the SOM relative to the first byte of the space.

aux_header_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the auxiliary header area. Setting all bits to zero indicates that the auxiliary header record is not defined in a SOM. The auxiliary header must start on a word boundary. *Aux_header_location* must have a value in the range 0 to $2^{31}-1$. See “Auxiliary Headers” on page 109. for restrictions on auxiliary headers.

aux_header_size

This field contains the byte length of the auxiliary header area. If the number of bytes is zero it indicates that no auxiliary headers are defined in the SOM. The size must be a multiple of 4 bytes. The field *aux_header_size* must have a value in the range 0 to $2^{31}-1$.

som_length

This field contains the length in bytes of the entire SOM. The field *som_length* must be in the range 0 to $2^{31}-1$.

presumed_dp

This field is only specified for shared libraries. It contains the value of the data pointer (DP) assumed during compilation or linking of this SOM. In a shared library, *presumed_dp* is the value of the data pointer that the linker used as a base to initialize data. The dynamic loader will subtract this value to get the offset of the data.

space_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the space dictionary. Setting all bits to zero in *space_location* indicates that the space dictionary is not defined in a SOM. The space dictionary must start on a word boundary. *Space_location* must have a value in the range 0 to $2^{31}-1$.

space_total

This field contains the number of space records in the space dictionary. Setting all bits to zero in *space_total* means that the space dictionary is not defined in a SOM. *Space_total* must have value in the range 0 to $2^{31}-1$.

subspace_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the subspace dictionary. Setting all bits to zero in *subspace_location* indicates that the subspace dictionary is not defined in a SOM. The subspace dictionary must start on a word boundary. *Subspace_location* must have a value in the range 0 to $2^{31}-1$.

subspace_total

This field contains the number of subspace records in the subspace dictionary. Setting all the bits to zero in *subspace_total* means that the subspace dictionary is not defined in a SOM. *Subspace_total* must have a value in the range 0 to $2^{31}-1$.

loader_fixup_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the loader fixup array. Loader fixup is used only in MPE/iX for relocation at load time. Setting all bits to zero in *loader_fixup_location* indicates that the loader fixup array is not defined in the SOM. The loader fixup array must start on a word boundary and the *loader_fixup_location* must have a value in the range 0 to $2^{31}-1$.

loader_fixup_total

This field contains the number of loader fixup records in the loader fixup array. Setting all bits to zero in *loader_fixup_total* indicates that the loader fixup array is not defined in the SOM. *loader_fixup_total* must have a value in the range 0 to $2^{31}-1$.

space_strings_location

Space_strings_location points to a string area that contains both space and subspace names. It is a byte offset relative to the first byte of the SOM header. Setting all bits to zero indicates that the space subspace string area is not defined in a SOM. The space subspace string area must start on a word boundary. *Space_strings_location* must have a value in the range 0 to $2^{31}-1$.

space_strings_size

This field contains the byte length of the space subspace string area. Setting all bits to zero in *space_strings_size* indicates that the string area is not defined in a SOM. *Space_strings_size* must be a multiple of 4 bytes and be in the range 0 to $2^{31}-1$.

init_array_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the initialization pointer array. Setting all bits to zero in *init_array_location* indicates that the initialization pointer array is not defined in the SOM. The initialization pointer array must start on a word boundary and the *init_array_location* must have a value in the range 0 to $2^{31}-1$.

init_array_total

This field contains the number of initialization pointer records in the initialization pointer array. Setting all bits to zero in *init_array_total* indicates that the initialization pointer array is not defined in the SOM. *init_array_total* must have a value in the range 0 to $2^{31}-1$.

compiler_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the compilation unit dictionary. Setting all bits to zero in *compiler_location* indicates that the compilation unit dictionary is not defined in a SOM. The compilation unit dictionary must start on a word boundary. *Compiler_location* must have a value in the range 0 to $2^{31}-1$.

compiler_total

This field contains the number of compilation unit records in the compilation unit dictionary. Setting all bits to zero in *compiler_total* means that the compilation unit dictionary is not defined in a SOM. *Compiler_total* must have a value in the range 0 to $2^{31}-1$.

symbol_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the symbol dictionary. Setting all bits to zero in *symbol_location* indicates that the symbol dictionary is not defined in a SOM. The symbol dictionary must start on a word boundary. *Symbol_location* must have a value in the range 0 to $2^{31}-1$.

symbol_total

This field contains the number of symbol records in the symbol dictionary (including symbol and argument extension records). Setting all bits to zero in *symbol_total* means that the symbol dictionary is not defined in a SOM. *Symbol_total* must have a value in the range 0 to $2^{31}-1$.

fixup_request_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the fixup request dictionary. Setting all bits to zero in *fixup_request_location* indicates that the fixup request array is not defined in a SOM. The fixup request array must start on a word boundary. *Fixup_request_location* must have a value in the range 0 to $2^{31}-1$.

fixup_request_total

This field contains the number of fixup request records in the fixup request dictionary. Setting all bits to zero in *fixup_request_total* means that the fixup request dictionary is not defined in a SOM. *fixup_request_total* must have a value in the range 0 to $2^{31}-1$.

symbol_strings_location

Symbol_strings_location is a pointer to an area that contains symbol names and compilation unit names. It is a byte offset relative to the first byte of the SOM header. Setting all bits to zero in *symbol_strings_location* indicates that there are no symbol or compilation unit names in a SOM. The symbol string area must start on a word boundary. *Symbol_strings_location* must have a value in the range 0 to $2^{31}-1$.

symbol_strings_size

This field contains the byte length of the symbol dictionary string area. Setting all bits to zero in *symbol_strings_size* indicates that the symbol string area is not defined in a SOM. *Symbol_strings_size* must be a multiple of 4 bytes and be in the range 0 to $2^{31}-1$.

unloadable_sp_location

This is a byte offset relative to the first byte of the SOM header that points to the first byte of the data for unloadable spaces. Setting all bits to zero in *unloadable_sp_location* indicates that there are no unloadable spaces defined in a SOM. The data for unloadable spaces must be double-word aligned. *Unloadable_sp_location* must have a value in the range 0 to $2^{31}-1$.

unloadable_sp_size

This field contains the byte length of the data for unloadable spaces. Setting all bits to zero in *unloadable_sp_size* indicates that the data for unloadable spaces is not defined in

a SOM. *Unloadable_sp_size* must be a multiple of 8 bytes and be in the range 0 to $2^{31}-1$.

checksum

This field is the exclusive OR of all the words, excluding the checksum field, of the SOM header. It will be used to quickly evaluate valid SOM headers.

3.2 Compilation Unit Records

A compilation unit is defined as the set of procedures compiled by a single invocation of a given compiler. The compilation unit dictionary contains one entry for each SOM created by an invocation of a compiler. The Compilation Unit Record contains information for version identification of the compiler which generated the given SOM. Each entry contains information which may be used to identify the source name, the compiler language, the compiler product number, and the particular version of the compiler used. Lastly, each entry contains time stamps which identify the last modification made to the (main) source file and the time of compilation.

```
struct compilation_unit {
    union name_p    name;
    union name_pt   language_name;
    union name_pt   product_id;
    union name_pt   version_id;
    unsigned int    reserved : 31;
    unsigned int    chunk_flag : 1;
    struct sys_clock compile_time;
    struct sys_clock source_time;
};
```

Figure 3-10: Definition of Compilation Unit Dictionary Record

name

This field contains a byte offset relative to the symbol string area which points to the first character of the string defining the entry name. The compilers should supply the name of the source file that produced the SOM.

language_name

This field contains a 32-bit index into the symbol string area, which points to the first character of the name of the language used when creating this SOM.

product_id

This field contains a 32-bit index into the symbol strings area which points to the first character of the identification number of the compiler.

version_id

This field contains a 32-bit index into the symbol strings area which points to the first character of the version id of the compiler.

reserved

These bits are reserved for future expansion.

chunk_flag

This field indicates that the compilation unit is not the first SOM in a multiple chunk compilation.

compile_time

compile time is a 64 bit value that represents the time the file was last compiled. The file time is actually composed of two 32 bit quantities where the first 32 bits is the number of seconds that have elapsed since January 1, 1970 (at 0:00 GMT), and the second 32 bits is the nano second of the second (which requires 30 bits to represent).

This value is independent of any modification time maintained by other subsystems (e.g. the file system). The use of this field is optional, but if it is not used it will be set to zero.

source_time

The file time is a 64 bit value that represents the time the file was last modified. The time is represented in the same format as *compile_time*.

This value is independent of any modification time maintained by other subsystems (e.g. the file system). The use of this field is optional, but if it is not used it will be set to zero.

3.3 Space Dictionary

The space dictionary consists of a collection of space records in contiguous bytes in the file. A space record is a template which defines attributes of a space (which correspond to the address spaces defined in the PA-RISC Architecture). Spaces, in general, are used as logical divisions of virtual memory. Current implementations may allow only one code and one data space. The *access_control_bits* field of a subspace record indicate

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whether a subspace is code or data. Each space record will indicate the space name, a pointer to the start of the subspace list, and a pointer to the start of the list of data initialization pointers that are to be applied to a space.

```
struct space_dictionary_record {
    union name_pt    name;           /* index to subspace name */
    unsigned int    is_loadable : 1; /* space is loadable */
    unsigned int    is_defined : 1;  /* space is defined within file */
    unsigned int    is_private : 1;  /* space is not sharable */
    unsigned int    has_intermediate_code: 1; /* contain intermediate code */
    unsigned int    is_tspecific : 1; /* contain intermediate code */
    unsigned int    reserved : 11;   /* reserved for future expansion */
    unsigned int    sort_key : 8;    /* sort key for space */
    unsigned int    reserved2 : 8;   /* reserved for future expansion */
    int             space_number;    /* space index */
    int             subspace_index;  /* index into subspace dictionary*/
    unsigned int    subspace_quantity; /* number of subspaces in space */
    int             loader_fix_index; /* loader usage*/
    unsigned int    loader_fix_quantity; /* loader usage*/
    int             init_pointer_index; /* index into data(initialization)
                                     pointer array */
    unsigned int    init_pointer_quantity; /* number of data (init) pointers*/
};
```

Figure 3-11: Space Dictionary Record Definition

name_pt

The field *name_pt* is an index into the space string area which points to the first character of the ascii representation of the space name. The index is a byte offset relative to the *space_strings_location* field of the SOM header. See the section on string areas for more details on the format of a name. *name_pt* is a byte offset relative to the field *space_strings_location* in the SOM header. *name_pt* can be converted to a file byte offset by:

```
offset = name_pt
        + space_strings_location (found in the SOM header)
        + address of the first byte of the SOM header.
```

If *name_pt* is greater than the field *space_strings_size* in the SOM header it is an error. Setting all bits to zero in *name_pt* indicates a null name pointer. *name_pt* must have a value in the range 0 to $2^{31}-1$.

is_loadable

Bit 0

If a space is loadable this flag is set to one. If a space is not loadable this flag is set to zero. Code and data for a load module will be the typical loadable spaces.

is_defined

Bit 1

If a space is defined in the file in which the space record resides the flag is set to one. If a space is not defined in the file in which the space record resides then the flag is set to zero.

is_private

Bit 2

If this flag is set then the space is non-sharable.

has_intermediate_code

Bit 3

This bit indicates that the space has only intermediate code in it (ISOM). The space will also be marked unloadable at the same time. The symbol dictionary information is complete but not meaningful since the \$TEXT\$ and \$PRIVATE\$ spaces are empty.

sort_key

Bits 16-23

This field specifies a sort key which may be used by the linker for ordering spaces in the output file.

reserved1

Bits 4-15, 24-31

These bits are reserved for future expansion.

space_number

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This field specifies the number assigned to this space. Current implementations may default the space number values. Current implementations may ignore this field.

subspace_index

This field is an index into the subspace dictionary. All of the subspace records for a particular space will be in contiguous records in the subspace dictionary. *subspace_index* can be converted to a file byte offset by:

$$\begin{aligned} \text{offset} = & \textit{subspace_index} * \text{size of (subspace record)} + \\ & \textit{subspace_dictionary_location} \text{ (found in the SOM header)} \\ & + \text{address of the first byte of the SOM header.} \end{aligned}$$

If *subspace_index* is greater than the field *subspace_dictionary_total* in the SOM header it is an error. If *subspace_index* is negative then there are no subspaces defined for that space. *Subspace_index* must have a value in the range -2^{31} to $2^{31}-1$.

subspace_quantity

Subspace_quantity is a number indicating how many subspaces are in a space. If *subspace_index* + *subspace_quantity* is greater than the field *subspace_dictionary_total* in the SOM header it is an error. If *subspace_quantity* is zero then there are no subspaces in that space. *Subspace_quantity* must have a value in the range 0 to $2^{31}-1$.

reserved2

This field is reserved for system use

reserved3

This field is reserved for system use.

init_pointer_index

This field is an index into the initialization pointer array. All of the initialization pointers for a particular space will be in contiguous records in the initialization pointer array. *init_pointer_index* can be converted to a file byte offset by:

$$\begin{aligned} \text{offset} = & \textit{init_pointer_index} * \text{sizeof (initialization pointer record)} \\ & + \textit{init_array_location} \text{ (found in the SOM header)} \\ & + \text{address of the first byte of the SOM header.} \end{aligned}$$

If *init_pointer_index* is greater than the field *init_array_total* in the SOM header it is an error. If *init_pointer_index* is negative then there are no initialization pointers for that space. *Init_pointer_index* must have a value in the range -2^{31} to $2^{31}-1$.

init_pointer_quantity

Init_pointer_quantity is a number indicating how many initialization pointers are in the space. If *init_pointer_index* + *init_pointer_quantity* is greater than *init_array_total* in the SOM header it is an error. If *init_pointer_quantity* is zero then there are no initialization pointers for that space. *Init_pointer_quantity* must have a value in the range 0 to $2^{31}-1$.

3.4 Subspace Dictionary

A subspace corresponds to a logical subdivision of an address space. A subspace record is a template used to define the attributes of a subspace. The subspace dictionary consists of a collection of subspace records in contiguous bytes in the file. The subspace records are grouped by space. They contain information that can be used for relocation, setting of access rights of pages, determining how to build data areas, requesting a subspace to be locked in memory, and alignment requests.

Subspaces cannot be broken up into smaller entities, therefore there must not be any inter-subspace references generated without also generating a fixup for that reference. Compilers are responsible for insuring that all branches can reach the beginning of their subspace.

space_index

This field is a index into the space dictionary. All of the space records will be in contiguous records in the space dictionary. *space_index* can be converted to a file byte offset by:

$$\begin{aligned} \text{offset} &= \text{space_index} * \text{size of (space record)} \\ &+ \text{space_dictionary_location (found in the SOM header)} \\ &+ \text{address of the first byte of the SOM header.} \end{aligned}$$

If a *space_index* is greater than the field *space_quantity* in the SOM header record it is an error. If *space_index* is negative it is an error. *Space_index* must have a value in the range 0 to $2^{31}-1$.

access_control_bits

The *access_control* bits specify the access rights and privilege level of the subspace. They also specify whether the subspace contains code or data. Bits 0-7 of the *access_control_bits* are defined in Table 11.

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```
struct subspace_dictionary_record {
    int            space_index;
    unsigned int  access_control_bits :7; /* access for PDIR entries */
    unsigned int  memory_resident :1; /* lock in memory during
                                     execution */
    unsigned int  dup_common :1; /* data name clashes allowed */
    unsigned int  is_common :1; /* subspace is a common
    block*/
    unsigned int  is_loadable :1;
    unsigned int  quadrant :2; /* quadrant request */
    unsigned int  initially_frozen :1; /* must be locked into memory
                                     when OS is booted */
    unsigned int  is_first :1; /* must be first subspace */
    unsigned int  code_only :1; /* must contain only code */
    unsigned int  sort_key :8; /* subspace sort key */
    unsigned int  replicate_init :1; /* init values replicated to
                                     fill subspace_length */
    unsigned int  continuation :1; /* subspace is a continuation*/
    unsigned int  is_tspecific :1; /* Is thread specific ?*/
    unsigned int  reserved :5;
    int           file_loc_init_value; /* file location or
                                     initialization value */
    unsigned int  initialization_length;
    unsigned int  subspace_start; /* starting offset */
    unsigned int  subspace_length; /* number of bytes defined
                                     by this subspace */
    unsigned int  reserved2 :5;
    unsigned int  alignment :27; /* alignment required for the
                                     subspace (largest alignment
                                     requested for any item in
                                     the subspace) */
    union name_pt name; /* index of subspace name */
    int           fixup_request_index; /* index into fixup array */
    unsigned int  fixup_request_quantity; /* number of fixup requests */
};
```

Figure 3-12: Subspace Dictionary Record Definition

memory_resident

If this flag is set to one then the subspace is to be locked in physical memory once the subspace goes into execution.

TABLE 11 **Subspace Access Control Bits**

Type (3 bits)	Read/Write/Execute/Gateway (4 bits)		Usage
	1st Field (PL1)	2nd Field (PL2)	
0	Read	Not Used	Read only data page
1	Read	Write	Normal data page
2	Read/Xleast	Xmost	Normal code page
3	Read/Xleast	Write/Xmost	Dynamic code page
4	Xleast	Xmost	Gateway to PL0
5	Xleast	Xmost	Gateway to PL1
6	Xleast	Xmost	Gateway to PL2
7	Xleast	Xmost	Gateway to PL3

dup_common

Bit 8

If this flag is set, then there may be more than one universal data symbol of the same name and the linker will not give a duplicate definition type of error. This field is used to facilitate implementation of Fortran initialized common and Cobol common.

is_common

Bit 9

This flag is set to one if the subspace is to define an initialized common data block. For example, Fortran initialized common, and Cobol common data blocks. Only one initialized data block is allowed per *is_common* subspace.

is_loadable

Bit 10

This flag is set to 1 if a subspace is loadable. Loadable subspaces must reside in loadable spaces. Unloadable subspaces must reside in unloadable spaces.

quadrant

Bits 11-12

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This is to specify which of the four possible quadrants of a space that this subspace is going to reside. Current implementations may ignore this field, and place the subspace in a pre-determined quadrant.

TABLE 12

Quadrant Values

Bits	Meaning
00	Quadrant 0
01	Quadrant 1
10	Quadrant 2
11	Quadrant 3

initially_frozen

Bit 13

If this flag is set to one then the subspace is to be locked in physical memory when the operating system is being booted.

is_first

Bit 14

If this flag is set then the subspace must be the first subspace.

code_only

Bit 15

If set, this flag specifies that this subspace must only contain code (no literal data).

sort_key

Bits 16-23

This field contains the primary sort key by which the linker arranges subspaces in an output file. Subspaces are first ordered by the sort key, then are arranged according to the subspace name. Within sort keys, the linker groups subspaces by their name but it does not sort by name. Instead, the subspaces are output in the order in which the linker first encounters each name.

replicate_init

Bit 24

If the initialization contained in the file is shorter than the subspace length, replicate it to fill the length of the subspace.

continuation

Bit 25

If set, the subspace is a continuation of a previous subspace and the two (or more) subspaces should be treated as a single unit.

reserved

Bits 26-31

These bits are reserved for future use.

file_loc_init_value

If *initialization_length* field is non-zero, the subspace is initialized, and this field contains a byte offset relative to the first byte of the SOM header. In other words, it is a file location of the initialization image.

If *initialization_length* is zero then this field contains a 32 bit quantity which is used as an initialization pattern for the entire subspace. The total length of the subspace is defined by the *subspace_length* field. This is how BSS subspaces are represented.

initialization_length

This field contains the size in bytes of the initialization area in the file. If this field is zero then the value contained in the field *file_loc_init_value* is used as the initialization pattern for the subspace.

The *initialization_length* field can also be non-zero, but less than the *subspace_length* field. In this case, the length of the initialization image is given by *initialization_length*, and the remainder of the subspace, up to *subspace_length*, is initialized with zeros.

subspace_start

This is a byte address of where the subspace is to start relative to the beginning of a space. It is a virtual address that indicates the assumed beginning of that subspace in memory. This value in conjunction with *subspace_length* will be used to insure that subspaces do not overlap. *Subspace_start* must have a value in the range 0 to $2^{32}-1$.

subspace_length

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This is the length in bytes of a subspace. A total length of a space will be kept, and if the addition of all of the *subspace_length* fields in a space is greater than $2^{32}-1$ then it is an error.

reserved2

Bits 0-15

These bits are reserved for future expansion.

alignment

Bits 16-31

This 2-byte field specifies what alignment is required for the subspace. The alignment request is in bytes. The subspace will start on the alignment byte boundary. The alignment value must be greater than zero.

name

The field *name* is an index into the space/subspace string area. The index is a byte relative offset which points to the first character of the string. See the chapter on string areas for more details on the format of a name. *name* can be converted to a file byte offset by:

$$\text{offset} = \text{name} + \text{space_strings_location} \text{ (found in the SOM header)}$$

+ address of the first byte of the SOM header.

If *name* is greater than the field *space_strings_size* in the SOM header it is an error. Setting the field name to zero means that it is a null name pointer.

fixup_request_index

This field is an index into the fixup request array. All of the fixup request records for a particular subspace will be in contiguous records in the fixup request array. *fixup_request_index* can be converted to a file byte offset by:

$$\text{offset} = \text{fixup_request_index} * \text{size of (fixup record)}$$

+ *fixup_request_location* (found in the SOM header)

+ address of the first byte of the SOM header.

If *fixup_request_index* is greater than the field *fixup_request_total* in the SOM header record it is an error. If *fixup_request_index* is negative then there are no fixup requests for that subspace. *Fixup_request_index* must have a value in the range -2^{31} to $2^{31}-1$.

fixup_request_quantity

Fixup_request_quantity is a number indicating how many fixup requests there are for a subspace. If *fixup_request_index* + *fixup_request_quantity* is greater than the field *fixup_request_total* in the SOM header record it is an error. *Fixup_request_quantity* must have a value in the range 0 to $2^{31}-1$. If *fixup_request_quantity* is zero then there are no fixup requests for that subspace.

3.5 String Areas

The string area contains all symbols used in the SOM, including space names, subspace names, export names, import requests, and compilation unit names. There will be two string areas; one for space and subspace names, and one for symbols and compilation unit names.

The first word of each string contains the total number of characters in the string. The byte immediately following the last byte of the string will be zero (the null character). Successive strings will begin on the next word boundary.

string header

This field contains the total number of characters contained in the string (does not include the terminating null character).

string data

Bits 0-??

The string is defined by the character data given here.

3.6 Fixup Requests

In the object files, relocation entries consist of a stream of bytes. The *fixup_request_index* field in the subspace dictionary entry is a byte offset into the fixup dictionary defined by the file header, and the *fixup_request_quantity* field defines the length of the fixup request stream, in bytes, for that subspace. The first byte of each fixup request (the opcode) identifies the request and determines the length of the request.

In general, the fixup stream is a series of linker instructions that governs how the linker places data in the a.out file. Fixups requests can be grouped into the following five categories:

- fixup requests that cause the linker to copy one or more bytes from the input subspace to the output subspace without change. For example, the

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R_NO_RELOCATION fixup that cause the linker to copy n bytes to the output subspace with no relocation.

- fixups that direct the linker to relocate words or resolve external references. For example, the R_DP_RELATIVE fixup used to relocate the target symbol in the output subspace. The address is calculated based on the offset from \$global\$, the data pointer (r27).
- fixups that direct the linker to insert zeroes in the output subspace. For example, the R_REPEATED_INIT to replicate the data to fill n bytes of initialized value in the output subspace.
- fixups that direct the linker to leave areas uninitialized without copying any data from the input subspace. For example, the R_UNINIT fixup that tells the linker to skip bytes in the output subspace.
- fixups that describe points in the code without contributing any new data to the output file. These fixups DO indirectly affect the output, they are considered fixups for changing the environment. For example, the rounding mode fixups (R_N_MODE, R_D_MODE and the R_ENTRY and R_EXIT fixups). They do affect how the data are to be interpreted for the output file.

The linker disassembles instructions so it can determine which part of the instruction needs to be relocated. It switches on the opcode field (the high-order six bits of the instruction) which is sufficient to identify the instruction format and the appropriate field selector (i.e. L' vs R' field selector).

3.6.1 Fixup Rounding Modes

TABLE 13

R and L-Class Fixups

L'	Set bits 21-31 to 0 (set the rightmost 11 bits to 0)
R'	Set bits 0-20 to 0
LD'	Add 0x800, set bits 21-31 to 0
RD'	Set bits 0-20 to 1
LR'	Round constant before evaluating expression, set bits 21-31 to 0
RR'	Round constant before evaluating expression, set bits 0-20 to 0, add (constant - round(constant)) round(constant) = (constant + 0x1000) & ~0x1FFF
LS'	If (bit 21) then add 0x800 and set bits 21-31 to 0
RS'	Sign extend from bit 21

All direct and dp-relative effective address calculations use the LR and RR rounding modes. In these rounding modes, the left part is computed based on a rounded constant instead of the actual constant. The constant is rounded to the nearest multiple of 8192 prior to computing the effective address. The right part is computed as the difference between the full value of the expression and the value used in the left-part relocation. Because the difference between the original constant and the rounded constant can be no larger than 4K, this result will always fit in a signed 14-bit field. This permits several

load and store instructions to reuse the result of a single ADDIL or LDIL instruction, as long as the symbol index and the rounded value of the constant are identical.

For pc-relative relocations, the standard L and R rounding modes are used. The expression is computed based on the actual effective address.

The following C language functions define the operation of the LR, RR,L, R, and RND functions:

```
unsigned long LR(unsigned long x, unsigned long constant)
{
    return L(x + RND(constant));
}
```

```
unsigned long RR(unsigned long x, unsigned long constant)
{
    return R(x + RND(constant)) + (constant - RND(constant));
}
```

```
unsigned long L(unsigned long x)
{
    return (x & 0xffff800);
}
```

```
unsigned long R(unsigned long x)
{
    return (x & 0x000007ff);
}
```

```
unsigned long RND(unsigned long x)
{
    return ((x + 0x1000) & 0xffffe000);
}
```

3.6.2 Interpretation of rounding mode and field selector

In a relocatable object file, the immediate fields of the instructions contain only the constant part of the expression. For a “symbol+constant” expression, the R_CODE_ONE_SYMBOL fixup identifies the symbol and the immediate field contains the constant. Whether the instruction is forming the left part or the right part of an address, the immediate field still contains the entire constant. If the constant is too large for the immediate field, the compilers precede the fixup with an R_DATA_OVERRIDE fixup that supplies the full 32 bits.

For a “symbol-\$global\$+constant” expression, the R_DP_RELATIVE fixup identifies the symbol, and the constant is in the immediate field. For other kinds of expression, the linker resort to the more general stack-based expression evaluation mechanism, and the

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R_CODE_EXPR fixup would be used. For example, “symbol1-symbol2+constant” would be represented by the fixup stream:

```
R_PUSH_SYM symbol1
R_PUSH_SYM symbol2
R_COMP1 R_SUB
R_CODE_EXPR
```

Again, the constant part of the expression is in the instruction itself.

The field selector in the assembly syntax really consists of two parts: the rounding mode (normal, D, R, S), and the field selector itself (F, L, or R).

The field selector is normally implied by the opcode. ADDIL and LDIL instructions only imply the L% field selector. Most other opcodes that take displacements or offsets imply the R% field selector, with the exception of the BL opcode, which implies the F% field selector, since it is most often used for a single-instruction procedure call. If the full 32-bit displacement for a BL instruction is too large (computed by the R_PCREL_CALL fixup), the linker creates a long branch stub. In all other cases, a displacement that does not fit in the instruction causes a link-time error.

Note that the default field selector in assembly syntax is F%. If an assembly instruction is coded with F% or with no field selector, the assembler must generate a field selector override fixup immediately preceding the regular fixup for that instruction. Likewise, if an assembly instruction with a field selector other than the default, an override must be generated.

The particular rounding mode selected in the assembly instruction affects only the fixups generated. If the rounding mode selected is different from the “current” rounding mode, a fixup is generated to change the current mode. Unlike the field selector override, the rounding mode is persistent, and must be changed back for the next instruction that uses a different mode.

The field selectors come in pairs, and an LDIL or ADDIL instruction must always be paired with an LDO/LDW/STW that uses the same rounding mode. The relations

```
L%expr + R%expr = expr
LD%expr + RD%expr = expr
LS%expr + RS%expr = expr
LR%expr + RR%expr = expr
```

always hold. R%expr is always positive, which implies that L%expr is always the first 2K boundary less than or equal to expr. This is the most straightforward definition.

RD%expr, however, is always negative, implying that LD%expr is always the first 2K boundary greater than expr. This mode is useful when the code is near a quadrant boundary, and the base register formed by LDIL and used by the LDW is on the higher quadrant. The space register used in an LDW instruction when the s field is 0 is determined solely by the upper two bits of the base register (not by the effective address). Therefore, if code is generated to access a non-zero based array, for example, this mode

can be used to ensure that the intermediate address is not down in quadrant 0 when the data to be accessed is in quadrant 1.

The next mode, LS%/RS%, is defined such that RS%*expr* is between -1024 and +1023, inclusive. This implies that LS%*expr* is the nearest 2K boundary to *expr*. If the second instruction of a pair is an ADDI instruction (or SUBI, COMICLR, ..etc.), this mode is essential, since there are only 11 bits of immediate field available, and the immediate is sign-extended.

The last mode, LR%/RR%, is the only one where the constant field is treated separately from the rest of the expression. This pair is defined like L% and R%, except that the lower bits of the constant do not participate in the LR% determination; they get added back in to the R% value. This allows the final value of RR%*expr* to be larger than 2K, but never too large to fit in the 14-bit signed immediate field of an LDW-class instruction. This mode is conveniently defined so that the compiler can share a single ADDIL instruction among several LDW-class instructions where the expressions are the same except for the constant part of the expression. Note that they can be shared as long as the constants are all equal in their upper bits. In other words, if the compiler knows that LR%*symbol*+con1 will evaluate to the same thing as LR%*symbol*+con2, it can share one ADDIL instruction with both corresponding LDW/STW instructions using RR%*symbol*+con1 and RR%*symbol*+con2. This is efficient when generating code to access structures and static data where several adjacent memory locations are all addressed by a single symbol.

3.6.3 Examples of applying the rounding mode

The following is an example of how the rounding modes are applied:

```
symbol 4 = 0x4000fff0
ADDIL 0x1000000,27          /* immediate is 8192 in decimal */
LDO 4104 (1), 25           /* immediate is in decimal as is */
```

For the LR% and RR% modes, the constant is rounded to the nearest 8K multiple before splitting the value in half. Then, after splitting, the difference is added back in to the right half. The following is the pseudo code for this algorithm:

```
#define FIXUP_ROUND(c) (((c) + 0x1000) & ~0x1fff)
expr = symbol_value + FIXUP_ROUND(constant);
left = expr & 0xFFFFF800;
right = (expr & 0x7FF) + (constant - FIXUP_ROUND(constant));
```

In this example, the ADDIL gets a “rounded” expression value of 0x4000fff0 + 0x1000 = 0x40010ff0, which gets truncated to 0x40010800. The LDO gets a “rounded” expression value of 0x4000fff0 + 0x1000 = 0x40010ff0, which gets truncated to 0x7f0, to which we add the difference between the constant 0x1008 and the rounded constant (0x1000), resulting in 0x07f8.

Thus, the ADDIL/LDO form the address 0x40010800 + 0x07f8 = 0x40010ff8, which is the same as 0x4000fff0 + 0x1008 (symbol #4 plus 4104).

As mentioned briefly in the previous section, the reason that this is done this way is that a single ADDIL can be accessed with many LDO/LDW/STW instruction, each of which may have a slightly different constant. As long as the constants all round to the same value, we can use a common ADDIL instruction for all of them. In practice, this works for accesses to the fields of a structure, where we use the same symbol with different displacements in several loads or stores.

3.6.4 Apply Fixups on instructions

The linker apply fixups to instructions in the following three steps:

1. Calculate the effective address. This depends on the fixup type. This usually involves checking the opcode and extracting a constant from the immediate or displacement field. Step one is where the linker actually looks at the opcode, decide what the default field selector should for step two, and identify which of the six instruction formats to use in step three.
2. Apply the field selector. This can be implied by the opcode, or can be overridden by a field selector override fixup (R_xSEL). It also depends on the current rounding mode. The default field selector is L% for LDIL and ADDIL, F% for BL, COMB, ADDB, and BB family of opcodes, and R% for everything else. For example, BE/ BLE instructions have an implicit R% field selector. If one were to code a BE/BLE in assembler without the R%, an F% field selector override fixup (R_FSEL) for that instruction is needed. This tells the linker not to chop off the top 21 bits of the effective address, and try to fit the address into the instruction as is. If the address is too large, the linker would issue a diagnostic such as “displacement too large”. Step two is where the expression gets converted from an absolute address to a pc-relative address. If the instruction format is i_rel12 or i_rel17, (pc+8) is subtracted from the effective address to obtain the proper pc-relative displacement.
3. Apply the resulting value to the target instruction. The opcode determines the actual disposition of the various bits. There are really only six different instruction formats: i_exp11 (ADDI), i_exp14 (LDW), i_exp21 (LDIL), i_rel12 (ADDIB), i_rel17 (BL) and i_abs17 (BE). These names are in <reloc.h>. i_rel17 and i_abs17 are really the same instruction format, but the linker adjust the space register field in the BE-class instructions based on where the target is.

3.6.5 List of fixup requests

The meaning of each fixup request is described below. The opcode ranges and parameters for each fixup are described in the table further below.

TABLE 14

Fixup Requests

R_NO_RELOCATION	Copy L bytes with no relocation.
R_ZEROES	Insert L zero bytes into the output subspace.
R_UNINIT	Skip L bytes in the output subspace.

TABLE 14 Fixup Requests

R_RELOCATION	Copy one data word with relocation. The word is assumed to contain a 32-bit pointer relative to its own subspace. It describes a single word whose value must be relocated, assuming it contains an address constant of a location within the same subspace. The word to be relocated comes from the initialization image, not from the fixup stream.
R_DATA_ONE_SYMBOL	Copy one data word with relocation relative to an external symbol whose symbol index is S.
R_DATA_PLABEL	Copy one data word as a 32-bit procedure label, referring to the symbol S. The original contents of the word should be 0 (no static link) or 2 (static link required).
R_SPACE_REF	Copy one data word as a space reference. This fixup request is not currently supported.
R_REPEATED_INIT	Copy L bytes from the input subspace, replicating the data to fill M bytes in the output subspace.
R_PCREL_CALL	Copy one instruction word with relocation. The word is assumed to be a pc-relative procedure call instruction for example, BL). The target procedure is identified by symbol S, and the parameter relocation bits are R.
R_SHORT_PCREL_MODE	this specifies that any following R_PCREL_CALL fixup (with the default field selector) is applied to a BL instruction with a maximum 17-bit signed displacement. It is a single-byte mode change fixup, and is the initial default mode.
R_LONG_PCREL_MODE	this specifies that any following R_PCREL_CALL fixup (with the default field selector) is applied to a BL instruction with a maximum 22-bit signed displacement (i.e., a BLL instruction). It is a single-byte mode change fixup.
R_ABS_CALL	Copy one instruction word with relocation. The word is assumed to be an absolute procedure call instruction (for example, BLE). The target procedure is identified by symbol S, and the parameter relocation bits are R.
R_DP_RELATIVE	Copy one instruction word with relocation. The word is assumed to be a dp-relative load or store instruction (for example, ADDIL, LDW, STW). The target symbol is identified by symbol S. The linker forms the difference between the value of the symbol S and the value of the symbol \$global\$. By convention, the value of \$global\$ is always contained in register 27. Instructions may have a small constant in the displacement field of the instruction.
R_PLT_REL	this is analogous to R_DLT_REL; it requests the displacement field of the instruction to be filled with the value <linkage table pointer address - PLT slot for symbol>. It is used for instructions in inlined import stubs. It is only available in a 4-byte form, in which the symbol index is encoded in the last 3 bytes of the fixup.

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TABLE 14 **Fixup Requests**

R_INDIRECT_CALL	This specifies that the targeted instruction is an indirect call through \$\$dyncall. It is used to optimize indirect calls, and is a single-byte fixup.
R_DLT_REL	Copy one instruction word with relocation. The word is assumed to be a register r19-relative load or store instruction (for example, LDW, LDO, STW). The target symbol is identified by symbol S. The linker computes a linkage table offset relative to register 19 (reserved for a linkage table pointer in position-independent-code) for the symbol S.
R_CODE_ONE_SYMBOL	Copy one instruction word with relocation. The word is assumed to be an instruction referring to symbol S (for example, LDIL, LDW, BE).
R_MILLI_REL	Copy one instruction word with relocation. The word is assumed to be a short millicode call instruction (for example, BLE). The linker forms the difference between the value of the target symbol S and the value of symbol 1 in the module's symbol table. By convention, the value of symbol 1 should have been previously loaded into the base register used in the BLE instruction. The instruction may have a small constant in the displacement field of the instruction.
R_CODE_PLABEL	Copy one instruction word with relocation. The word is assumed to be part of a code sequence forming a procedure label (for example, LDIL, LDO), referring to symbol S. The LDO instruction should contain the value 0 (no static link) or 2 (static link required) in its displacement field.
R_BREAKPOINT	Copy one instruction word conditionally. On HP-UX, the linker always replaces the word with a NOP instruction.
R_ENTRY	Define a procedure entry point. The stack unwind bits, U, and the frame size, F, are recorded in a stack unwind descriptor (copied to words 3 and 4 for the unwind region).
R_ALT_ENTRY	Define an alternate procedure entry point.
R_EXIT	Define a procedure exit point.

TABLE 14 Fixup Requests

R_BEGIN_TRY	<p>Define the beginning of a try/recover region.</p> <p>The try/recover mechanism is designed to support features such as try/recover in Pascal and try/catch in C++. The recover table is constructed by the linker and consists of some number of recover descriptors. A recover descriptor consists of three words:</p> <ul style="list-style-type: none"> word 1: the starting address of the “try” region. word 2: the ending address of the “try” region. word 3: an address pointing at language-dependent region. <p>For example:</p> <ul style="list-style-type: none"> Pascal: the address of the exception handler Ada: the address of a descriptor block C++: a pointer to a C++ data structure <p>The linker builds try/recover descriptors based on the R_BEGIN_TRY/R_END_TRY fixups. The first two words of the try/recover descriptor are just the addresses of the beginning and end of the guarded region as indicated by the placement of the fixups. The third word is the address of the end of the guarded region (the second word) plus four times the argument of R_END_TRY. This region is sometimes referred to as the “recover block”. The END_TRY fixup contains a pc-relative offset to the recover block. The actual meaning of the recover block is language dependent. In Pascal, it is just a pointer to the recover code, so it is often the address immediately following the guarded region so the constant in the END_TRY fixup is often 0.</p> <p>The C++ exception handling mechanism uses a recover block that points to other information. The first word of this recover block is a pointer to the code in the catch block. Like the Pascal case above, the catch block often immediately follows the guarded region, so this pointer often points back to the first instruction beyond the END_TRY fixup. Since this pointer is actually a self-relative offset, it often is the same number as was found in the END_TRY fixup. This may be a frequent case, but it is not guaranteed, for example, nested try/catch blocks will probably show a difference.</p>
R_END_TRY	Define the end of a try/recover region. The offset R defines the distance in words from the end of the region to the beginning of the recover block.
R_BEGIN_BRTAB	Define the beginning of a branch table.
R_END_BRTAB	Define the end of a branch table.
R_STATEMENT	Define the beginning of statement number N.
R_DATA_EXPR	Pop one word from the expression stack and copy one data word from the input subspace to the output subspace, adding the popped value to it.
R_CODE_EXPR	Pop one word from the expression stack, and copy one instruction word from the input subspace to the output subspace, adding the popped value to the displacement field of the instruction.

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TABLE 14 **Fixup Requests**

R_FSEL	Use an F' field selector for the next fixup request instead of the default appropriate for the instruction. An F field selector denotes "no change". The "default" modes can be any of the R-class or L-class field selectors.
R_LSEL	Use an L'-class field selector for the next fixup request instead of the default appropriate for the instruction. Depending on the current rounding mode, L', LS', LD', or LR' may be used.
R_RSEL	Use an R-class field selector for the next fixup request instead of the default appropriate for the instruction. Depending on the current rounding mode, R', RS', RD', or RR' may be used.
R_N_MODE	Select round-down mode (L'/R'). This is the default mode at the beginning of each subspace. This setting remains in effect until explicitly changed or until the end of the subspace.
R_S_MODE	Select round-to-nearest-page mode (LS'/RS'). This setting remains in effect until explicitly changed or until the end of the subspace.
R_D_MODE	Select round-up mode (LD'/RD'). This setting remains in effect until explicitly changed or until the end of the subspace.
R_R_MODE	Select round-down-with-adjusted-constant mode (LR'/RR'). This setting remains in effect until explicitly changed or until the end of the subspace.
R_DATA_OVERRIDE	Use the constant V for the next fixup request in place of the constant from the data word or instruction in the input subspace.
R_TRANSLATED	Toggle "translated" mode. This fixup request is generated only by the linker during a relocatable link to indicate a subspace that was originally read from an old-format relocatable object file.
R_AUX_UNWIND	Define an auxiliary unwind table. CN is a symbol index of the symbol that labels the beginning of the compilation unit string table. SN is the offset, relative to the CN symbol, of the scope name string. SK is an integer specifying the scope kind.
R_COMP1	Stack operations. The second byte of this fixup request contains a secondary opcode. In the descriptions below, A refers to the top of the stack and B refers to the next item on the stack. All items on the stack are considered signed 32-bit integers.

TABLE 14 **Fixup Requests**

R_PUSH_PCON1	Push the (positive) constant V.
R_PUSH_DOT	Push the current virtual address.
R_MAX	Pop A and B, then push max(A, B).
R_MIN	Pop A and B, then push min(A, B).
R_ADD	Pop A and B, then push A + B.
R_SUB	Pop A and B, then push B - A.
R_MULT	Pop A and B, then push A * B.
R_DIV	Pop A and B, then push B / A.
R_MOD	Pop A and B, then push B % A.
R_AND	Pop A and B, then push A & B.
R_OR	Pop A and B, then push A B.
R_XOR	Pop A and B, then push A XOR B.
R_NOT	Replace A with its complement.
R_LSHIFT	If C = 0, pop A and B, then push B <<< A. Otherwise, replace A with A <<< C.
R_ARITH_RSHIFT	If C = 0, pop A and B, then push B >>> A. Otherwise, replace A with A >>> C. The shifting is done with sign extension.
R_LOGIC_RSHIFT	If C = 0, pop A and B, then push B >>> A. Otherwise, replace A with A >>> C. The shifting is done with zero fill.
R_PUSH_NCON1	Push the (negative) constant V.
R_COMP2	More stack operations.
R_PUSH_PCON2	Push the (positive) constant V.
R_PUSH_SYM	Push the value of the symbol S.
R_PUSH_PLABEL	Push the value of a procedure label for symbol S. The static link bit is L.
R_PUSH_NCON2	Push the (negative) constant V.
R_COMP3	More stack operations.
R_PUSH_PROC	Push the value of the procedure entry point S. The parameter relocation bits are R.
R_PUSH_CONST	Push the constant V.
R_PREV_FIXUP	The linker keeps a queue of the last four unique multi-byte fixup requests; this is an abbreviation for a fixup request identical to one on the queue. The queue index X references one of the four; X = 0 refers to the most recent. As a side effect of this fixup request, the referenced fixup is moved to the front of the queue.
R_SEC_STMT	Secondary statement number.
R_NOSEL	Indicates that the following fixup is applied to the first of a three-instruction sequence to access data, generated by the compilers to enable the importing of shared library data.

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TABLE 14 **Fixup Requests**

R_NISEL	Uses a N field selector for the next fixup request; this indicates that zero bits are to be used for the displacement on the instruction. This fixup is used to identify three-instruction sequences to access data (for importing shared library data).
R_LINETAB	<p>The compilers generate this fixup to request that debugging optimized code (DOC) line tables be built. The first parameter is a 1-byte version number which identifies the line table version (format). The actual value is not important to the linker. The second parameter is a symbol index to be used in conjunction with the third parameter, an offset, as a location which is to be filled with the offset (relative to the \$LINES\$ subspace) of the line table about to be built.</p> <p>The line number information is passed to the linker via the R_STATEMENT fixup request, which is embedded within the fixups for the code at statement boundaries. The R_STATEMENT fixup has three variants to handle one-, two-, and three-byte statement or line numbers as necessary. The actual meaning assigned to the number, whether it be statement number or line numbers, is irrelevant to the linker, and needs to be agreed upon only by the compiler and the end user of the line table information.</p>
R_LINETAB_ESC	<p>Fixup used to place escape entries into the line table. There are several escape entries defined in the line table format which are used by the debugger and other tools when processing the line table. Some of these escapes must be generated by the linker, the others are generated by the compiler and the linker does not need to know the details of these escapes. The escapes entries which are not generated by the linker are entered into the line table via a combination of the R_LINETAB_ESC and R_STATEMENT fixups.</p> <p>The second parm specifies how many of the following R_STATEMENT entries contain data to be entered directly into the line table (these statement fixups will not contain line numbers. Instead, they hold data which is to be placed directly into the line number table as part of an escape sequence. With the currently defined escapes the value of the second parameter will be in the range [0,4].</p>
R_LTP_OVERRIDE	<p>Override the following fixup which is expected to be an R_DATA_ONE_SYMBOL fixup. If the linker encounters an R_DATA_ONE_SYMBOL with the override set and it is building a shared library then it will convert the relocatable address representing the data item into a absolute offset by subtracting the presumed link time R19 value from the relocatable address. This will eventually require a run time relocation before it can be used to access the data item. There is currently no way to generate this fixup through the assembler interface.</p> <p>If the linker is not building a shared library, the absolute virtual address is placed in the target subspace.</p>

TABLE 14 **Fixup Requests**

R_COMMENT	Fixup used to pass comment information from the compiler to the linker. This fixup has a 5 byte argument that can be skipped and ignored by most applications.
R_RESERVED	Fixups in this range are reserved for internal use by the compilers and linker.

3.6.6 Fixup opcodes, lengths and parameters

The include file <reloc.h> defines constants for each major opcode. Many fixup requests use a range of opcodes; only a constant for the beginning of the range is defined.

Table 15 shows the mnemonic fixup request type and length and parameter information for each range of opcodes. In the parameters column, the symbol D refers to the difference between the opcode and the beginning of the range described by that table entry; the symbols B1, B2, B3, and B4 refer to the value of the next one, two, three, or four bytes of the fixup request, respectively.

TABLE 15 **Fixup Request Opcodes and Parameters**

mnemonic	opcodes	length	parameters
R_NO_RELOCATION	0-23	1	$L = (D+1) * 4$
	24-27	2	$L = (D \ll 8 + B1 + 1) * 4$
	28-30	3	$L = (D \ll 16 + B2 + 1) * 4$
	31	4	$L = B3 + 1$
R_ZEROES	32	2	$L = (B1 + 1) * 4$
	33	4	$L = B3 + 1$
R_UNINIT	34	2	$L = (B1 + 1) * 4$
	35	4	$L = B3 + 1$
R_RELOCATION	36	1	none
R_DATA_ONE_SYMBOL	37	2	$S = B1$
	38	4	$S = B3$
R_DATA_PLABEL	39	2	$S = B1$
	40	4	$S = B3$
R_SPACE_REF	41	1	none
R_REPEATED_INIT	42	2	$L = 4; M = (B1 + 1) * 4$
	43	3	$L = (B1 + 1) * 4; M = (B1 + 1) * L$
	44	5	$L = (B1 + 1) * 4; M = (B3 + 1) * 4$
	45	8	$L = B3 + 1; M = B4 + 1$
R_PCREL_CALL	48-57	2	$R = \text{rbits } 1(D); S = B1$

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TABLE 15 Fixup Request Opcodes and Parameters

mnemonic	opcodes	length	parameters
	58-59	3	R = rbits2(D<<8 + B1); S = B1
	60-61	5	R = rbits2(D<<8 + B1); S = B3
R_ABS_CALL	64-73	2	R = rbits1(D); S = B1
	74-75	3	R = rbits2(D<<8 + B1); S = B1
	76-77	5	R = rbits2(D<<8 + B1); S = B3
R_DP_RELATIVE	80-111	1	S = D
	112	2	S = B1
	113	4	S = B3
R_DLT_REL	120	2	S = B1
	121	4	S = B3
R_CODE_ONE_SYMBOL	128-159	1	S = D
	160	2	S = B1
	161	4	S = B3
R_MILLI_REL	174	2	S = B1
	175	4	S = B3
R_CODE_PLABEL	176	2	S = B1
	177	4	S = B3
R_BREAKPOINT	178	1	none
R_ENTRY	179	9	U,F = B8 (U is 37 bits; F is 27 bits)
	180	6	U = B5 >> 3; F = pop A
R_ALT_ENTRY	181	1	none
R_EXIT	182	1	none
R_BEGIN_TRY	183	1	none
R_END_TRY	184	1	R = 0
	185	2	R = B1 * 4
	186	4	R = sign-extend(B3) * 4
R_BEGI_BRTAB	187	1	none
R_END_BRTAB	188	1	none
R_STATEMENT	189	2	N = B1
	190	3	N = B2
	191	4	N = B3
R_DATA_EXPR	192	1	none
R_CODE_EXPR	193	1	none
R_FSEL	194	1	none
R_LSEL	195	1	none
R_RSEL	196	1	none

TABLE 15

Fixup Request Opcodes and Parameters

mnemonic	opcodes	length	parameters
R_N_MODE	197	1	none
R_S_MODE	198	1	none
R_D_MODE	199	1	none
R_R_MODE	200	1	none
R_DATA_OVERRIDE	201	1	V = 0
	202	2	V = sign-extend(B1)
	203	3	V = sign-extend(B2)
	204	4	V = sign-extend(B3)
	205	5	V = B4
R_TRANSLATED	206	1	none
R_AUX_UNWIND	207	12	CU,SN,SK = B11 (CU is 24 bits;SN is 32)
R_COMP1	208	2	OP = B1; V = OP & 0x3f; C = OP & 0x1f
R_COMP2	209	5	OP = B1; S = B3; L = OP & 1; V = ((OP & 0x7f) << 24) S
R_COMP3	210	6	OP = B1; V = B4; R = ((OP & 1) << 8) (V >> 16); S = V & 0xfffff
R_PREV_FIXUP	211-214	1	X = D
R_SEC_STMT	215	1	none
R_NOSEL	216	1	none
R_NISEL	217	1	none
R_LINETAB	218	10	version number = B1 symbol index = B2 to B5 (symbol-relative loc to patch w/ line table offset) offset = B6 to B9 (symbol + offset, location to patch w/line table offset)
R_LINETAB_ESC	219	3	escape code = B1 number of following R_STATEMENT fix-ups containing escape data in B2
R_LTP_OVERRIDE	220	1	none
R_COMMENT	221	6	OP=B1 V = B2 to B6
R_RESERVED	222-255	-	reserved

3.6.7 Parameter Relocation Bits (rbits1, rbits2)

Parameter relocation bits are encoded in the fixup requests in two ways, noted as rbits1 and rbits2 in Table 15. The first encoding recognizes that the most common procedure calls have only general register arguments with no holes in the parameter list. The encoding for such calls is simply the number of parameters in general registers (0 to 4), plus 5 if there is a return value in a general register.

Here is how “rbits1” decodes its parameter. The “diff” is the difference between the actual opcode and the first opcode of the range. When “rbits1” is used, it is describing a function call with 0 to 4 general register parameters (no holes, and no floating point register parameters), and either a general register return value or no return value. The “diff” can be from 0 to 9; if it is between 0 and 4, it indicates 0 to 4 parameters with no return value; if it’s between 5 and 9, it indicates 0 to 4 parameters with a return value. Here is some code that turns this into the 10-bit parameter relocation field:

```
if (diff >= 5)
    j = diff - 5;
else
    j = diff;
for (i = 0; i < 4; i++)
    arg = (arg << 2) + (i < j);
arg = (arg << 2) + (diff >= 5);
```

The second encoding is more complex (presumably less common); the 10 argument relocation bits are compressed into 9 bits by eliminating some impossible combinations. The encoding is the combination of three contributions. The first contribution is the pair of bits for the return value, which are not modified. The second contribution is 9 if the first two parameter words together form a double-precision parameter; otherwise, it is 3 times the pair of bits for the first word plus the pair of bits for the second word. Similarly, the third contribution is formed based on the third and fourth parameter words. The second contribution is multiplied by 40, the third is multiplied by 4, then the three are added together. Here is some code to decode the “rbits” encoding:

```
i = ((diff & 1) << 8) + next_fixup_byte;
```

```
arg = decode_arg_reloc(i);
```

where:

```
int decode_arg_reloc(i)
int i;
{
    int j, k, ret_val;
    ret_val = i & 03;
    i >>= 2;
    j = i / 10;
    i -= 10*j;
    if (j == 9)
        ret_val += (03 << 6);           /* FARGU */
    else {
        k = j / 3;
        j -= 3*k;
        ret_val += (k << 8) + (j << 6);
```



```
    }  
    if (i == 9)  
        ret_val += (03 << 2);           /* FARGU */  
    else {  
        k = i / 3;  
        i -= 3*k;  
        ret_val += (k << 4) + (i << 2);  
    }  
    return (ret_val);  
}
```

3.7 Symbol Table

The symbol table or symbol dictionary for a SOM consists of symbol records strung together in contiguous space within the SOM. The byte offset of the dictionary, relative to the SOM header, is contained in the variable *symbol_dictionary_location* in the SOM header and the number of entries is contained in the variable *symbol_dictionary_total*, also in the SOM header.

Relocatable Object Files

A particular symbol in the dictionary can be located either by scanning the dictionary until it is found, or the symbol's index can be used to index into the dictionary as if it were an array of five word elements.

Note



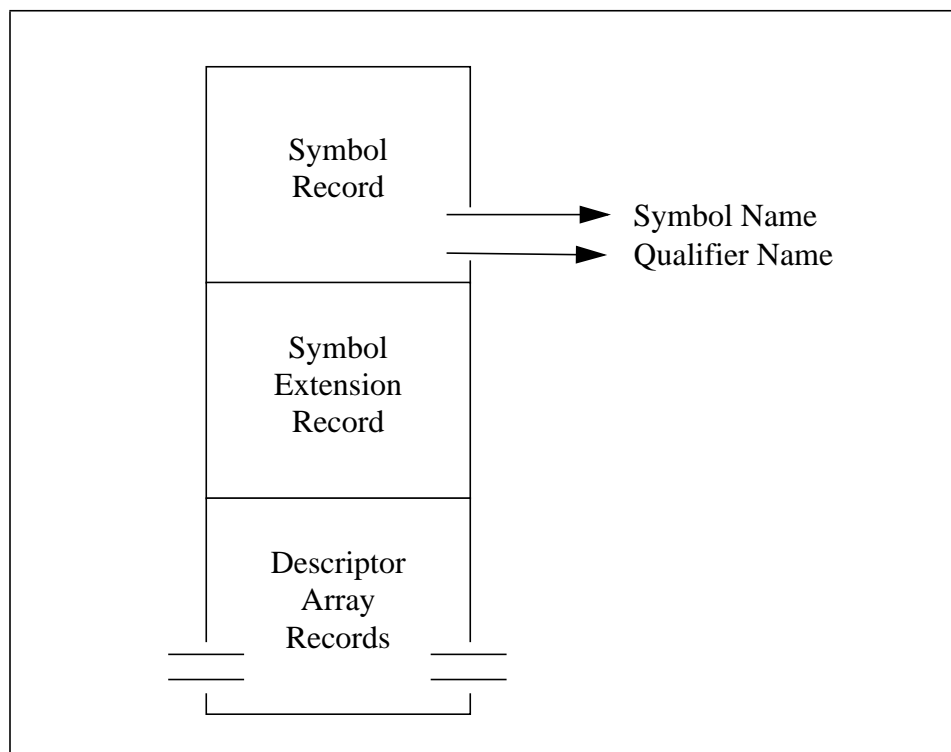
A symbol's index is NOT its relative entry number in the symbol dictionary since some entries use extension records and argument descriptor arrays. But all entries are a multiple of 5-words in length so the index can be used to index into the symbol dictionary.

```
struct symbol_dictionary_record {
    unsigned int    hidden           : 1;
    unsigned int    secondary_def    : 1;
    unsigned int    symbol_type      : 6;
    unsigned int    symbol_scope     : 4;
    unsigned int    check_level      : 3;
    unsigned int    must_qualify     : 1;
    unsigned int    initially_frozen : 1;
    unsigned int    memory_resident  : 1;
    unsigned int    is_common        : 1;
    unsigned int    dup_common       : 1;
    unsigned int    xleast           : 2;
    unsigned int    arg_reloc        :10;
    union name_pt   name;
    union name_pt   qualifier_name;
    unsigned int    has_long_return  :1;
    unsigned int    no_relocation    :1;
    unsigned int    reserved         :6;
    unsigned int    symbol_info      :24;
    unsigned int    symbol_value;
};
```

Figure 3-13: Symbol Dictionary Record Definition

An entry in the dictionary consists of the symbol dictionary record and an optional extension record and 0 to 61 descriptor array records as shown in Figure 3-13. Symbol records do not need to be sorted.

Figure 3-14: Structure of a Dictionary Entry



Whether an extension record and argument descriptor arrays follow the symbol record is dependent upon the check level and the number of parameters according to the following algorithm:

```

IF CHECK_LEVEL >= 1
  THEN
    An extension record will be present.
    IF num_args > 3 AND check_level >= 3
      THEN
        In addition to the extension record there will be enough
        argument descriptor arrays to contain one descriptor for each
        argument except the first 3.
        i.e. NUM_DESCS = round_up ( (NUM_ARGS-3)/4 )
  
```

Two symbol types, SYM_EXT and ARG_EXT, are defined to mark the symbol extension and argument descriptor array records respectively.

hidden

Relocatable Object Files

Bit 0

If this flag is set to one, it indicates that the symbol is to be hidden from the loader for the purpose of resolving external (inter-SOM) references. It has no effect on linking. This flag allows a procedure to be made private to its own executable SOM, although it has universal scope within that SOM.

secondary_def

Bit 1

If this flag is set to one, the symbol is a secondary definition and has an additional name that is preceded by “_”. The linker will ignore duplicate definitions involving secondary definitions.

symbol_type

Bits 2-7

This field defines what type of information this symbol represents. A complete list of the defined symbol types is presented in Table 16, however only certain ones may be valid depending on the use (e.g. import/export, relocatable/executable, etc.).

TABLE 16

symbol_type Definition

#	Symbol	Description
0	NULL	Invalid symbol record. The contents of the entire record is undefined (it is 5 words long).
1	ABSOLUTE	Absolute constant.
2	DATA	Normal initialized data. Initialized data symbols including Fortran and Cobol initialized common data blocks, as well as C initialized data. Data can be either imported or exported. For example C construct “EXTERN INT I” would be imported data. And the C construct “INT I = 1” would be exported data.
3	CODE	Unspecified code. For example, code labels. Code labels are only relevant up to link time, and they cannot be the target of interspace calls.
4	PRI_PROG	Primary program entry point.
5	SEC_PROG	Secondary Program entry point.
6	ENTRY	Any code entry point. Includes both primary and secondary entry points. Code entry point symbols may be used as targets of inter-space calls.
7	STORAGE	The value of the symbol is not known, but the length of the area is given. If a matching definition is not found, storage is allocated within a specified subspace and the symbol’s value becomes the virtual address of that storage. For example, Fortran and Cobol uninitialized common data blocks, and the C construct “INT I” would be storage requests with no initial value.

TABLE 16

symbol_type Definition

#	Symbol	Description
8	STUB	This symbol marks an import (outbound) external call stub (EXTERNAL scope) or a parameter relocation stub (LOCAL scope). The linker may create an import stub for any unsatisfied code symbols, and the loader would be responsible for satisfying the reference by filling in the XRT entry allocated for this stub.
9	MODULE	This symbol is a source module name.
10	SYM_EXT	This type is used to indicate that an entry in the SOM symbol dictionary is an extension record of the current entry (previous valid symbol entry in the list).
11	ARG_EXT	This type is used to indicate that an entry in the SOM symbol dictionary is an extension record of the current entry (previous valid symbol entry in the list).
12	MILLICODE	This is the name of the millicode routine.
13	PLABEL	This symbol defines an export stub for a procedure for which a procedure label has been generated. The loader must build an XRT entry for the procedure at the offset allocated by the linker.
14	OCT_DIS	This type is used to indicate that the pointer to a translated code segment exists, but has been disabled. Used by the Object Code Translator only.
15	MILLI_EXT	This symbol defines the address of an external millicode subroutine. It should be treated as an constant.
15	ST_TDATA	Thread specific data.

symbol_scope

Bits 8-11

The scope of a symbol defines the range over which an exported symbol is valid, or the range of the binding used to import the symbol. In addition, this field is used to determine whether the requested symbol record is a import or export request.

The scope of a symbol will be one of the following:

Imports

0: UNSAT Import request that has not been satisfied.

1: EXTERNAL Import request linked to a symbol in another SOM. This symbol will require additional linking when it is loaded.

Internal

2: LOCAL This symbol is not exported for use outside the SOM. It may be used as the target for fixups, but the linker does not use this symbol for resolving symbol references.

Relocatable Object Files

Exports

3: UNIVERSAL This symbol is exported for use outside the SOM.

Table 17 shows the valid values of the scope field given the type of the symbol. Any square that does not contain an “X” is an invalid value for that type.

TABLE 17

Valid *symbol_scope* Values

TYPE	UNSAT	EXTERNAL	LOCAL	UNIV
PRI_PROG				X
SEC_PROG				X
ENTRY			X	X
STUB		X	X	
MODULE			X	X
ABSOLUTE	X		X	X
CODE	X		X	X
DATA	X		X	X
STORAGE	X			
PLABEL			X	

check_level

Bits 12-14

This value indicates how closely an import definition must match an export definition during linking. This checking can be applied to both code and data linkage according to the following checking levels:

- 0 No checking.
- 1 Check the symbol type descriptor only.
- 2 Level 1, plus check the number of arguments passed by the import with the minimum and maximum range declared in the export (code types only).
- 3 Level 2, plus check the type of each argument passed (code types only).

must_qualify

Bit 15

If this bit is set to one, it indicates that there is more than one entry in the symbol directory that has the same name as this entry, and is the same generic type (i.e. code, data or stub). Therefore, the qualifier name must be used to fully qualify the symbol.

If this flag is not set, the qualifier name will only be used to qualify the symbol name if the name it is being compared with is also fully qualified.

The flag is used for both import and export requests.

initially_frozen

Bit 16

If this flag is set to one it indicates that the code importing or exporting this symbol is to be locked in physical memory when the operating system is being booted.

memory_resident

Bit 17

If this field is set to one it indicates that the code that is importing or exporting this symbol is frozen in memory. This flag is used so that links between memory resident procedures can also be frozen in memory.

is_common

Bit 18

Specifies that this symbol is an initialized common data block. Each initialized common data block resides in its own subspace. For example, a Fortran initialized common declaration would produce a symbol of type data with the *is_common* flag set to one. Refer to the Language Requirements Document for implementation details.

dup_common

Bit 19

If this flag is set to one, it specifies that this symbol name may conflict with another symbol of the same name if both are of type data. This is to facilitate the Cobol “common” feature, since Cobol allows duplicate initialization of “common” data blocks. This flag would be set to one if the language allows duplicate initialization, otherwise it will be set to zero for symbols of type data. Refer to the Language Requirements Document for implementation details.

xleast

Bits 20-21

Relocatable Object Files

This is the execution level that is required to call this entry point. This XLEAST level is placed in any XRT entry linked to this entry point. The XLEAST level will be checked by the Spectrum external procedure call primitive during execution.

This field is not used if (i.e. its content is meaningless):

- 1) the symbol is an import.
- 2) the symbol is not one of the code types.

XLEAST must be a value in the range of 0 to 3. Furthermore, if the value is not in the range of XLEAST to XMOST of the page containing the entry point a run time error can occur.

arg_reloc

Bits 22-31

This field is used to communicate the location of the first four words of the parameter list, and the location of the function return value to the linker and loader. This field is meaningful only for exported ENTRY, PRI_PROG, and SEC_PROG symbols.

The linker matches the argument relocation bits of an exported symbol with the argument relocation bits in each fixup that references the symbol. If it finds a mismatch, it builds an argument relocation stub and redirects the call to that stub.

The ten bits of this field are broken down as follows:

- bits 22-23 define the location of parameter list word 0
- bits 24-25 define the location of parameter list word 1
- bits 26-27 define the location of parameter list word 2
- bits 28-29 define the location of parameter list word 3
- bits 30-31 define the location of the function return

For MPE/iX, this field can contain new values if the shared_data bit in the LST SOM Auxiliary header is set:

For Storage requests and Data Universals, this field is set to the access rights of the subspace the data is defined in.

For Data Unsats, this field is set to the access rights of the subspace that contains the reference.

The argument location value is defined as follows:

Value	Mnemonic	Location
0		Do not relocate - Mismatch is not an error.
1	ARG	Argument Register
2	FARG	Floating point coprocessor register, bits 0 to 31.
3	FARGupper	Floating point coprocessor register, bits 32 to 64.

The FARGupper tag can be used only for parameter list words 0 and 2, or for the function return. If it is used for parameter list words 0 or 2, then parameter list word 1 or 3, respectively, must be tagged as FARG; this indicates a double-precision floating-point number in a single floating point coprocessor register. If it is used for the function return, it indicates a double-precision floating point return value in a single floating point coprocessor register.

name

This variable is used to locate the name of the symbol in the symbol dictionary string table of the SOM. Its value is the byte offset, relative to the beginning of the string table, to the first character (not the length) of the symbol name. The name begins on a word boundary and is preceded by a 32 bit number that contains the number of characters in the name. The symbol is terminated with an 8 bit zero, but the terminator is not included as part of the length.

The size of the symbol dictionary string area can be used to bounds check this variable such that it is a value in the range of 0 to the value of the variable *symbol_strings_size* found in the SOM header.

qualifier_name

This field contains a byte offset relative to the beginning of the symbol strings area which points to the first character of a symbol name which may be used to further qualify the current symbol.

If there is no qualifier, this field should be set to 0.

has_long_return

this bit is set for an Entry Universal symbol means its return sequence can cross a space; setting it for a Code Unsat asserts that the called entry point will have a long return sequence.

no_relocation

Relocatable Object Files

Setting the `no_relocation` bit for an Entry Universal is unnecessary, but should be done for any such symbol record whose `arg_reloc` field is 0. Setting the bit for a Code Unsat asserts that the called entry point will not require any parameter relocation.

symbol_info

This field contains variant information depending on the scope of the symbol. The following list shows the interpretation of this field:

Scope	Meaning
UNSAT	Contains the index of the subspace that imported this symbol. If <code>STORAGE_REQUEST</code> then it is the index of the subspace which may contain this symbol.
EXTERNAL	Contains the XRT offset allocated by the linker for the import stub.
LOCAL	Index of the subspace containing this symbol. For export stubs (procedure labels), this field contains the XRT offset instead.
UNIVERSAL	Index of the subspace containing this symbol.

For MPE/iX, this field can contain new values if the `shared_data` bit in the LST SOM Auxiliary header is set:

For Storage Requests, this field is set to the size of the storage request.

For Data Unsats, this field is set to the index of the subspace that contained the reference.

symbol_value

This field contains the 32 bit value of this particular symbol.

Depending on the type and scope of the symbol this field may have a different meaning. The following matrix shows the meaning of the symbol value for each valid combination of type and scope. Invalid combinations will be denoted as a blank cell in the matrix. Immediately following the matrix are the definitions for the mnemonics used.

TABLE 18

Valid symbol_value Mnemonics

TYPE	UNSAT	EXTRN	LOCAL	UNIV
PRI_PROG				SOFF
SEC_PROG				SOFF
ENTRY			SOFF	SOFF
STUB		SOFF	SOFF	
MODULE			UNUSED	UNUSED

TABLE 18

Valid symbol_value Mnemonics

TYPE	UNSAT	EXTRN	LOCAL	UNIV
ABSOLUTE	UNUSED		CONST	CONST
CODE	UNUSED		SOFF	SOFF
DATA	UNUSED		SOFF	SOFF
STORAGE	LEN			
PLABEL			SOFF	

SOFF - This stands for space offset and it is the byte offset within a space (when it is loaded in virtual memory) to an entry point (i.e. the first instruction to be executed). For code symbols, bits 30-31 of the offset will contain the privilege level that the procedure will execute at (subject to privilege level checking at load time and XLEAST / XMOST level checking during execution).

CONST - This stands for a numeric constant or its value may be the virtual address of a location within a subspace defined by this SOM.

LEN - This is the length of the storage request in bytes.

UNUSED- The content of this field is meaningless.

For MPE/iX, this field can contain new values if the shared_data bit in the LST SOM Auxiliary header is set:

For Data and Storage Universals, this field is set to the DP-positive address of the symbol.

For Data Unsats, this field is set to the DXRT offset for the symbol (will be a negative offset).

Symbol Dictionary Extension Record

```

struct symbol_extension_record {
    unsigned int    type                :8;
    unsigned int    max_num_args        :8;
    unsigned int    min_num_args        :8;
    unsigned int    num_args            :8;
    union arg_descriptorsymbol_desc;
    union arg_descriptorargument_desc[3];
};

```

Figure 3-15:

Symbol Dictionary Extension Record Fields

type

Bits 0-7

This field will be set to SYM_EXT (i.e. 12) so that it can be identified as an extension to the symbol definition of the previous entry in the symbol list (see SYMBOL_TYPE of symbol dictionary record fields).

max_num_args

Bits 8-15

If CHECK_LEVEL indicates that the number of arguments passed should be checked, the num_args field of the imported symbol (this field is in the exported symbol) must be less than or equal to this value.

This field is not used if (i.e. its content is meaningless) if the symbol is an import.

The range of this variable is min_num_args to 255.

min_num_args

Bits 16-23

If CHECK_LEVEL indicates that the number of arguments passed should be checked, the num_args field of the imported symbol (this field is in the exported symbol) must be greater than or equal to this value.

This field is not used if (i.e. its content is meaningless) if the symbol is an import.

The range of this variable is 0 to max_num_args".

num_args

Bits 24-31

This value is the number of arguments associated with the symbol. A procedure return value is NOT counted as an argument.

The range of this variable is 0 to 255. Since this variable is not essential for linking or loading, compilers are not constrained to limit the number of parameters to 255. However, if this limit is exceeded, functions that use this field (e.g. parameter checking) may produce unpredictable results.

symbol_desc

This is an argument descriptor for the procedure's type or the data type depending upon the type of the symbol (see argument descriptor definition, section 9.5).

This field is not used (i.e. its content is meaningless) if the checking level is 0.

argument_desc [1]

This is the argument descriptor for the first argument in the procedure's argument list.

This field is not used (i.e. its content is meaningless) if the checking level is less than 3 or the number of arguments is 0.

argument_desc [2]

This is the argument descriptor for the second argument in the procedure's argument list.

This field is not used (i.e. its content is meaningless) if the checking level is less than 3 or the number of arguments is less than 2.

argument_desc [3]

This is the argument descriptor for the third argument in the procedures argument list.

This field is not used (i.e. its content is meaningless) if the checking level is less than 3 or the number of arguments is less than 3.

Argument Descriptor

```
struct argument_desc_array {
    unsigned int          type : 8;
    unsigned int          reserved : 24;
    union arg_descriptor  argument_desc[4];
};
```

Argument Descriptor Fields

```
union arg_descriptor {
    struct {
        unsigned int    reserved           :3;
        unsigned int    packing           :1;
        unsigned int    alignment         :4;
        unsigned int    mode              :4;
        unsigned int    structure         :4;
        unsigned int    hash              :1;
        int             arg_type          :15;
    } arg_desc;
    unsigned int    word;
};
```

Figure 3-16: Argument Descriptor Definition

reserved

Bits 0-2

These bits are reserved for future use, and must be set to zero.

packing

Bit 3

This field specifies the packing algorithm used in calculating the storage layout, the alignment of, and the data representation of the particular item. The real number data representation on Spectrum is different from that of the HP 3000. This field may be increased in size to allow more packing possibilities, such as 9000 or 1000 packing. The valid values for this field are:

- | | |
|---|--|
| 0 | Spectrum packing and IEEE real numbers |
| 1 | 3000 mode packing and real numbers alignment |

Bits 4-7

This field specifies the alignment of the descriptor. The valid values for this field are:

- | | |
|---|---------------------|
| 0 | Byte aligned |
| 1 | Half-word aligned |
| 2 | Word aligned |
| 3 | Double-word aligned |

4	Cache line (2 ⁴ byte, 16-byte) aligned
5	Cache line (2 ⁵ byte, 32-byte) aligned
..	..
n	Cache line (2 ⁿ byte) aligned
..	..
12	Page (2 ¹² byte, 4096-byte) aligned

mode

Bits 8-11

This field specifies the type of the descriptor and its use. A value of zero for this field is used to match with any other value. The valid values for this field are:

0	Wild card
1	Parameter, passed by value
2	Parameter, passed by reference
3	Parameter, passed by value-result
4	Parameter, passed by name
5	Global/External/Module variable
6	Function return
7	Procedure
8	Parameter, passed by long reference

structure

Bits 12-15

This field specifies the structure for a particular item.

A value of zero for this field will match any other value.

The valid values for this field are:

0	Wild card
1	Simple variable
2	Array
3	Record or composite
4	Short pointer
5	Long pointer
6	String, zero terminated
7	String, with length word
8	Procedure
9	Function
10	Label

hash

Bit 16

This bit, when set, specifies that the `arg_type` field contains a hash value, rather than a predefined type.

arg_type

Bits 17-31

This field specifies the basic machine type for the particular item. If the item is a record, string, or procedure (structure field 3, 6, 7, or 8), the type will be void. Type 17 (structure or array) is allowed only when the structure field is type 2 (array), which describes an array or structure within an array. A value of zero for this field is used to match with any other valid value. The valid values for this field are:

0	Wild card
1	Void
2	Signed byte(8 bits)
3	Unsigned byte(8 bits)
4	Signed half-word(16 bits)
5	Unsigned half-word(16 bits)
6	Signed word(32 bits)
7	Unsigned word(32 bits)
8	Signed double-word(64 bits)
9	Unsigned double-word(64 bits)
10	Short real(32 bits)
11	Real(64 bits)
12	Long real(128 bits)
13	Short complex(64 bits)
14	Complex(128 bits)
15	Long complex(256 bits)
16	Packed decimal
17	Structure or array

Relocatable Libraries

A relocatable library is a file of one or more SOMs and the data structures needed to efficiently manage the SOMs. At the front of the file is a Library Symbol Table (LST) header. The header is used to identify the file structure and locate the major sub-structures of the library. In particular, the header contains the location of the symbol directory, the SOM directory, an optional area for auxiliary headers and the free space list.

Relocatable Libraries

Figure 4-17 on page 90 shows a general layout of a relocatable library. Note that each

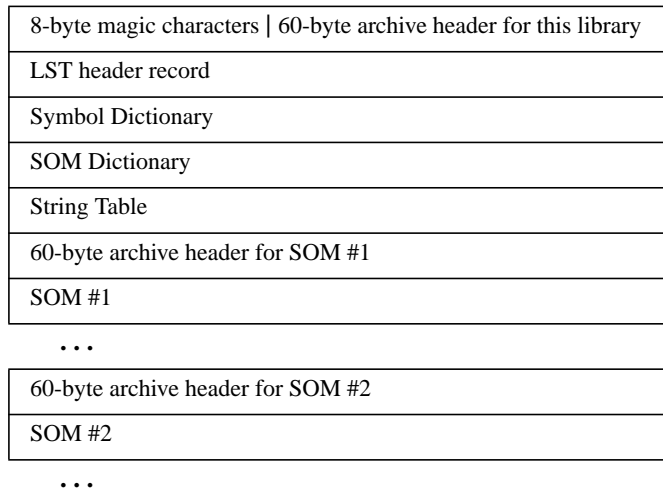


Figure 4-17: General Layout of a Relocatable Library

relocatable library is identifiable by the following 8-byte magic characters at the beginning of the file:

!<arch>\n

where\n is the new line, or the line feed character (hex 0A).

4.1 Archive Header

The archive header appears in front of every SOM in a library, and in front of the LST in a relocatable library. It defines the name of the SOM that follows and its length (in bytes), as well as several other fields that are used by the HP-UX archiver utility. See the HP-UX Users' Manual for further details.

```
struct ar_hdr { /* archive file member header - printable ascii */
    char    ar_name[16];          /* file member name - '/' terminated */
    char    ar_date[12];         /* file member date - decimal */
    char    ar_uid[6];           /* file member user id - decimal */
    char    ar_gid[6];           /* file member group id - decimal */
    char    ar_mode[8];          /* file member mode - octal */
    char    ar_size[10];         /* file member size - decimal */
    char    ar_fmag[2];          /* ARFMAG - string to end header */
};
```

Figure 4-18: Definition of Archive Header Record

ar_name

This field contains the name of the following SOM. The name is that of the “.o” file that was copied into the library. The name must be left justified in the field, terminated by a slash (“/”), and padded on the right with blanks.

For the archive header that precedes the LST, this field should contain a blank name (i.e., a single slash padded with 15 blanks).

If a member with a file name greater than 15 bytes exists within the archive, then the archive will also contain an additional special member to store the long file name string table. The special string table member also has a zero length name where `ar_name[0] == '/'` and `ar_name[1] == '/'`.

If a special string table exists, it will precede all non-special archive members. If both a symbol table member and a string table member exist then the symbol table member will always precede the string table member.

Each entry in the string table is followed by a slash and a new-line character. The offset of the table begins at zero. If an archive member name exceeds 15 bytes, then the `ar_name` entry in the members header does not hold a name, but holds the offset into the string table preceded by a slash.

For example, the member name *thisverylongfilename.o* contains `/0` for the `ar_name` value. This value represents the offset into the string table. The member name *yetanotherfilename.o* contains `/27` for the `ar_name` value. The long name string table would have the following format:

	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
0	t	h	i	s	i	s	a	v	e	r
10	y	l	o	n	g	f	i	l	e	n
20	a	m	e	.	o	/	\n	y	e	t
30	a	n	o	t	h	e	r	l	o	n
40	g	f	i	l	e	n	a	m	e	.
50	o	/	\n							

ar_date

This field contains the modification date and time of the following SOM or LST. It should be a decimal number (in ASCII characters) representing the number of seconds since January 1, 1970. The number should be left adjusted in the field and padded with blanks.

Relocatable Libraries

ar_uid

This field contains the user id of the owner of the following SOM or LST. It should be a decimal number (in ASCII), left adjusted and blank padded.

ar_gid

This field contains the group id of the owner of the following SOM or LST. It should be a decimal number (in ASCII), left adjusted and blank padded.

ar_mode

This field contains the mode bits for the following SOM or LST. It is an octal number, left adjusted and blank padded.

ar_size

This field contains the size of the following SOM or LST in bytes. It is an ASCII decimal number, left adjusted and blank padded. The size does not include the archive header.

ar_fmag

This field always contains the two ASCII characters “” and newline (or line feed, hex 0A).

4.2 Library Symbol Table Header Record

The Library Symbol Table always begins with a LST header record. For a relocatable library, the LST header begins immediately following the 8-byte archive “magic string” and the 60-byte archive header; the file name field in the archive header is empty (i.e., “/” followed by 15 blanks).

The first four bytes of the LST header will contain a number that identifies the file as a library format file (actually it has a sub-structure of two 16 bit numbers). In addition, the header is used to locate the major sub-structures of the library. In particular, the header contains the locations of the symbol directory, the SOM directory, the import table which is always set to zero, an optional area for auxiliary headers and the free space list.

system_id

Bits 0-15

This field is used to identify the architecture that this object file is targeted for. The PA-RISC 1.1 architecture *system_id* is 210 (hexadecimal).

```
struct lst_header {
    short int    system_id;
    short int    a_magic;
    unsigned int version_id;
    struct sys_clockfile_time;
    unsigned int hash_loc;
    unsigned int hash_size;
    unsigned int module_count;
    unsigned int module_limit;
    unsigned int dir_loc;
    unsigned int export_loc;
    unsigned int export_count;
    unsigned int 0 (import_loc);
    unsigned int aux_loc;
    unsigned int aux_size;
    unsigned int string_loc;
    unsigned int string_size;
    unsigned int free_list;
    unsigned int file_end;
    unsigned int checksum;
};
```

Figure 4-19: LST Header Definition

a_magic

Bits 16-31

This is a number that indicates the format and function of the file.

The magic number for a relocatable library is 0619 (hex), and for an executable library is 0104 (hex).

version_id

This is a number that is used to associate the LST with the correct definition of its internal organization. The value of the number will be an encoding of the date the LST version was defined.

The version ID can be interpreted by viewing it in decimal form and separating it into character packets of YYMMDDHH, where YY is the year, MM is the month, DD is the day, and HH is the hour.

The only version_id that is currently defined for use by conforming applications is 85082112.

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file_time

file_time is a 64 bit value that represents the time the file was last modified. *file_time* is actually composed of two 32 bit quantities where the first 32 bits is the number of seconds that have elapsed since January 1, 1970 (at 0:00 GMT), and the second 32 bits is the nano second of the second (which requires 30 bits to represent).

This value is independent of any modification time maintained by other subsystems (e.g. the file system). The use of this field is optional, but if it is not used it will be set to zero.

hash_loc

This is the LST relative byte offset to the LST directory hash table.

hash_size

This is the number of entries in the LST directory hash table.

Since the number of entries in the hash table is also the number of symbol lists in the directory, changing this value can affect the length of the symbol lists. The length of the symbol lists in turn, affects the overhead required to locate a symbol.

This value must be a number between 1 and $2^{31}-1$. The maximum size of the hash table is not constrained by the range of this variable, but by other resource constraints (e.g. file size).

module_count

This contains the index beyond the last used SOM directory entry.

module_limit

This is the maximum number of SOMs that can be in this file. Therefore, it is also the number of entries in the SOM directory table and the number of entries in the import table.

This value must be a number between 1 and $2^{31}-1$. The maximum value of this variable will be constrained by external resource constraints (e.g. system tables with SOM reference counts may use fixed length arrays).

dir_loc

This is the LST relative byte offset to the SOM directory.

export_loc

This is the LST relative byte offset to the export table. Not all exported symbols are necessarily contained within the bounds defined by *export_loc* and *export_count*, but most symbols should be. These fields are provided to allow programs that process the export table to read in the majority of the symbol table efficiently.

export_count

This is the number of symbols contained in the main portion of the export table. Overflow symbols (symbols allocated after this table is full) may be scattered throughout the LST.

import_loc

This is the LST relative byte offset to the import table. It is set to zero for relocatable library.

aux_loc

This is the LST relative byte offset to the auxiliary header area. If no auxiliary headers are present this variable will be set to zero.

aux_size

This is the size of the auxiliary header area in bytes. If no auxiliary headers are present this variable will be set to zero.

string_loc

This is the LST relative byte offset to the string area of the LST.

string_size

This is the size of the LST string area in bytes.

free_list

This is the LST relative byte offset to the first free area in the file.

file_end

This is the LST relative offset to the first byte past the end of the file.

checksum

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This field contains the value of all the other fields (i.e. not including this field) in the LST header record after they have been exclusive ORed together.

If (in the future) there is are undefined bits in this record they must be set to zero so that they do not affect the value of *checksum*.

4.3 Library Symbol Table Format

Data structures in relocatable library are designed to efficiently manage the SOMs in the library. The LST header record contains addresses and ranges of the sub-structures inside the library. Symbol dictionary and SOM dictionary are the two most important data structures of a relocatable library. describes a relocatable as a block diagram seen from the LST header record, the rest of this section describes the data structures in the relocatable library.

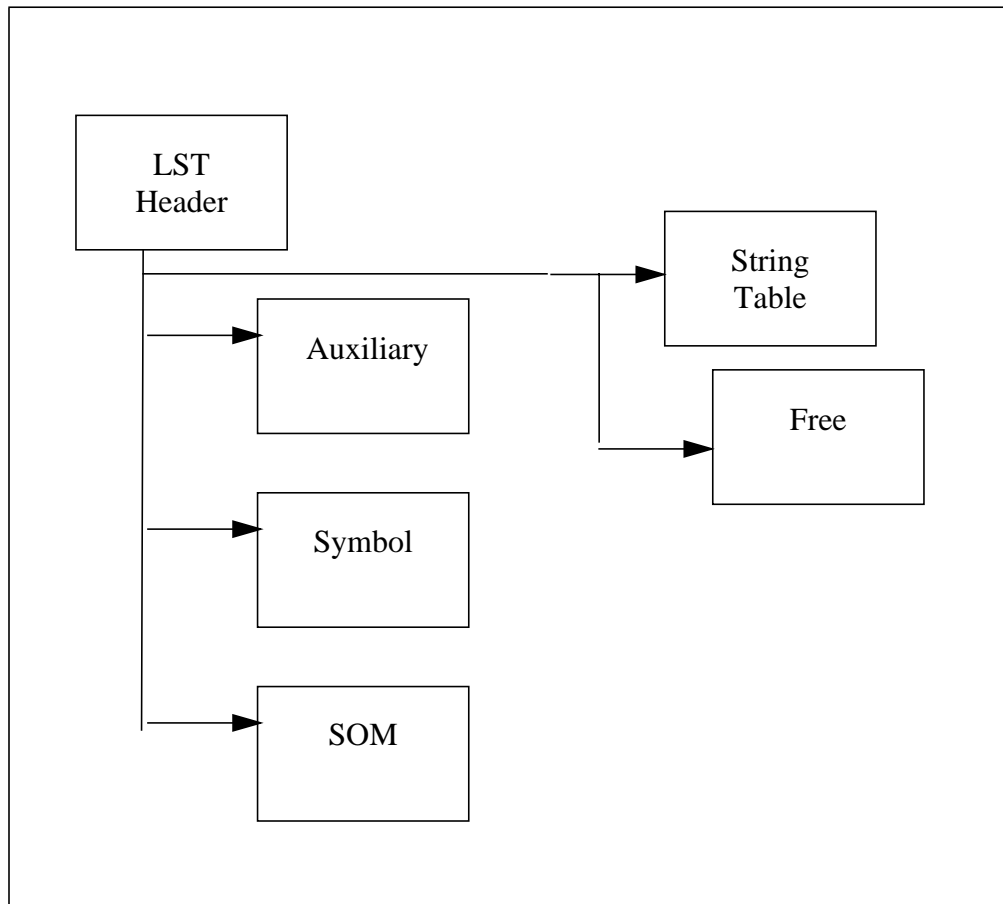


Figure 4-20: Block Diagram of a Relocatable Library

4.3.1 Symbol Directory

The symbol directory provides direct access to the definitions of all the exported symbols in the library. Each symbol definition, in turn, contains the index number of the SOM that exported the symbol. The SOM index can be used to index into the SOM directory or the import table (to locate the SOM or its import list).

The LST directory search algorithm will support more than one entry with the same name provided it can be qualified by its module name or by the general type of the symbol (i.e. code, data or stub).

The symbol directory is implemented as a hash table. Each entry contains an offset to a “hash bucket” which is a chained list of symbols that hash to the same index. If a bucket is empty, its hash table entry will be zero and the bucket will not exist. The number of entries in the hash table is contained in the variable *hash_size* in the LST header and the hash table location is contained in the variable *hash_loc*.

The hash function that is used for indexing the symbol directory is *hash_key* modulo *hash_size*. The hash key is a 4 byte variable where the first byte is the length of the symbol, the second byte of the key is the second character in the symbol, the third byte of the key is the next to last character in the symbol, and the last byte of the key is the last character in the symbol. If the symbol is only one character long, then that character is used as the second byte of the key and the last two bytes of the key are the same as the first two bytes. The result of the hash function is the hash table entry number, not the offset into the hash table.

Note

If a symbol is greater than 128 characters the first byte of the key will be the symbol length modulo 128 (256 is not used to eliminate any affect the sign bit may have on the modulo operation).

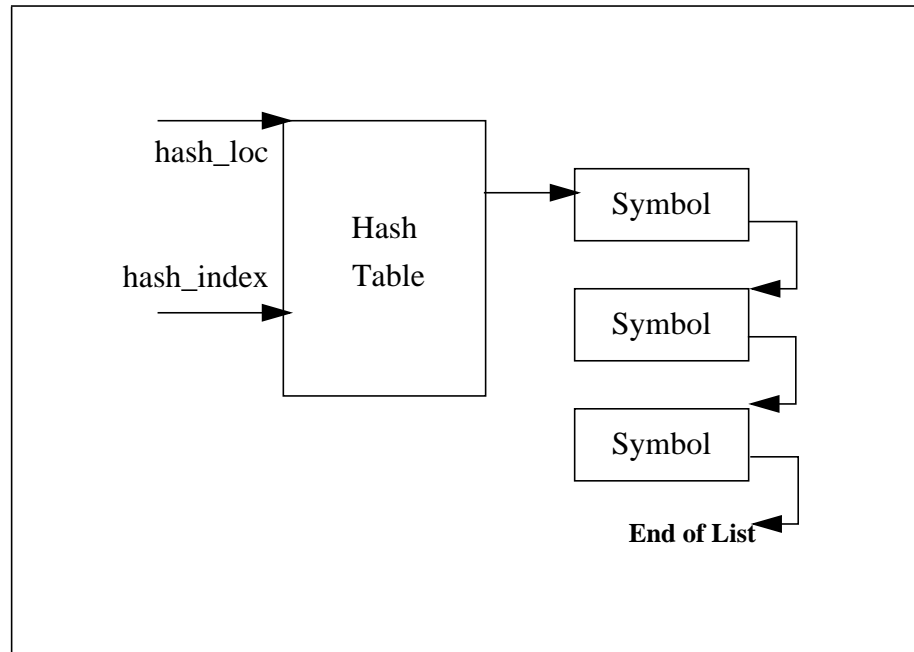


Figure 4-21: Block Diagram of Symbol Directory

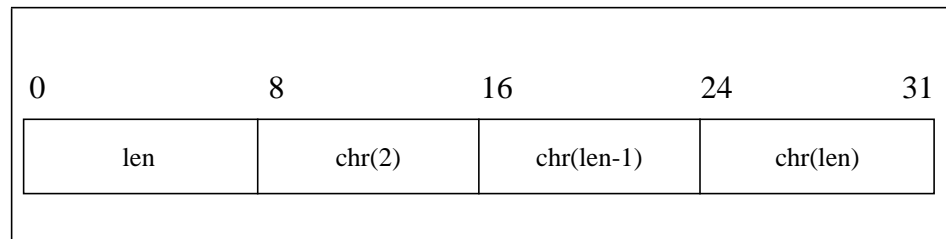


Figure 4-22: `hash_key` Format (symbol length > 1 byte)

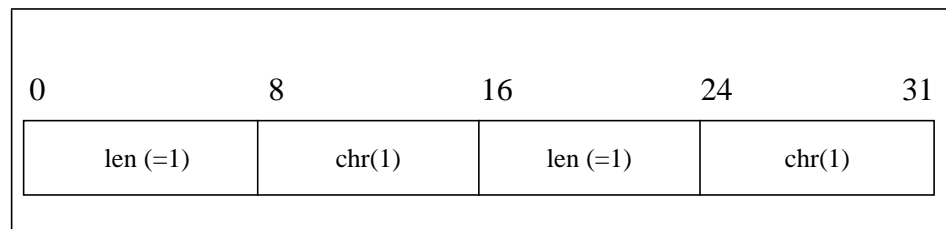


Figure 4-23: `hash_key` Format (symbol length = 1 byte)

A symbol record consists of a symbol header record and 0 to 255 argument descriptors constructed as shown in Figure 4-24.

Symbol records are used for the symbol entries in both the LST symbol directory and the import list symbol entries.

The symbol header contains the information needed to import or export a symbol when the file is loaded. The presence and number of argument descriptors is determined by a combination of the checking level and the number of arguments according to the following algorithm:

```
IF CHECKING_LEVEL < 3
THEN
  No argument descriptors present (except the symbol descriptor
  in the header).
ELSE
  There will be one descriptor for every argument passed.
```

The `lst_symbol_record` structure

In general, the `lst_symbol_record` structure is very similar to the `symbol_dictionary_record` of the SOM with the addition of the `som_index`, `symbol_key`, and `next_entry` fields to support symbol searching.

hidden

Bit 0

If this flag is set to one, it indicates that the symbol is to be hidden from the loader for the purpose of resolving external (inter-SOM) references. It has no effect on linking. This flag allows a procedure to be made private to its own executable SOM, although it has universal scope within that SOM.

secondary_def

Bit 1

If this flag is set to one, the symbol is a secondary definition and has an additional name that is preceded by “_”. The linker will ignore duplicate definitions involving secondary definitions. This field is implemented to support the external naming convention.

`symbol_type`

Bits 2-7

This field defines what type of information this symbol represents.

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```
struct lst_symbol_record {
    unsigned int hidden           : 1;
    unsigned int secondary_def   : 1;
    unsigned int symbol_type     : 6;
    unsigned int symbol_scope    : 4;
    unsigned int check_level     : 3;
    unsigned int must_qualify    : 1;
    unsigned int initially_frozen : 1;
    unsigned int memory_resident : 1;
    unsigned int is_common      : 1;
    unsigned int dup_common     : 1;
    unsigned int xleast         : 2;
    unsigned int arg_reloc      :10;
    union name_pt name;
    union name_pt qualifier_name;
    unsigned int symbol_info;
    unsigned int symbol_value;
    unsigned int symbol_descriptor;
    unsigned int reserved       : 8;
    unsigned int max_num_args   : 8;
    unsigned int min_num_args   : 8;
    unsigned int num_args       : 8;
    unsigned int som_index;
    unsigned int symbol_key;
    unsigned int next_entry;
};
```

Figure 4-24: LST Symbol Record Definition

See “symbol_type” on page 76.

symbol_scope

Bits 8-11

The scope of a symbol defines the range over which an exported symbol is valid, or the range of the binding used to import the symbol. In addition, this field is used to determine whether the symbol record is a import or export request.

See “symbol_scope” on page 77.

check_level

Bits 12-14

This value indicates how closely an import definition must match an export definition during linking.

See “check_level” on page 78.

must_qualify

Bit 15

If this bit is set to one, it indicates that there is more than one entry in the symbol directory that has the same name as this entry, and is the same generic type (i.e. code, data, or stub). Therefore, the qualifier name must be used to fully qualify the symbol.

If this flag is not set, the qualifier name will only be used to qualify the symbol name if the name it is being compared with is also fully qualified.

must_qualify is used for both import and export requests.

initially_frozen

Bit 16

If this flag is set to one it indicates that the code importing or exporting this symbol is to be locked in physical memory when the operating system is being booted.

memory_resident

Bit 17

If this field is set to one it indicates that the code that is importing or exporting this symbol is frozen in memory. This flag is used so that links between memory resident procedures can also be frozen in memory.

is_common

Bit 18

Specifies that this symbol is an initialized common data block. Each initialized common data block resides in its own subspace. For example, a Fortran initialized common declaration would produce a symbol of type data with the *is_common* flag set to one.

duplicate_common

Bit 19

If this flag is set to one, it specifies that this symbol name may conflict with another symbol of the same name if both are of type data. This is to facilitate the Cobol “com-

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mon” feature, since Cobol allows duplicate initialization of “common” data blocks. This flag would be set to one if the language allows duplicate initialization, otherwise it will be set to zero for symbols of type data.

xleast

Bits 20-21

This is the execution level that is required to call this entry point. This *xleast* level is placed in any XRT entry linked to this entry point. The *xleast* level will be checked by the Spectrum external procedure call primitive during execution.

See “xleast” on page 79.

arg_reloc

Bits 22-31

This field is used to communicate the location of the first four words of the parameter list, and the location of the function return value to the linker and loader. This field is meaningful only for exported ENTRY, PRI_PROG, and SEC_PROG symbols.

See “arg_reloc” on page 80.

name

This variable is used to locate the name of the symbol in the string table of the LST. Its value is the byte offset, relative to the beginning of the string table, to the first character (not the length) of the symbol name. *name* begins on a word boundary and is preceded by a 32 bit number that contains the number of characters in the name. The symbol is terminated with an 8 bit zero, but the terminator is not included as part of the length.

This variable may point to any location within the library file (although it must always be relative to the beginning of the LST string table). In particular, it may point to a string within a symbol string table belonging to one of the SOMs contained within the library. Although this may save space in the library file, it may have a negative impact on loader performance.

If this field is not used, this symbol will be treated as unnamed common data and must be of type *storage_request*. In this case, this field will be set to 0.

Note



Zero is not a legal string table offset since the first name in the string will be at offset 4.

qualifier_name

This variable is used to locate the name of a qualifier that may be user to further qualify this symbol. Its value is the byte offset, relative to the beginning of the LST string table, to the first character (not the length) of the qualifier name. The name begins on a word boundary and is preceded by a 32 bit number that contains the number of characters in the name. The name is terminated with an 8 bit zero, but the terminator is not included as part of the length.

This variable may point to any location within the library file (although it must always be relative to the beginning of the LST string table). In particular, it may point to a string within the symbol string table belonging to one of the SOMs contained within the library. Although this may save space in the library file, it may have a negative impact on loader performance.

If there is no qualifier, this field should be set to 0.

symbol_info

This field contains variant information depending on the scope of the symbol.

See “symbol_info” on page 82.

For MPE/iX, this field can contain new values if the shared_data bit in the LST SOM Auxiliary header is set:

For Data Universals, this field is set to the index of the subspace the symbol is defined in.

For Storage Universals, this field is set to the size of the storage request.

For Data Unsats, this field is set to the DXRT offset for the symbol (will be a negative offset).

symbol_value

This field contains the 32 bit value of this particular symbol. Depending on the type and scope of the symbol this field may have a different meaning.

See “symbol_type” on page 76.

For MPE/iX, this field can contain new values if the shared_data bit in the LST SOM Auxiliary header is set:

For Data and Storage Universals, this field is set to the DP-positive address of the symbol.

For Data Unsats, this field is set to the index of the subspace the symbol was referenced in.

symbol_descriptor

This is an argument descriptor for the procedure's type or the data type depending upon the type of the symbol (see argument descriptor definition, section 9.5).

See “symbol_desc” on page 84.

reserved

Bits 0-7

These bits are reserved for future expansion.

max_num_args

Bits 8-15

If *check_level* indicates that the number of arguments passed should be checked, the *num_args* field of the imported symbol (this field is in the exported symbol) must be less than or equal to this value.

See “max_num_args” on page 84.

min_num_args

Bits 16-23


If *check_level* indicates that the number of arguments passed should be checked, the *num_args* field of the imported symbol (this field is in the exported symbol) must be greater than or equal to this value.

See “min_num_args” on page 84.

num_args

Bits 24-31

This value is the number of arguments associated with the symbol.

Note  A procedure return value is NOT counted as an argument. The range of this variable is 0 to 255. Since this variable is not essential for linking or loading, compilers are not constrained to limit the number of parameters to 255. However, if this limit is exceeded, functions that use this field (e.g. parameter checking) may produce unpredictable results.

som_index

This value is an index that identifies the SOM that defines this symbol. The index can be used (when multiplied by the entry size) to index into the SOM pointer table that follows LST header and thereby, be used to locate the SOM.

The SOM index must be a number between 0 and value of the variable *module_limit-1* in the LST header.

This field is not used if the symbol is an import.

symbol_key

This is the 4 byte hash key for this symbol. The key is supplied to provide a quick check before comparing each byte of the symbol to determine if this is the correct symbol. Refer to “Symbol Directory” on page 97 for the hash algorithm to get this key.

next_entry

This value is the LST relative byte offset to the next entry in the list that contains this symbol. If this symbol is the last entry in the list, this field is set to zero.

Argument Descriptor Fields

See “Argument Descriptor” on page 85.

4.3.2 SOM Directory

The SOM directory is a table of entries that contain the location and length of every SOM within the file. Both the location and length are in bytes. The location is relative to the start of the file (not to the LST header), and points to the first byte of the SOM header (not to the archive header). The length does not include the archive header. The index of a SOM is used to index into the SOM directory.

Since each SOM will require a SOM directory entry, the variable *module_limit* in the LST header will contain the number of entries in the SOM directory. The table is pointed to by the variable *dir_loc*, which contains the LST header relative byte offset to the beginning of the SOM directory.

If a SOM does not exist, its entry in the SOM directory table will be set with a length of zero and the location set so that all bits are one.

Figure 4-25 shows the structure of the SOM directory.

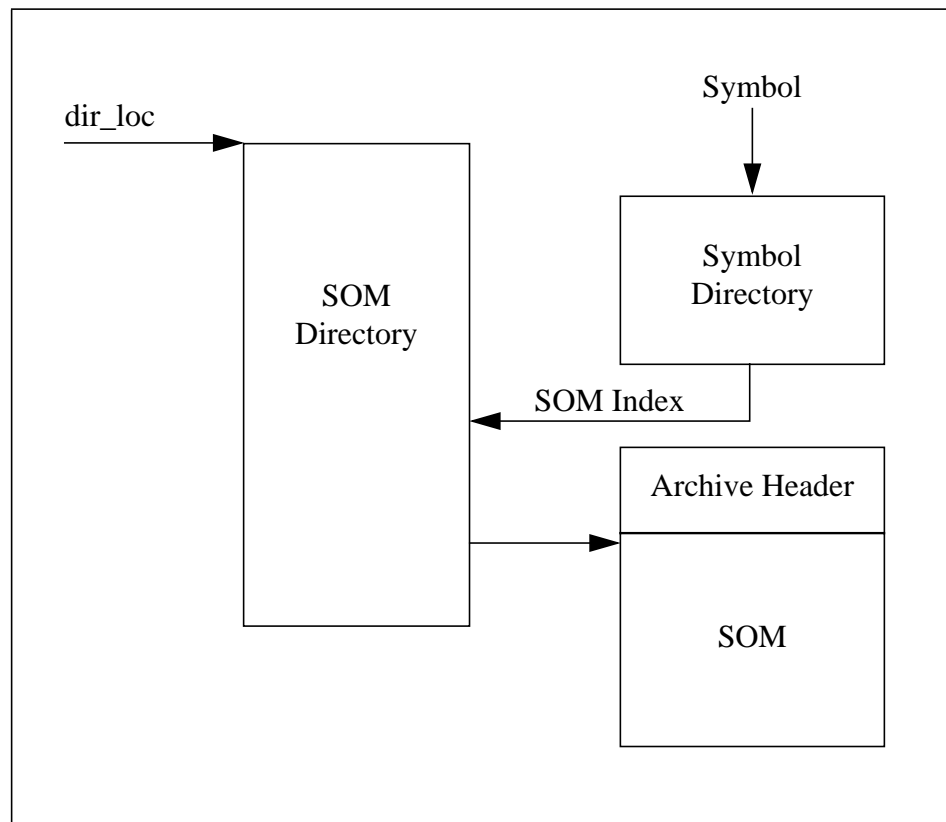


Figure 4-25: Structure of the SOM directory

4.3.3 Free Space List

A linked list of free areas within the file is maintained to support additions and deletions to an existing library file. The first free area is located by the variable *free_list*, which contains the LST header relative byte offset to the first free area. Free areas are kept track of by linking each area with a free link.

A free link is a three word link stored at the front of each free area. The first word is the LST header relative byte offset to the previous entry in the list, the second word is the

LST header relative byte offset to the next entry in the list, and the third word is the size of the current entry in bytes.

The previous link field in the first free link and the next link field in the last free link will be set to zero in order to mark the corresponding end of the free list. If the file has no free space, the free list pointer in the LST header will be set to zero.

Free space is always allocated from the free list in multiples of 4 bytes, beginning on a 4 byte boundary. If a free area is smaller than a free link it will be ignored and become lost space.

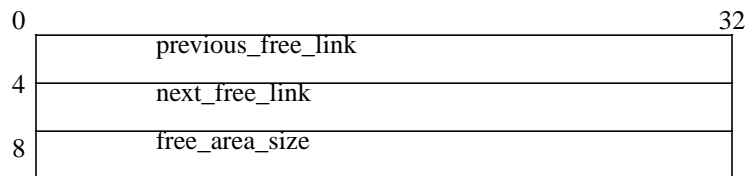


Figure 4-26: FREE_LINK Format

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5.1 Object File Header

The object file header must be present, and must be at the beginning of an executable file. Magic numbers reserved for executable file are 0x107, 0x108, and most commonly 0x10B. Refer to Section 3.1 on page 39 for a detail description of the object file header and Table 10 on page 41 for more information regarding the magic numbers.

5.2 Auxiliary Headers

If the auxiliary area is present it will contain one or more auxiliary header records. The first two words of every auxiliary header record (also known as *auxiliary header identifier*) will identify the type and length of the auxiliary header. A provision has been made to allow user defined auxiliary header records, however, there will be no centralized control over the assignment of user defined auxiliary header types.

The structure of the auxiliary header id defined below in Figure 5-27.

```
struct aux_id {
    unsigned int mandatory : 1;
    unsigned int copy : 1;
    unsigned int append : 1;
    unsigned int ignore : 1;
    unsigned int reserved : 12;
    unsigned int type : 16;
    unsigned int length;
};
```

Figure 5-27: Definition of the Auxiliary Header

mandatory

Bits 0

If this bit flag is set to one it indicates that this auxiliary header contains information that the linker must understand. If the type field is undefined for the version of the linker being used, it is an error.

copy

Bits 1

If this bit flag is set to one it indicates that this auxiliary header is to be copied without modification to any new SOM created from this SOM. Two auxiliary headers with the same type field should not be merged together but left as separate entries.

append

Bits 2

This bit flag is the same as the *copy* flag above except that multiple entries with the same type and append set of “action flags” (i.e., *mandatory*, *copy*, *append*, *ignore*) should be merged (concatenation of the data portion). The order of merging is not important.

ignore

Bits 3

If this bit flag is set to one it indicates that this auxiliary header should be ignored if its type field is unknown (i.e., do not copy, do not merge).

reserved

Bits 4-15

These bits are reserved for future use.

type

Bits 16-31

This field is a numeric value that defines the contents of the auxiliary header.

This field has a range of 0 to 65535. TYPE values less than 32767 are reserved for Hewlett-Packard defined auxiliary header record types. TYPE values greater than 32767 are user definable.

The currently defined auxiliary header type values are defined in Table 19 on page 111.

TABLE 19**Auxiliary Header Types**

Value	Usage
0	NULL
1	Linker footprint
2	Obsolete (used to be MEP/iX program)
3	Debugger footprint
4	Exec Auxiliary Header
5	IPL auxiliary header
6	Version string
7	MPE/iX program
8	MPE/iX SOM
9	Copyright
10	Shared Library version information
11	Product specifics
12	NetWare Loadable Module

length

This is the length of the auxiliary header in bytes. This value does NOT include the two word identifier at the front of the header.

An auxiliary header is not constrained to be an integral number of words in length. If it is not word aligned, the next auxiliary header or the end of the auxiliary header area will be placed at the next word boundary. The value of pad bytes are not defined. If two auxiliary headers are merged and the first is not word aligned, the next one will start on the very next byte.

Note



The mandatory, copy, append and ignore bits fields in the auxiliary header are not used consistently. Thus, users should consider these fields meaningless and unreliable.

5.2.1 Loader Auxiliary Headers

Currently there are three type of loader auxiliary headers:

- *HP-UX auxiliary header*: This auxiliary header contains run-time information used by the HP-UX loader to do a fast and efficient program load of an executable SOM. See Section 6.1 on page 117 for the detail structure of this auxiliary header.
- *MPE/iX program and SOM auxiliary headers*: These are auxiliary headers used by the MPE/iX loader to load program (executable SOM) or executable library. See Section 7.1 on page 149 for descriptions of these auxiliary headers.
- *IPL auxiliary header*: This auxiliary header is used to provide information that is needed for loading bootable utilities. All bootable utilities accessible through the LIF directory must have enough of a common format for IPL to load and launch utilities through a standard method. IPL may need to know the intended physical destination address for which the module was linked, as well as the entry point and the length of the image. This auxiliary header meets IPL's needs for loading and launching bootable utilities.

Following is the IPL auxiliary header definition and its fields description:

```
struct ipl_aux_hdr {
    struct aux_id header_id;
    unsigned int file_length;
    unsigned int address_dest;
    unsigned int entry_offset;
    unsigned int bss_size;
    unsigned int checksum;
};
```

Figure 5-28: Definition of the Auxiliary Header

header_id

This is the auxiliary header id for an IPL SOM. The type field of this id must be 5.

file_length

This field contains the length of the entire SOM including all headers.

address_dest

This field specifies the destination address at which the file should be loaded. For those utilities which are position independent, this field can be set to -1 and IPL will load it at the first available memory after IPL.

entry_offset

This field contains the file offset of the entry point relative to the beginning of the file.

bss_size

This field specifies the length of the un-initialized data area for the program. The loader must allocate this area immediately following the initialized data and fills it with zeroes.

checksum

This field contains the checksum of the entire file. The checksum is computed as the negated arithmetic sum of every word in the file (not including itself). In other words, the arithmetic sum of all the words in a valid file, including the checksum would be zero.

5.2.2 Other Auxiliary Headers

a. Linker footprint

The linker footprint auxiliary header is used to record the last time the linker modified this SOM or LST (whichever applies). The presence of the linker footprint is optional. Following is the linker footprint auxiliary header definition and its fields description:

```
struct linker_footprint {
    struct aux_id header_id;
    char product_id[12];
    char version_id[8];
    struct sys_clock htime;
};
```

Figure 5-29: Definition of the Linker Footprint Auxiliary Header

header_id

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This is the auxiliary header id for the linker footprint. The type field of this id must be 1.

product_id

bits 0--95

This twelve character array contains the HP product identification number of the linker that last modified this SOM or LST.

version_id

This twelve character array contains the HP version number of the linker that last modified this SOM or LST.

htime

The htime is a 64 bit value that represents the time the file was last modified by the linker. The htime is actually composed of two 32 bit quantities where the first 32 bits is the second of the century (maximum value is 3162240000-1, which requires 32 bits to represent) and the second 32 bits is the nano second of the second (which requires 30 bits to represent).

This value is independent of any modification time maintained by other subsystems (e.g. the file system). The use of this field is optional, but if it is not used it will be set to zero.

b. Debugger_footprint

The debugger footprint auxiliary header is used to record the last time the debugger modified this SOM or LST (whichever applies). The presence of the debugger footprint is optional. Following is the debugger footprint auxiliary header definition and its fields description:

```
struct debugger_footprint {
    struct aux_id header_id;
    char debugger_product_id[12];
    char debugger_version_id[8];
    struct sys_clock debug_time;
};
```

Figure 5-30: Definition of the Debugger Footprint Auxiliary Header

header_id

This is the auxiliary header id for the debugger footprint. The type field of this id must be 3.

debugger_product_id

bits 0--95

This twelve character array contains the HP product identification number of the debug program that last modified this SOM or LST.

debugger_version_id

This eight character array contains the HP version number of the linker that last modified this SOM or LST.

debug_time

The *debug_time* is a 64 bit value that represents the time the file was last modified by the debugger . The *debug_time* is actually composed of two 32 bit quantities where the first 32 bits is the second of the century (maximum value is 3162240000-1, which requires 32 bits to represent) and the second 32 bits is the nano second of the second (which requires 30 bits to represent).

This value is independent of any modification time maintained by other subsystems (e.g. the file system). The use of this field is optional, but if it is not used it will be set to zero.

c. Version String Auxiliary Header

The *Version_String* auxiliary header can be used for any user-defined string. The length of the string is essentially unbounded. The string must be null-terminated. The *string_length* field contains the length of the user-defined version string, not including the null () terminator. (Note that the length field in *aux_header_id* includes both the *string_length* field and the padding bytes of the string.)

Additional auxiliary header types for other kinds of user strings may be added in the future, rather than reserving one auxiliary header type for all such user strings.

Following is the version string auxiliary header definition. Note that the type of the *header_id* field must be 6:

```
struct version_string_aux_hdr {
    struct aux_id header_id;
    unsigned int string_length;
    char user_string[1];
};
```

Figure 5-31: Definition of the Version String Auxiliary Header

Executable Files

5.3 Symbol Table

The symbol table (also known as symbol dictionary) has the same format as the symbol table in the relocatable object file. Please refer to Section 3.7 on page 73 for detail descriptions of the symbol table.

5.4 Stack Unwind Table

Each entry in the unwind table contains two addresses which describe a region of code, typically the starting and ending address of a procedure. Each entry also contains an *unwind descriptor* which holds information about the frame and register usage of that region. When an unwind operation is required, the unwind table is searched to find the region containing the instruction where the exception or interrupt occurred.

Please refer to the “Stack Unwind Library” chapter for more information on unwind.

5.5 Recover Table

The recover table has three words entries that contains the beginning and the end addresses of the unwind region and the resume address. Please refer to the “Stack Unwind Library” chapter for more information on unwind and recover.

5.6 Auxiliary Unwind Table

The auxiliary unwind table is implemented to mainly support the Ada trace back mechanism. The auxiliary unwind table parallels to the unwind table and contains four words entries that describe information on the compilation unit, the scope name, the scope type and the address of the line table. Please refer to the “Stack Unwind Library” chapter for more information on Ada procedure trace back tables and mechanism.

6.1 HP-UX Auxiliary Header

The exec auxiliary header (also known as the 'HP-UX' auxiliary header within Hewlett-Packard) is used to contain run-time information for executable SOM files which conform to the notion of a 32-bit local address space. This header is filled in by the linker and is used by the system loader. The exec auxiliary header must immediately follow the SOM header record. This auxiliary header contains all the information needed by the system loader to perform fast and efficient program load of an executable SOM. All fields are mandatory and are expected to be filled in by the linker.

The Exec Auxiliary Header is required in all incomplete executables and relocatable objects. Figure 6-32 on page 117 defines the Exec Auxiliary Header.

```
struct som_exec_auxhdr {
    struct aux_id som_auxhdr;    /* som auxiliary header */
    long exec_tsize;           /* text size in bytes */
    long exec_tmem;            /* offset of text in memory */
    long exec_tfile;           /* location of text in file */
    long exec_dsize;           /* initialized data */
    long exec_dmem;            /* offset of data in memory */
    long exec_dfile;           /* location of data in file */
    long exec_bsize;           /* uninitialized data (bss) */
    long exec_entry;           /* offset of entrypoint */
    long exec_flags;           /* loader flags */
    long exec_bfill;           /* bss initialization value */
};
```

Figure 6-32: Definition of Exec Auxiliary Header

som_auxhdr

This field contains the auxiliary header identifier for a program file. The type field of this header id must be 4.

exec_tsize

This field specifies the text (code) size in bytes (does not have to be a multiple of 4 Kbytes). The actual size of the text section in the file must be a multiple of 4 Kbytes and can be padded with zeroes to make it a multiple of 4 Kbytes.

exec_tmem

This field specifies the space-relative byte offset of text (code) in memory. The address must be page aligned.

exec_tfile

This field contains the location of the text (code) in the file. The value will be a byte offset relative to the first byte of the SOM.

exec_dsize

This field specifies the size in bytes of the initialized data (does not have to be a multiple of 4 Kbytes). The actual size of the data section in the file must be a multiple of 4 Kbytes and can be padded with zeroes to make it a multiple of 4 Kbytes.

exec_dmem

This field specifies the space-relative byte offset of data in memory. The address must be 4 Kbyte aligned.

exec_dfile

This field contains a location of the data in the file. The value is a byte offset relative to the beginning of the SOM.

exec_bsize

This field contains the size in bytes of the uninitialized data in the file.

exec_entry

This field contains the space-relative byte offset of the main entry point for this file.

exec_flags

This field contains a series of one-bit flags for use by the loader.

The low-order bit (bit 31) is defined to indicate whether nil-pointer dereferences should be trapped by the operating system. If the bit is set, dereferences of nil pointers will be trapped; if the bit is not set, dereferences of nil pointers will return 0.

Bit 30 indicates that external millicode (if implemented) is used by this program file.

Bit 29 indicates dynamically linked (incomplete) executables (for example, an executable linked with shared libraries).

Bit 28 indicates executable built with the aid of profile information.

The remaining bits are reserved for future use.

exec_bfill

This field specifies the value to which uninitialized data (BSS) should be initialized.

6.2 Program Startup

All programs must be linked with the relocatable startup object *crt0.o*. This object code defines entry points, sets up data pointer register (DP), initializes program variables, and checks for dynamic (shared) libraries.

Table 7 on page 34 summarizes program variables that are defined by *crt0*, and Table 8 on page 35 lists the register definition at process initialization.

Here is how shared libraries work at run time: Startup code in */usr/ccs/lib/crt0.o* invokes the dynamic loader, */usr/lib/dld.sl*, which in turn maps all the shared libraries, binds all the symbols, and applies all the dynamic relocations, then branches back to the invoking executable file.

The magic numbers and aux headers are the same between an incomplete and a fully bound executable. To decide whether to invoke the dynamic loader, *crt0* looks at the first word in the TEXT space, found by looking at `__text_start` symbol created by the linker. If this matches the value of the `DL_HEADER_VERSION_ID` or `DL_HEADER_VERSION_ID2` in `<shl.h>`, then the executable is an incompletely bound program file.

crt0 will then map *dld.sl*. First it opens the file; then it reads the text, data, and bss sizes from the HP-UX aux header; then it calls `mmap(2)` to map all three sections into memory. Finally, it invokes the entry point for *dld.sl* indirectly, by adding the `exec_entry` field of the aux header to the mapped address of *dld*'s text start, and makes an indirect function call to this point.

Several parameters are sent to *dld*'s main entry point in this call. These include the starting and ending addresses of *dld*'s text, data, and bss, as well as the name of the program file, its starting and ending addresses, and a value that *dld* will use as its stack location.

Since *dld* runs before the program file itself, and it uses the stack as pointed to by `%r30` for local variables just as any code, by the time the program file routines are entered, the stack is likely to be non-zero -- that is, dirty. This has caused no small concern to various (poorly-written) applications that expect their local variables to start out with a zero

initial value. In order to prevent a dirty stack on program entry, dld bumps the stack by 8K bytes on entry, and uses this value as its starting stack address.

Actually, crt0 bumps the stack by this new value before it invokes dld, then restores the original SP value upon dld's return. But this stack location is sent to dld so that it can use the same minimum address when it is invoked during program execution: specifically, when deferred binding is on and a procedure call must be bound at first invocation.

6.2.1 Sample Assembly Listing of crt0 code

```
#define etext _etext
#define monitor _monitor

;;; these constants come from /usr/include/sh1.h
DL_HDR_VERSION_ID .equ 89060912
DL_HDR_VERSION_ID2 .equ 93092112

#include <machine/break.h>

.space$TEXT$
.subspa$UNWIND_START$,QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=56
.subspa$UNWIND$MILLICODE$,QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=62
.subspa$CODE$
.import __text_start, data
.proc
.callinfo SAVE_SP,FRAME=128
.export$$START$,entry
.entry
$START$
ldil L'$global$,dp ;Initialize the global data
ldo R'$global$(dp),dp ; pointer
ldo 128(sp),sp ;Allocate frame, marker, and argument
depi 0,31,3,sp ; list and doubleword align sp
ldw 0(arg1),r3 ;Get argv[0]...
addil L'$ARGV-$global$,dp
stw r3,R'$ARGV-$global$(r1) ; and stash it away

addilL'_environ-$global$,dp ; Initialize _environ
stwarg2,R'_environ-$global$(r1) ; so getenv(3) works

; Floating point status register initialization.
; We use the dld ltptr location at dp-4 as a scratch area

fstws fr0,-4(0,dp)
ldil LR'_fp_status,r5 ;symbol value set by ld +FP option
ldo RR'_fp_status(r5),r5 ;default value is 0
ldw -4(dp),r4
orr4,r5,r5 ;we OR into the current status
stwr5,-4(dp) ;store result into scratch area

addil L' DL_HDR_VERSION_ID2, %r0 ; load constant here to avoid
ldo R' DL_HDR_VERSION_ID2 (%r1), %r19 ; interlock from store

fldws-4(dp),fr0; load the fp status register from the
; scratch area we saved it in
```



```
; This is the documentation of the structure pointed to by
; %arg3. Learn it, know it, live it. Its definition lives in
; /usr/include/machine/cpu.h, the structure name is keybit_info.
; +-----+
; | cpu_version |
; +-----+
; | FP status reg after copr 0,0 |
; +-----+
; | number of words of keybits |
; +-----+
; | Keybits_1 |
; +-----+
; | additional opt. keybits |
; | . |
; | . |
; | . |
; +-----+
; | -1 |
; +-----+
; The -1 marks the end of the list. This way, we can extend this
; structure in the future, and add fields besides keybits if we want.
.import _is_89_0
copy %r26, %r4 ; save arvc, argv and envp
copy %r25, %r5
copy %r24, %r6
copy %r23, %r7 ; save keybits pointer
ldil L'_is_89_0,r31 ; Make sure we are not on a 8.0 or 9.0 system
ble R'_is_89_0(sr4,r31) ; before we de-reference the keybits pointer
copy r31,rp
copy %r4, %r26 ; restore arvc, argv and envp
copy %r5, %r25
copy %r6, %r24
copy %r7, %r23 ; restore keybits pointer

comb,<>,n %ret0, %r0, L$0002 ; If return value is non-zero, we are
; on a 9.0 system, and should not
; de-reference the keybits pointer.

; Even though we check to make sure we are not on 8.0 or 9.0
; above, still validate pointer in case we are running on a pre-8.0
; system.
; The pointer validation assumes that exec will always place
; the CPU_INFO structure higher on the stack than envp.
comb,>>,n %arg3,%sp,L$0002 ; If passed_ptr > sp, it must be a
; bogus pointer.
comb,<<,n %arg3,%arg2,L$0002 ; If passed_ptr < envp, it must be a
; bogus pointer.

; We have a valid pointer
ldw (%arg3),%r5 ; Get first word of structure (cpu_version)
addil L'_CPU_REVISION-$global$,dp ; Store _CPU_REVISION info
stw %r5,R'_CPU_REVISION-$global$(r1) ; passed in from the kernel

ldw 12(%arg3),%r5 ; Get first word of keybits (key_bits[0])
addil L'_CPU_KEYBITS_1-$global$,dp ; Store key bits loaded from stack
stw %r5,R'_CPU_KEYBITS_1-$global$(r1) ; into _CPU_KEYBITS_1

; Now we set up the _FPU_MODEL and _FPU_REVISION globals with
; the data from the fpu_info field of the keybit_info structure
```

HP-UX Specifics

```
ldil L'_FPU_MODEL,%r4 ; put the address of _FPU_MODEL
ldo R'_FPU_MODEL(%r4),%r4 ; in %r4
ldw 4(%arg3),%r5 ; put copr 0,0 results into %r5
extru %r5,15,6,%r6 ; put the fpu model into %r6
sth %r6,(%r4) ; store the fpu model in _FPU_MODEL
extru %r5,20,5,%r6 ; put the fpu revision into %r6
sth %r6,2(%r4) ; store the revision _FPU_REVISION
L$0002
```

```
; Shared Library support -- mapping dld.sl
; check a.out file for dl_header
; dl_header is the first thing in the text space.
```

```
ldil L'__text_start,r1 ; dl_header.hdr_version
ldw R'__text_start(r1),r31
addil L'DL_HDR_VERSION_ID,%r0 ; start loading old version number
combt,=,n %r19,%r31,L$0004 ; if new version, go map dld now
ldo R'DL_HDR_VERSION_ID (%r1), %r19
combf,=,n %r19,%r31,L$0001 ; if not old version, skip mapping
L$0004
```

```
.import __map_dld
.import __stack_zero, absolute
; map_dld
; set sp to skip nominal 8K to maintain clean stack (dld uses sp+8k
; for sp) - actually linker-set value of "__stack_zero", setable
; with ld -FS <val>, where val is in decimal bytes.
copy sp, %r7 ; save sp
addil LR'__stack_zero, sp
ldo RR'__stack_zero(%r1),sp
copy %r26, %r4 ; save arvc, argv and envp
copy %r25, %r5
copy %r24, %r6
copy sp, arg1 ;pass dld's sp as 2nd arg
;envp is already in place for 3rd arg
copy %r7, arg3 ;pass in orig user sp (saved in gr7) as 4th
arg
copy r3, arg0 ;pass in program file name as 1st arg
ldil L'__map_dld,r31
ble R'__map_dld(sr4,r31)
copy r31,rp

copy %r4, %r26 ; restore arvc, argv and envp
copy %r5, %r25
copy %r6, %r24
copy %r7, sp ; restore original sp.
```

```
L$0001
```

```
.import _start
.call
stw r0,-4(sp) ;Mark last stack frame (null
fm_esp)

addil L'_environ-$global$,dp ; Pass in the (possibly)
ldw R'_environ-$global$(r1),arg2 ; updated value of _environ
ldil L'_start,r31
ble R'_start(sr4,r31)
copy r31,rp
$START_RTN$
```

```
break BI1_AZURE,BI2_AZURE_CRT0      ;Should never get here
.procend

.proc                                ; so a profiling SOM will load with this.
.callinfo                            ;
.export _mcount,entry               ;
.entry
_mcount
.exit
bv,n(rp)
nop
.procend

.proc
.callinfo
.export _clear_counters,entry
.entry
_clear_counters
.exit
bv,n(rp)
nop
.procend

.proc                                ; _sr4export serves as target of calls
.callinfo export_stub               ; from dynamically-loaded code to the
.export _sr4export,code             ; basis code.
_sr4export
ble 0(sr4,r22)                       ; branch to real entry point
copy r31,rp                          ; ...return link in rp
ldw -24(sp),rp                       ; restore return link from stack
ldsld (rp),r1; get space id for return
mtsp r1,sr0
be,n 0(sr0,rp); return
nop
.procend

.proc                                ; __d_trap is used by HP/PAK
.callinfo
.export __d_trap,entry
.entry
__d_trap
.exit
bv,n(rp)                             ; just return
nop
.procend

.subspa $UNWIND_START$               ;Declare subspace start symbols
.export $UNWIND_START, data
$UNWIND_START
.subspa $UNWIND_END$,QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=72
.export $UNWIND_END, data
$UNWIND_END

.subspa $RECOVER_START$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=73
.export $RECOVER_START, data
$RECOVER_START
.subspa $RECOVER$MILLICODE$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=78
.subspa $RECOVER$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=80
.subspa $RECOVER_END$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=88
.export $RECOVER_END, data
```

HP-UX Specifics

```
$RECOVER_END

.space $PRIVATE$

.subspa $GLOBAL$
.export $global$
.export __dld_flags, data
.export __dld_hook, data
.export __dld_list, data

; NOTE: We must always make sure that $global$ is double-word aligned

__dld_list
.WORD 0 ; holds address of pointer to dld library handle list
; provided to support core file debugging.

__dld_hook
.WORD 0 ; word to hold label of routine for dld to call back
; into the a.out so xdb can hit known breakpoint.

__dld_flags
.WORD 4 ; Bit vector for xdb or other external process to
; pass flags to crt0.o/dld.sl. All writes to
; this flag must OR in the previous contents.
;
; Meaning of bits
; 0 - if set -> dld should map libraries private
; 1 - if set -> dld should call hook routine
; 2 - if set -> dld allowed to store address
; of pointer to dld library handle list at
; location __dld_list
; 3 - if set and hook routine valid, dld should call
; hook routine during BOR (bind on reference).
; Dynamically changed.
;
; All other bits must be zero until defined later.

.WORD 0 ; leave word at dp-4 to hold LT-pointer of dld.sl
; This location is also used as a scratch area
; by startup code in crt0
;

$global$ ;Contents of dp for HP-UX

;DO NOT PUT ANY DATA ON THIS SIDE OF $global$ - YOU WILL FOUL UP PASCAL's
;SCHEME FOR ALLOCATING THEIR MAIN PROGRAM GLOBALS HERE INSTEAD OF ON THE
;STACK

; Define data sym to hold the system id of final executable
; __SYSTEM_ID will be defined by ld(1)
.subspa $DATA$
.import __SYSTEM_ID,ABSOLUTE
.align 8
__SYSTEM_ID
.word __SYSTEM_ID
.export __SYSTEM_ID

__FPU_MODEL
.half 0
; YOU MUST KEEP __FPU_REVISION IMMEDIATELY AFTER __FPU_MODEL, SINCE THE
; CODE IN CRT0.S RELIES ON THIS!!!!!!!!!!!!!!
__FPU_REVISION
```

```
.half 0
.export _FPU_MODEL,data
.export _FPU_REVISION,data

_CPU_REVISION
.word 0
.export _CPU_REVISION,data

_CPU_KEYBITS_1
.word 0
.export _CPU_KEYBITS_1,data

_environ
environ
.word 0
.export _environ,data
.export environ,data,sec_def

.import _fp_status,ABSOLUTE

__d_trap_fptr
.word P'__d_trap
.export __d_trap_fptr,data

.subspa $PFA_COUNTER$,QUAD=1,ALIGN=4,ACCESS=0x1f, SORT=8
.export $ARGV
$ARGV .word 0;Copy of argv[0]
.align8
.export $PFA_C_START
$PFA_C_START
.subspa $PFA_COUNTER_END$,QUAD=1,ALIGN=4,ACCESS=0x1f, SORT=10
.export $PFA_C_END
$PFA_C_END

.end
```

6.3 Shared Libraries

6.3.1 Shared Library Memory Model

The HP-UX shared memory starts at hexadecimal address 0x80000000 and ends at 0xFFFFFFFF (third and fourth quadrant) with the upper 256 megabytes of the fourth quadrant reserved for system use. The above address range is mapped into memory using space register SR6 and SR7.

6.3.2 Linkage Table

The Linkage Table is located in the \$DATA\$ space of a shared library and/or program file. It is divided into two parts: a Data Linkage Table (DLT) for data references and a Procedure Linkage Table (PLT) for procedure calls. The linkage table is used as a branch table to handle indirect procedure and data references. The DLT contains an entry for each data or procedure symbol that is accessed via the DLT_REL fixup request. The

PLT contains an entry for each unresolved procedure symbol referenced within the object.

6.3.2.1 Data Linkage Table

Each DLT entry is a single word which contains a pointer to the actual data item referenced via a T' fixup; this pointer value is assigned by the dynamic loader, after mapping the shared library. Since T' references to data items go directly through the DLT (rather than a stub), the register r19 is reserved to point to the middle of the DLT, to provide maximum addressability for short load instructions. The linker allocates r19-relative offsets for each DLT entry, and uses those offsets when rewriting code that accesses data with the DLT_REL fixup.

6.3.2.2 Procedure Linkage Table

The Procedure Linkage Table (PLT) is created for both shared libraries and incomplete executables, and is placed immediately following the DLT (if one exists). A PLT entry is created for each unique procedure symbol imported by the object. The linker creates an import stub for each unresolved procedure and redirects the reference to the import stub created, which uses the address in the PLT entry to branch to the actual procedure. In PIC code (shared libraries), import stubs use a long r19-relative offset to access an entry in the PLT; therefore, PLT entries are not constrained to be a fixed distance from r19 (as the DLT references are). For non-PIC code (incomplete executables), register r19 is not reserved, and import stubs will be able to access the PLT entries directly (because the executable program knows where its Linkage Table is allocated: right before DP). Each PLT entry consists of two words: the first word contains the address of the target procedure, and the second word contains the r19 (linkage table pointer) value required by the procedure being called.

```
struct PLT_entry {
    int proc_addr;      /* address of procedure */
    int ltptr_value;   /* value of r19 required for this procedure */
};
```

Figure 6-33: PLT Entry Definition

proc_addr

This field contains the address of the procedure to be branched to, taken from the export table of a shared library or program file. It can also be initialized to the address of the bind on reference (BOR) dynamic loader routine that will bind the procedure upon first reference.

ltptr_value

If *proc_addr* points to the BOR routine, this holds the import index of the code symbol. Once the actual destination address has been calculated and stored in *proc_addr*, this field holds the Linkage Table pointer value for the callee routine.

6.3.3 The DL Header and Other Tables

The DL header appears in every shared library and in incomplete executables (program files linked with shared libraries--may contain unsatisfied symbols which will be satisfied at run time by the dynamic loader). It is assumed to be at offset 0 in the \$TEXT\$ space. It defines fields used by the dynamic loader and various other tools when attaching the shared libraries at run time. The header contains information on the location of the export and import lists, the module table, the linkage tables, as well as the sizes of the tables.

Figure 6-34 on page 128 defines the `dl_header` structure. The followings are its fields description:

hdr_version

This field is used to denote the version of the DL header. The old value was set to the decimal number “89060912” prior to 10.0. The new value is “93092112”.

ltptr_value

This field is the data-relative offset of the Linkage Table pointer (GR 19 for shared libraries, GR 27 for incomplete executables). The linkage table pointer is used by the dynamic loader to access the Data Linkage Table and Procedure Linkage Table entries at load time so it can bind symbols and attach shared libraries. All data references and PIC code in a shared library must go indirectly through the linkage pointer.

shlib_list_loc

This field is the text-relative offset of the shared library list. The shared library list is a list of shared libraries that the given file depends on for symbol bindings. If the shared library list in a shared library is present, the shared library is said to “depend” on the libraries in the shared library list.

shlib_list_count

This field is the number of entries in the shared library list.

import_list_loc

This field is the text-relative offset of the import list. The dynamic loader searches the import list and binds each entry in the list at load time.

import_list_count

This field is the number of entries in the import list.

hash_table_loc

This field is the text-relative offset of the hash table.

hash_table_size

This field is the number of slots used in the hash table.

```

struct dl_header {
    int          hdr_version;          /* header version number */
    int          ltptr_value;          /* data offset of LT pointer (R19) */
    int          shlib_list_loc;       /* text offset of shlib list */
    int          shlib_list_count;     /* count of items in shlib list */
    int          import_list_loc;      /* text offset of import list */
    int          import_list_count;    /* count of items in import list */
    int          hash_table_loc;       /* text offset of export hash table */
    int          hash_table_size;      /* count of slots in export hash table */
    int          export_list_loc;      /* text offset of export list */
    int          export_list_count;    /* count of items in export list */
    int          string_table_loc;     /* text offset of string table */
    int          string_table_size;    /* length in bytes of string table */
    int          dreloc_loc;           /* text offset of dynamic reloc records */
    /*
    int          dreloc_count;         /* number of dynamic relocation
records */
    int          dlt_loc;              /* data offset of data linkage table */
    int          plt_loc;              /* data offset of procedure linkage
table */
    int          dlt_count;            /* number of dlt entries in linkage table
*/
    int          plt_count;            /* number of plt entries in linkage table
*/
    short        highwater_mark;      /* highest version number seen in lib or
in shlib list*/
    short        flags;                /* various flags */
    int          export_ext_loc;       /* text offset of export extension tbl */
    int          module_loc;           /* text offset of module table*/
    int          module_count;         /* number of module entries */
    int          elaborator;           /* import index of elaborator */
    int          initializer;          /* import index of initializer */
    int          embedded_path;        /* index into string table for search
path */
                                        /* index must be > 0 to be valid */
    int          initializer_count;    /* number of initializers declared*/
    int          reserved3;            /* currently initialized to 0 */
    int          reserved4;            /* currently initialized to 0 */
};

```

Figure 6-34: Definition of DL Header

export_list_loc

This field is the text-relative offset of the export list.

export_list_count

This field is the number of export entries.

string_table_loc

This field is the text-relative offset of the string table.

string_table_size

This field is the length of the string table.

dreloc_loc

This field is the text-relative offset of the dynamic relocation records. Dynamic relocation records are built for each data location initialized with the address of a function or data item.

dreloc_count

This field is the number of dynamic relocation records generated.

dlt_loc

This field is the offset in the \$DATA\$ space of the Data Linkage Table. The Data Linkage Table consists of one word entries for each static data item that is referenced by Position Independent Code (PIC).

plt_loc

This field is the offset in the \$DATA\$ space of the Procedure Linkage Table. The Procedure Linkage Table contains entries for each unresolved procedure call in a shared library or for calls to exported procedure symbols. The dynamic loader binds procedure symbols at run time.

dlt_count

This field is the number of entries in the DLT.

plt_count

This field is the number of entries in the PLT.

highwater_mark

Bits 0-15

The highest version number of any symbol defined in the shared library or in the set of highwater marks of the shared libraries in the shared library list. For a program file, a highwater version of each library linked with the program is recorded. *highwater_mark* is used by the dynamic loader at run time to determine which shared library symbol is to be used for binding the program file's symbol reference.

flags

Bits 16-31

This field is used to specify the `dl_header` flags, such as to denote if initializers or elaborators have been seen in the libraries. The valid values for this field are:

```
#define ELAB_DEFINED 1    /* an elaborator has been defined for this library */
#define INIT_DEFINED 2    /* an initializer has been defined for this library */
#define SHLIB_PATH_ENABLE 4 /* allow search of SHLIB_PATH at runtime */
#define EMBED_PATH_ENABLE 8 /*allow search of embed path at runtime*/
#define SHLIB_PATH_FIRST 16 /* search SHLIB_PATH first */
#define SEARCH_ALL_STORS 32 /* search all shlibs to satisfy STOR import */
#define SHLIB_INTERNAL_NAME 64 /*shlib has an internal name, for library-level
                                versioning support*/
```

See “Library-Level Versioning” on page 144 for details about the usage of `SHLIB_INTERNAL_NAME` for library level versioning support.

export_ext_loc

This field is the text-relative offset of the export extension table. The export extension table contains information about a symbol such as its size, the start of the drelloc list, and a list of exports with the same value.

module_loc

This field is the text-relative offset of the module table. The module table is a structure containing information on the modules used to build the shared library. It has the information on defined and referenced symbols for each module in the table.

module_count

This field is the number of modules in the module table.

elaborator

This field holds an index into the import table if the `elab_ref` bit in the flags field is set.

initializer

This field holds an index into the import table if the `init_ref` bit in the flags field is set and the `initializer_count` field is set 0. If `initializer_count` is non-zero, then the `initializer` field will no longer contain an import index. Instead it will be an offset of the initializer import list relative to the beginning of the `$TEXT$` space. The contents of the table will be import indexes of the specified initializers.

embedded_path

This field is an index into the shared library string table.

initializer_count

This field holds the number of initializers declared.

reserved3

This field is reserved for future use (currently set to 0).

reserved4

This field is reserved for future use (currently set to 0).

6.3.4 Version Auxiliary Header

The shared library version auxiliary header is used to record the version number of the object module. This auxiliary header is optional. The linker can use this auxiliary header to determine the version of the exported symbols within the module plus the high water mark for a shared library or incomplete executable.

```
struct shlib_version_aux_hdr {
    struct aux_id    header_id;
    short           version;
};
```

Figure 6-35: Shared Library Version Auxiliary Header Definition

aux_header_id

Bits 0-63

This field contains the auxiliary header identifier for the object module.

version

Bits 0-15

This field contains the version number of the object module. The version number is represented as the number of months since January, 1990.

6.3.5 Import List

An import list is created for both incomplete executables and shared libraries. The import list is allocated in the TEXT space of the object, and consists of an array of import entries. Each import entry contains information about the symbol name, symbol type, and the shared library which defined the symbol at link time. The import list must maintain a one-to-one correspondence with the linkage table. There is an import symbol for each DLT entry in the linkage table, followed by an import symbol for each PLT entry in the linkage table.

The following is the `import_entry` data structure, which makes up the import list in incomplete executables and shared libraries.

name

Bits 0-31

```
struct import_entry {
    int          name;                /* offset in string table */
    short        reserved2;          /* unused */
    unsigned char type;              /* symbol type */
    unsigned int bypassable : 1;     /* address of code symbol
not taken in shlib */
    unsigned int reserved1 : 7;     /* unused, init to 0 */
};
```

Figure 6-36: Import entry structure

This field contains an offset into the string table denoting the symbol name.

reserved2

Bits 0-15

Unused. Initialized to -1 if a shared library, 0 if an incomplete executable.

type

Bits 16-23

This field specifies the symbol type (text, data, or bss).

bypassable

Bits 24

This bit is set (1) in shared libraries for code imports which do NOT have their address taken in that shared library. Otherwise, it is 0. The bypassable bit controls a runtime optimization performed by dld.sl. This optimization bypasses export stubs for shared library imports that are satisfied by exports from a shared library (either the same library or a different library).

reserved1

Bits 25-31

These bits are reserved for future expansion (currently initialized to 0).

6.3.6 Export Table

The export table is allocated in the TEXT space of the object and is built for both shared library and incomplete executables files. The export table has an associated hash table for fast lookup; each one-word entry in the hash table contains an index into the export entry list. The next field of the export record holds the index of the next export record on the hash chain. A NIL (-1) next value terminates the list. Each entry in the export list contains information about the symbol name, symbol type, symbol address (symbol offset), and symbol version number. There is a separate entry for each version of a symbol. Parameter relocation information is not currently used.

```
struct misc_info {
    short version;    /* months since January, 1990 */
    unsigned int reserved2: 6;
    unsigned int arg_reloc: 10;    /* parameter relocation bits (5*2) */
}

struct export_entry {
    int next;    /* index of next export entry in hash chain */
    int name;    /* offset within string table */
    int value;    /* offset of symbol (subject to relocation) */
    union {
        int size;    /* storage request area size in bytes */
        struct misc_info misc;    /* version, etc. N/A to storage requests */
    } info;
    unsigned char type;    /* symbol type */
    char reserved1;    /* currently unused */
    short module_index;    /* index of module defining this symbol */
};
```

next

Bits 0-31

This field contains an index to the next export record in the hash chain.

name

Bits 0-31

This field contains an offset into the string table denoting the symbol name.

value

Bits 0-31

This field specifies the symbol address (subject to relocation).

info

Bits 0-63

If the exported symbol is of type `STORAGE`, this field specifies the size of the storage request area in bytes. Otherwise, this field contains the version of the exported symbol along with argument relocation information.***type***

Bits 0-7

This field specifies the symbol type. Valid symbol types are:

`ST_CODE`

ST_DATA
ST_STORAGE
ST_PLABEL

reserved1

Bits 8-15

These bits are reserved for future expansion.

module_index

Bits 16-31

This field contains the index into the module table of the module defining this symbol.

6.3.7 Export Table Extension

The export table extension is allocated in the TEXT space of the object and only appears in shared libraries. It runs parallel to the export table and provides extra information about each export record. Currently, the information in this extension contains information needed to perform data copying from a shared library to the program file. It indicates the size in bytes of each data item as well as any dynamic relocations that must be applied. A same list field is included to ensure that all data symbols that refer to the same physical location within the shared library are copied to the program file. This ensures that all alias names, common with secondary defs, refer to the same location in the resulting program. The information in the export extension table is only used at link time, in order to correctly apply DR_PROPAGATE dreloc records; it currently is not accessed by the dynamic loader anywhere.

```
struct export_entry_ext {  
    int size;    /*export symbol size, data only */  
    int dreloc; /* start of dreloc list for this symbol */  
    int same_list; /* circular list of exports that have the same value */  
    int reserved2;  
    int reserved3;  
};
```

size

Bits 0-31

This field is the size in bytes of the export symbol and is only valid for exports of type ST_DATA. For other export types, this field is initialized to -1.

dreloc

Bits 0-31

This field is the start of the dreloc records for the exported symbol. If no relocation records exist for this symbol, this field is initialized to -1.

same_list

Bits 0-31

This field is a circular list of exports that have the same value (physical location) in the library. This is to ensure that all data symbols that refer to the same physical location in the library are copied to the program file.

reserved2

Bits 0-31

This field is reserved for future expansion (currently initialized to 0).

reserved3

Bits 0-31

This field is reserved for future expansion (currently initialized to 0).

6.3.8 Shared Library List

The shared library list is built for both shared libraries and incomplete executables. This list is allocated in the TEXT space, and contains an entry for each shared library specified at static link time. The shared library list is an array of entries which contain information about the library name, whether the library was specified with “-lc” or as an absolute path name, and whether the library was specified with an immediate or deferred binding attribute. The shared library name, as placed into the string table, should be the fully qualified path name of the shared library as determined at static link time. Please see Section 6.3.15 on page 144 for details of handling library versioning when the `internal_name` bit is set.

```
struct shlib_list_entry {
    int shlib_name;    /* offset within string table */
    unsigned char reserved1:6;
    unsigned char internal_name:1;    /* shlib entry is an internal name */
    unsigned char dash_l_reference:1; /*referenced with -lc or absolute path */
    unsigned char bind;    /* BIND_IMMEDIATE, BIND_DEFERRED or
                           BIND_REFERENCE */
    short highwater_mark; /* highwater mark of the library */
}
```

shlib_name

Bits 0-31

This field contains an index into the string table of the fully qualified path name of the shared library specified at static link time.

reserved1

Bits 0-5

This field is reserved for future use.

internal_name

Bits 6

This field is a flag to indicate if shared library entry is an internal name. Please see Section 6.3.15 on page 144 for details of handling library versioning for specifying internal name with the +h linker option.

dash_l_reference

Bits 7

This field is a flag to denote if the shared library was specified on the link line with the -l option or not. If specified with -l, this flag is set to true. If the incomplete executable was linked with either the +b or +s options, the dynamic loader will search for those libraries specified with -l at link time using the path(s) given. This allows a different path to be searched at run time than what was specified at link time.

bind

Bits 8-15

This field describes the binding-time preference specified at link time when the program is built. Valid binding modes are bind-deferred and bind-immediate. Bind-deferred means the symbols are bound upon reference by the dynamic loader. Bind-immediate means the symbols are bound at program start-up.

highwater_mark

Bits 16-31

This field contains the highwater_mark seen in the shared library at link time and is only valid for shared library lists located in program files.

6.3.9 Module Table

The module table is allocated in the TEXT space and is only present in shared libraries. This table was implemented to support the smart-bind binding algorithm within dld.sl. The table consists of records that describe the symbols that are imported from the modules (object files) that comprise the library. These records allow the loader to select which imports need to be resolved based on which modules are reachable. This is very similar to the way the linker deals with archive libraries at link time. The linker selects modules based on their ability to resolve current unsats of the main program. As these modules are selected, they introduce new unsatisfied symbols that must then be resolved. Eventually, imports are resolved without the need of more modules and we have closure for a correct program. If closure cannot be reached, unsatisfied symbol errors will result. The drelocs field indicates the relocation records that must be applied if this module is used. The module_dependencies field indicates the number of modules that this module directly depends on. Direct dependency can result when one module

calls a routine in another module and these symbols are then hidden. Since there is no symbolic trace of the call, the loader cannot detect the dependency through symbol records. The `imports` field points to an array of integers used to determine dependencies. Module dependencies appear first on this list followed by `import_count` import table indices.

```
struct module_entry {
    int drelocs;    /* text offset into module dynamic relocation array. */
    int imports;   /* text offset into module import array */
    int import_count; /* number of entries into module import array */
    char flags;    /* currently flags defined: ELAB_REF */
    char reserved1;
    unsigned short module_dependencies;
    int reserved2;
}
```

drelocs

Bits 0-31

This field is a text address (subject to relocation) into the dynamic relocation table.

imports

Bits 0-31

This field contains a text address (subject to relocation) into the module import table. This table is a list of import symbols and module table indices. The modules and symbols in this list must be resolved before the module can be used.

import_count

Bits 0-31

This field is the number of import symbol entries in the module import table belonging to this module.

flags

Bits 0-7

This field denotes if an elaborator was referenced in the module

module_dependencies

Bits 8-15

This field is the number of modules the current module needs to have bound before all of its own import symbols can be bound.

reserved2

Bits 0-31

This field is reserved for future expansion (currently initialized to 0).

6.3.10 Shared Library Unwind Info

The `shlib_unwind_info` structure is used to provide the necessary unwind information for debugging shared library code. The debuggers (`adb`, `xdb`) need a way to access the unwind tables for shared libraries. The dynamic loader will also use this table to access stack unwind, try/recover and line table information. Currently, in a program file, the unwind information is accessed symbolically, using the `$UNWIND_START$`, `$UNWIND_END$`, `$RECOVER_START$`, and `$RECOVER_END$` symbols. For shared libraries, there will be separate unwind tables for each shared library at addresses which are unknown at static link time; therefore the `shlib_unwind_info` structure must be accessed through a known offset off of `r19` (which is reserved to point to the Linkage Table for a shared library). The `shlib_unwind_info` structure is only placed into shared library files, since program files can continue to access the unwind information symbolically. One DLT entry at `r19 + 0`, is reserved to contain an `r19`-relative offset to the following structure:

```
struct shlib_unwind_info {
    int magic;           /* magic number for unwind detection */
    int shlib_name;     /* index into string table */
    int text_start;     /* virtual address of the start of text */
    int data_start;     /* virtual address of the start of data */
    int unwind_start;   /* text-relative offset of unwind table */
    int unwind_end;     /* text-relative offset of stub unwind table */
    int recover_start;  /* text-relative offset of recover table */
    int recover_end;    /* text-relative offset of the line table */
};
```

This structure is initialized by the static linker which sets the `shlib_name` field to point to the shared name of the shared library in the string table and sets the `unwind_start`, `unwind_end`, `recover_start`, and `recover_end` fields to text-relative offsets for the corresponding tables. The dynamic loader will then fill in the `text_start` and `data_start` fields when the library is mapped into memory, and the `unwind_start`, `unwind`, `recover_start` and `recover_end` fields will be patched with the virtual address for the unwind tables.

magic

Bits 0-31

This field identifies the header as a shared library unwind header.

shlib_name

Bits 0-31

This field is the name of the shared library. Within the shared library file, this field holds an offset into the shared library string table. At run time, the dynamic loader converts this offset into the actual unwind address of the string.

text_start

Bits 0-31

This field specifies the presumed virtual address of the start of data. At run time, this field is relocated to hold the true address at which data is mapped.

data_start

Bits 0-31

This field specifies the presumed virtual address of the start of data. At run time, this field is relocated to hold the true address at which data is mapped.

unwind_start

Bits 0-31

This field denotes the presumed text address of the stack unwind table. At run time, this field is relocated to hold the true unwind address of the stack unwind table.

unwind_end

Bits 0-31

This field denotes the presumed text address of the stub unwind table. At run time, this field is relocated to hold the true address of the stub unwind table.

recover_start

Bits 0-31

This field denotes the presumed text address of the start of the try-recover table. At run time, this field is relocated to hold the true address of the try-recover table.

recover_end

Bits 0-31

This field denotes the presumed text address of the line table. At run time, this field is relocated to hold the true address of the line table.

6.3.11 String Table

The string table is allocated in the TEXT space for both shared libraries and incomplete executables. This table consists of a series of null-terminated strings, which represent the names of all symbols exported or imported in this file, and all library names specified at static link time. Note: this string table is distinct from the “normal” string table in a SOM.

6.3.12 Dynamic Relocation Records

Dynamic relocation, or dreloc records are used by the dynamic loader to apply run time patches to the data area of shared libraries and incomplete executables. A dynamic relocation record is built in an object each time it has a data item initialized to the address of a shared library’s function or variable. The dynamic relocation record is needed since the linker does not know the actual address for code and data items within a shared library; the final address of library code and data is only known at run time, after the shared library has been mapped into memory. When the executable imports data, using

data copying, that is affected by that library's relocation record (i.e. it imports a data item that needs relocation) a special DR_PROPAGATE relocation record is generated in the program file that allows the loader to first determine the original shared library that supplied the data item and then use the relocation records within the shared library to update the data item that has been copied to the program file. When an incomplete executable imports data from a shared library, only the data item itself is copied into the executable, with the size of the data item being determined by the export extension record.

With HP-UX 9.0, run time data copying has been implemented as well as copying the data statically at link time. This causes a DR_PROPAGATE dreloc record to be emitted for each data copied object between a shared library and the program file. (The current plan is to eliminate data copying entirely for HP-UX 10.0; this will obsolete the use of the DR_PROPAGATE dreloc record altogether.)

```
struct dreloc_record {
    int shlib;        /* Reserved */
    int symbol;      /* index into import table of shlib if *_EXT type
                    low-order 16 bits used for module index if *_INT type*/
    int location;    /* offset of location to patch data-relative */
    int value;       /* text for data-relative offset to use for patch if
                    internal-type fixup */
    unsigned char type; /* type of dreloc record */
    char reserved;    /* currently unused */
    short module_index; /* Reserved */
}
```

shlib

Bits 0-31
Reserved.

symbol

Bits 0-31
This field is an index into the import table if the relocation is an external type.

location

Bits 0-31
This field is the data-relative offset of the data item the dreloc record refers to

value

Bits 0-31
This is the text or data-relative offset to use for a patch if it is an internal fixup type.

type

Bits 0-7

The field represents the of the dynamic relocation record. Valid relocation types are:

```
#define DR_PLABEL_EXT    1  /* initialized to a external code label (PLT)*/
#define DR_PLABEL_INT    2  /* initialized to internal (local code label (PLT)*/
#define DR_DATA_EXT      3  /* initialized to external data symbol */
#define DR_DATA_INT      4  /* initialized to internal data offset;
                             data-relative "value" field */
#define DR_PROPAGATE     5  /* data item copied from shared library into a.out*/
#define DR_INVOKE        6  /* invoke elaborator function */
#define DR_TEXT_INT      7  /* initialized to internal text offset; text-relative
                             "value" field */
```

Note that DR_INVOKE is for C++ shared libraries with static constructors. A C++ shared library is built with a procedure called an “elaborator”, identified by a symbol index in the dl_header. For each DR_INVOKE relocation record seen, the elaborator is called with three arguments, the location field from the relocation record, the symbol index from the relocation record, and the shared library handle. DR_INVOKE are applied after all other fixups.

The PLABEL_EXT relocation record is the result of an initialized function pointer in the data segment. It points to the code import list entry, which corresponds to a PLT slot. The dynamic loader will fixup the initialized function pointer with the address of the “canonical” PLT entry for the referenced procedure, which may or may not be the one provided by the importing module. Every module that creates a plabel allocates a PLT slot for the imported procedure, and the loader picks one to serve as the canonical one. This ensures that plabels for the same routine will compare equal. Unfortunately, there are still cases where this cannot work, like when libraries are dynamically loaded and unloaded. For this reason, we have a plabel comparison millicode routine that compares the contents of plabels rather than their addresses.

reserved

Bits 8-15

These bits are reserved for future expansion (currently initialized to 0)

module_index

Bits 16-31

Reserved.

6.3.13 Loading Shared Libraries

6.3.13.1 Loading Libraries

When a program begins execution, the first thing it does is attach all shared libraries that were searched at link time. This activity is performed by the startup code in `crt0.o`, which maps in the *dynamic loader* which then scans a list (built at link time and stored in the program file) of shared libraries that were searched by the linker.

This list of libraries in the program file contains the paths of the libraries specified on the linker command line. Library names referred to with the `-l` option will be expanded by the linker to the fully qualified pathname for the library, as found at link time.

If a library is listed explicitly, without the `-l` option, the library name in the list will be exactly as specified on the command line.

The directories searched by the linker are by default, `/usr/lib` and `/opt/langtools/lib`, but they may be overridden by the environment variable `LPATH` (see the `ld(1)` manual page for details).

Note that the `LPATH` specified at link time will be used when creating the shared library list used by the dynamic loader, that is, the shared library names will be the fully qualified path names of the libraries as found at link time. The `LPATH` environment variable will not be used during dynamic loading of the library.

6.3.13.2 Dynamic Library Path Support

On the Series 700/800, support has been added for the run-time path lookup of shared libraries needed by a program file. Directory search information can come from two sources; the program file itself and an environment variable.

The program provides directory search information if it is linked with the `+b path_list` option where `path_list` is a list of directories to search. If `path_list` is a single colon `'.'`, the linker will construct a list of directories to search consisting of all the `-L` directories followed by the directories specified by the `LPATH` environment variable. The directory search list will be stored in the program file itself and will be made available to the dynamic loader at run-time.

The environment variable `SHLIB_PATH` can be used by the dynamic loader to dynamically locate shared library files if the program file was linked with the `+s` option. If both the `+b` and `+s` options are specified at link time, the relative order of these options on the command line indicates which path list will be searched first. The environment will be scanned once at program start up for the value of the `SHLIB_PATH` environment variable. Future modifications to this environment variable by the executing program will not be picked up by the dynamic loader.

If dynamic path lookup is enabled either through `+b` or `+s`, only shared libraries specified on the link line via the `-l` option are subject to path lookup. For libraries loaded via the `shl_load()` call, the library will be subject to dynamic search only if the `DYNAMIC_PATH` flag is passed to `shl_load()`.

For both the SHLIB_PATH environment variable and the path list specified via the *+b* option, a path list consists of a colon ':' separated list of directories with leading and trailing colons ':' being optional. The directories will be searched in the order in which they appear in the path list. A null directory specification "::" indicates that the default library path stored by the linker in the program file or provided via a shl_load() call should be used at that point in the search. If a directory specified in the path list is relative (does not begin with a '/'), the directory actually searched will depend on the current working directory, not the directory where the program file actually resides. For example, if SHLIB_PATH were set to the path list "/usr/lib/X11::../mylibs:/usr/lib/Motif1.1" and the loader was presented with a shared library path list via a shl_load() call or by searching the library list in the program file or the dependency list of a shared library, the following locations would be probed in order:

input library path: /mnt/usr/local/thislib.sl

- 1) /usr/lib/X11/thislib.sl
- 2) /mnt/usr/local/thislib.sl
- 3) \$PWD/../mylibs/thislib.sl
- 4) /usr/lib/Motif1.1/thislib.sl

If the loader has attempted to perform a dynamic path lookup for a shared library and failed to find it using the supplied directories, it will search the default path list of "::".

Note, no special provisions related to security issues are taken for programs that perform chown(2) or chgrp(2). The builder of such a program file must ensure that the user cannot substitute his own library on a search path and gain undesirable privileges. Since the default when building the program file is to not allow any dynamic shared library searching, this is not considered a security hole in the program development environment, rather it is a responsibility of the program builder.

The chatr(1) command has been modified to allow the user to control several aspects of shared library behavior. The options include:

- B bind - Modify symbol binding modes, same as ld(1) -B
- +b flag - Control whether the program directory path list can be used, flag = enable or disable
- +s flag - Control whether the environment variable SHLIB_PATH can be used, flag = enable or disable
- l library - Indicates that the specified shared library is subject to dynamic path lookup.
- +l library - Indicates that the specified shared library is not subject to dynamic path lookup.

6.3.14 Intra-library Version Control

Prior to 10.0, all library versioning are done at the "intra-library" level in that version control is done at program object level. Please refer to "Programming on HP-UX" for details on how to handle version control by using compiler directives and linker options. Since code from a shared library is mapped in at run time from a separate shared library

file, modifications to a shared library may alter the behavior of existing executables. In some cases, this may cause programs to operate incorrectly. A means of version control is provided to solve this problem.

Whenever an incompatible change is made to a library interface, both versions of the affected module or modules are included in the library. A mark indicating the date (month/year) the change was made is recorded in the new module in a Shared Library Version Auxiliary Header (See “Version Auxiliary Header” on page 131.) This date applies to all symbols defined within the module. A high water mark giving the date of the latest incompatible change is recorded in the shared library, and the high water mark for each library linked with the program is recorded in the incomplete executable file.

At run time, the dynamic loader checks the high water mark of each library and loads the library only if it is at least as new as the high water mark recorded at link time. When binding symbolic references, the loader chooses the latest version of a symbol that is not later than the high water mark recorded at link time. These two checks help ensure that the version of each library interface used at run time is the same as was expected.

6.3.15 Library-Level Versioning

Starting at HP-UX 10.0, shared library versioning will now be provided on an entire library. We will refer to this as “library-level versioning”, as distinguished from “intra-library” shared library versioning we provided prior to HP-UX 10.0. Note that the intra-library versioning functionality will not be going away anytime soon, as some users depend on this functionality; the library-level scheme will be an additional feature.

Here is how library-level versioning works in general: The traditional name of a delivered shared library will now be a symbolic link that points to the latest version of that library on the file system. All the “real” shared libraries will be suffixed with the pattern

`lib_name.<digit>`

instead of “lib_name.sl”; e.g., “libc.2”. Many versions of shared libraries may reside on the system at a given time, older versions will use lower numbered digits. The internal name, e.g. “lib2.2” is recorded in the library when it is built. See Section 6.3.15.1 on page 145 for details of building libraries with internal names.

When the user links an application against a shared library on the filesystem, the file specified will have a standard “.sl” suffix; normally this is done with a “-l<name>” option to the linker, which searches for a shared library called “<path>/libname.sl”.

Since this library is a symlink to the latest version available, the linker will actually open this latest shared library and link against it; it is the internal name of *this* library that is recorded in the library list of the application. For example, if these files exist on a system (Note: at HP-UX 10.0, the highest digit suffix will be “1”):

```
/usr/lib/libfoo.0
/usr/lib/libfoo.1
/usr/lib/libfoo.sl -> ./libfoo.1
```



```
/usr/lib/libbar.0
/usr/lib/libbar.1
/usr/lib/libbar.2
/usr/lib/libbar.sl -> ./libbar.2
```

```
/usr/lib/libc.0
/usr/lib/libc.1
/usr/lib/libc.2
/usr/lib/libc.3
/usr/lib/libc.sl -> /usr/lib/libc.3
```

and the user links an application with this command line:

```
ld /usr/ccs/lib/crt0.o main.o -lfoo -lbar -lc -o prog
```

then these shared libraries will be recorded in the file “prog”:

```
/usr/lib/libfoo.1
/usr/lib/libbar.2
/usr/lib/libc.3
```

If then in subsequent releases all of these libraries were versioned with incompatible changes (e.g.: if “libfoo.sl” now pointed to a new library, “libfoo.2”), the file “prog”, if not relinked, would always bind against these *same* shared libraries, which would remain *completely unchanged* for the life of the application.

Libraries loaded programmatically, dynamically loaded libraries (shl_load(3x)), should explicitly load the *real* file. For example, loading /usr/lib/libfoo.1 explicitly rather than the symlink /usr/lib/libfoo.sl. In this way, when the application is moved forward, it will always use the correct version.

6.3.15.1 Building libraries

In order to use the “library-level” versioning scheme, libraries must be built with the new linker option, “+h <internal-name>”. This “internal name” to be supplied on the linker command line is usually the basename of the file where it will eventually be installed. When the +h option is specified, the SHLIB_INTERNAL_NAME in the flags field of the dl_header will be set to true. Using the same example in this section, the latest versions of the three libraries will be built as follow:

```
ld -b *.o ... +h libfoo.1 -o libfoo.1
ld -b *.o ... +h libbar.2 -o libbar.2
ld -b *.o ... +h libc.3 -o libc.3
```

This “internal name” will be used by the linker to write into the library list of any application or shared library that is linked against the symbolic links of a shared library; not the name of the file itself. The linker will use the *directory* where it searches for the library, concatenated with the *internal name* in the library, to be recorded in the library list. For example, if /usr/lib/libfoo.sl is the shared library used to link with, and this file has an internal name of “libfoo.1”, then the name recorded in the library list will be /usr/

lib/libfoo.1. Users must take extra caution when a path is specified in the internal name. If the internal name is an absolute path, i.e. file name that begins with “/”, then the recorded dependency in the library list is the absolute path name. Otherwise, the base name is appended to the recorded dependency path.

For example:

If /usr/lib/libfoo.sl
is a sym link to
/xxx/libfoo.1

<u>internal name with +h</u>	<u>recorded dependency</u>
libfoo.1	/usr/lib/libfoo.1
/xxx/libfoo.1	/xxx/libfoo.1
./mylib/libfoo.1	/usr/lib/./mylib/libfoo.1

Please see “Programming on HP-UX” for details on how to build libraries with “Library-Level Versioning”.

6.3.15.2 Pre-10.0 Applications

At 10.0, the dynamic loader has an enhancement to help migrate 9.0 applications because of the filesystem changes. Any shared library in /lib will be searched for in /usr/lib before the dynamic loader aborts, so /lib/libc.sl will be found correctly in /usr/lib/libc.sl.

6.3.15.3 Migrating to Library-Level Versioning

The dynamic loader has a special “compatibility enhancement” in place, strictly for the purposes of providing a suitable run-time environment for older applications moving forward when applications are migrating to Library-Level versioning.

If the dynamic loader encounters an application with no internal name specified, then when it attempts to bind a shared library to the process it will first change the “.sl” suffix to “.0” in the filename before it makes the open(2) call. If it does not find a “.0” shared library, it will use the library as *specified in the application*.

For example, if there is no /usr/lib/libfoo.0 on the 10.0 system, it will look for and use /usr/lib/libfoo.sl, just like it did for 9.0x systems.

6.3.16 Import and Export Stubs

All procedure calls from the shared library to entry points outside the library, or to exported entry points in the library, are routed through import stubs. These stubs are created by the linker in the code space of the library, and manage both the indirect reference through the linkage table and the possibility of inter-space procedure calls.

In addition, each exported procedure (including non-exported procedures whose addresses are taken) is assigned an export stub, which handles the return path of inter-space calls.

The stubs generated by the linker are defined as follows:

Import Stub (Incomplete Executable)

```
X':  ADDIL    L'lt_ptr+ltoff,dp      ; get procedure entry point.
      LDW     R'lt_ptr+ltoff(1),21
      LDW     R'lt_ptr+ltoff+4(1),r19 ; get new r19 value.
      LDSID   (r21),r1
      MTSP    r1,sr0
      BE      0(sr0,r21) ; branch to target.
      STW     rp,-24(sp) ; do this as a favor to the export stub.
```

Import Stub (Shared Library)

```
X':  ADDIL    L'ltoff,r19 ; get procedure entry point.
      LDW     R'ltoff(r1),r21;
      LDW     R'ltoff+4(r1),r19 ; get new r19 value.
      LDSID   (r21),r1
      MTSP    r1,sr0
      BE      0(sr0,r21) ; branch to target.
      STW     rp,-24(sp) ; do this as a favor to the export stub.
```

Export Stub (Shared libs and Incomplete Executables)

```
X':  BL,N     X,rp ; trap the return.
      NOP
      LDW     -24(sp),rp ; restore the original rp.
      LDSID   (rp),r1
      MTSP    r1,sr0
      BE,N    0(sr0,rp) ; inter-space return.
```

6.4 System Calls

The HP-UX operating system defines a large set of system calls. These system calls can be made indirectly by calling the interface routines in the C run-time library, or they can be made directly from assembly code. All system calls are funneled through a single entry point in the system space, which is identified by space register 7 (SR7). Each system call is assigned a unique number, which must be loaded into general register 22 (GR22). The arguments to the system routine should be loaded into argument registers: GR26, GR25, GR24, and GR23 (arg0, arg1, arg2, arg3 respectively) as necessary. When the system call returns, a status code is also returned in GR22. If the status code is zero, the system call succeeded and the return value, if any, is in GR28. If the status is not zero, the system call failed and the error number is found in GR28.

A list of system call numbers as well as the location of the system call entry points is in the standard include file */usr/include/sys/syscall.h*.

Following is an example of a code fragment shows a call to the *read* system call:

```
READCALL
or      %r0, %r0, %arg0 ; file descriptor = 0
addil   L%buf-$global$, %dp ; set up buffer address in arg1
ldo     R%buf-$global$ (%r1), %arg1
```

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```
ldo      10, %arg2                ; length = 10 into arg2
ldil     L%0xC0000004, %r1        ; load system call entry point and
ble      R%0xC0000004(%sr7,%r1)   ; branch to it
ldo      3, %r22                  ; read system call number is 3
```

In the above code fragment, the last instruction loads the constant 3, which is the unique number for the *read* system call, into GR22, and executes in the delay slot of the BLE instruction.

The standard procedure calling convention should be used to call the system call interface routines in the C library.

This chapter covers items specific to the MPE/iX system. Included are sections on the program auxiliary header, initialization pointers, MPE loader fixups, and executable library format.

7.1 MPE Program Auxiliary Header

The MPE program auxiliary header (also known as the 'HPE' auxiliary header) contains information that is used by the MPE operating system to load an executable file. If the fields specifying the default values for the RUN command are not needed, the MPE program auxiliary header may be omitted.

This auxiliary header must be contained within the LST portion of an executable library or program file, not as part of a SOM within an executable library. This header is also known as the LST auxiliary header.

```
struct mpe_prog_aux_hdr {
    struct aux_id      header_id;
    unsigned int      entry_name;
    unsigned int      unsat_name;
    int               search_list;
    struct cap_list   capabilities;
    unsigned int      max_stacksize;
    unsigned int      max_heap_size;
    unsigned int      reserved: 13;
    unsigned int      bind_mode          : 1;
    unsigned int      allow_override    : 1;
    unsigned int      posix             : 1;
    unsigned int      max_priority      : 8;
    unsigned int      priority          : 8;
};

struct cap_list {
    unsigned int      reserved1          :23;
    unsigned int      batch_acc          : 1; /* BA */
    unsigned int      inter_acc         : 1; /* IA */
    unsigned int      priv_mode         : 1; /* PM */
    unsigned int      reserved2         : 2;
    unsigned int      multiple_rins     : 1; /* MR */
    unsigned int      reserved3         : 1;
    unsigned int      extra_data_seg    : 1; /* DS */
    unsigned int      process_hand      : 1; /* PH */
};
```

Figure 7-37: Definition of MPE Program Auxiliary Header

aux_header_id

Bits 0-63

This field contains the auxiliary header identifier for an MPE program file.

entry_name

This field contains a string index, into the symbol strings area, of the name of the primary entry point of the program.

This parameter is a default value for a run-time parameter. If it is not used, this field is set to zero and the entry point name will be taken from the RUN command. If this field is used it can be overridden when the program is loaded.

unsat_name

This field contains a string index, into the symbol strings area, of the name of the UNSAT procedure. The UNSAT procedure is linked to all external references that cannot be resolved when the program is loaded.

This parameter is a default value for a run-time parameter. If it is not used this field is set to zero and the UNSAT procedure name will be taken from the RUN command. If this field is used it can be overridden when the program is loaded.

search_list

This field contains a string index, into the symbol strings area, to a string containing a list of library names. These libraries may be used when the program is loaded to resolve any remaining external references.

The entire library list is a single string in the format defined for the LIBLIST parameter on the MPE RUN command.

This parameter is a default value for a run-time parameter. If it is not used this field is set to zero and the library list will be taken from the RUN command. If this field is used it can be overridden when the program is loaded.

capabilities

This field contains the set of capabilities that the program will need during execution. This parameter is merely a request for capabilities which will be checked by the file system when the program is loaded.

Any capability may be assigned to a program; however, only certain capabilities are associated with a process executing the program. These are PH, PM, IA and BA.

If no capabilities are specified, the program's capability set will default to IA, and BA. Currently, this parameter cannot be overridden at load time. This restriction is a carry-over from MPE which checked the capabilities at both link and load time.

The format of the capability word is shown below..

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TABLE 20

Capability Word Format

0	1	2	3	4	5	6	7	8
NU								
9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26
					BA	IA	PM	
27	28	29	30	31				
	MR		DS	PH				

Cap	Meaning
NU	Null
PH	Process Handling
PM	Privilege Mode
IA	Interactive Access
BA	Local Batch Access
DS	Extra Data Segments
MR	Multiple RINs

Bit 0 (NULL) should never be set. Likewise, the undefined bits should never be set.

max_stacksize

The maximum size to which the process stack will be allowed to grow in bytes. The maximum number of bytes in the stack will be rounded up to an even number of pages and will be forced to be in the range:

Minimum stack size configured by system manager.	<=	MAX_STACKSIZE	<=	Maximum stack size configured by system manager.
--	----	---------------	----	--

This parameter can be overridden when the program is loaded.

max_heap_size

The maximum size to which the process heap will be allowed to grow in bytes. The maximum number of bytes in the heap will be rounded up to an even number of pages and forced to be in the range:

0	<=	MAX_HEAP_SIZE	<=	Maximum heap size configured by system manager.
---	----	---------------	----	---

This parameter can be overridden when the program is loaded.

reserved

Bits 0-12

These bits are reserved for future expansion.

bind_mode

This bit is not currently used. In the future, if the loader chooses to support this, this bit, if set, will denote deferred binding of symbols at run time by the loader. The default is to bind immediately.

allow_override

This bit is not currently used. In the future, if the loader chooses to support this, this bit, if set, will denote runtime overrides of the shared library the executable was linked with. The loader will search the shared libraries specified at run time instead of the ones the program was linked with.

posix

Bit 15

If this flag is set to one, it indicates that this HPE program file was linked as a POSIX program.

max_priority

Bits 16-23

The maximum execution priority that a program can have at run time. The maximum priority has to be either BS, CS, DS, ES or a number between 100 and 255 inclusive. BS has the highest priority, ES the lowest. The integer equivalents are shown in Table 2.

TABLE 21**Priority Bits**

BS	16979
CS	17235
DS	17491
ES	17747

priority

Bits 24-31

The execution priority that the program will have at run time. The priority has to be either BS, CS, DS, ES or a number between 100 and 255 inclusive. BS has the highest priority, ES the lowest. See the above table for the integer equivalents.

7.2 MPE SOM Auxiliary Header

```
struct mpe_som_aux_hdr {
    struct aux_id    header_id;
    unsigned int    reserved : 27;
    unsigned int    shared_data : 1;
    unsigned int    thread_private : 1;
    unsigned int    dumpworthy : 1;
    unsigned int    hpe_som : 1;
    unsigned int    system_som : 1;
    unsigned int    num_xrts;
    unsigned int    unwind_start;
    unsigned int    unwind_end;
    unsigned int    recover_start;
    unsigned int    recover_end;
    unsigned int    num_dxrts;
    unsigned int    data_imports;
    unsigned int    data_exports;
};
```

Figure 7-38: Definition of MPE SOM Auxiliary Header

header_id

Bits 0-63

This field contains the auxiliary header identifier for an MPE program file.

shared_data

If this flag is set to one, then the SOM is a shared global data SOM and imports and/or exports data symbols; otherwise, it is an old-style SOM.

thread_private

If this flag is set to one, then this SOM is a thread-private SOM.

dumpworthy

If this flag is set to one, then this SOM is dumpable.

hpe_som

If this flag is set to one, then this SOM is part of the MPE bootable image.

system_som

If this flag is set to one, then this SOM is part of the MPE kernel.

num_xrts

This field contains the number of XRT entries.

unwind_start

This field contains the virtual address of start of unwind table.

unwind_end

This field contains the virtual address of end of the unwind table.

recover_start

This field contains the virtual address of start of the try-recover table.

recover_end

This field contains the virtual address of end of the try-recover table.

num_dxrts

This field contains the number of DXRT entries. This field will only be valid if the `shared_data` bit is set.

data_imports

This field contains the number of LST data imports. This field will only be valid if the `shared_data` bit is set.

data_exports

This field contains the number of LST data exports. This field will only be valid if the `shared_data` bit is set.

7.3 Initialization Pointers

The initialization pointer array is used to determine how to initialize virtual space when a file is loaded. The fields in the initialization pointer record are very similar to the fields in the subspace record, but the initialization pointer record can be used to initialize more than one subspace. The initialization pointer information is used by the loader after subspaces have been relocated and are in their "final" position within a space. Compilers should use the fields provided in the subspace record to convey initialization information to the linker, since relocatable subspaces are not guaranteed to remain contiguous.

```
struct init_pointer_record {
    unsigned int    space_index;           /* index of space entry */
    unsigned int    access_control_bits:7; /* access for PDIR */
    unsigned int    has_data:1;           /* file pages exist for this area of
                                         memory */
    unsigned int    memory_resident:1;    /* lock in memory during execution */
    unsigned int    initially_frozen:1;   /* must be locked into memory when OS
                                         is booted */
    unsigned int    new_locality:1;      /* init pointer begins a new locality */
    unsigned int    reserved:21;
    unsigned int    file_loc_init_value;  /* starting location in file (page
                                         aligned) */
    unsigned int    initialization_length; /* size of area to be initialized */
    unsigned int    space_offset;        /* starting offset in space (page
                                         aligned) */
};
```

Figure 7-39: Definition of Initialization Pointer Record

space_index

This field is a index into the space dictionary. All of the space records will be in contiguous records in the space dictionary. *space_index* can be converted to a file byte offset by:

offset = *space_index* * size of (space record)

+ *space_dictionary_location* (found in the SOM header)

+ address of the first byte of the SOM header.

If a *space_index* is greater than the field *space_quantity* in the SOM header record it is an error. If *space_index* is negative it is an error. *Space_index* must have a value in the range 0 to $2^{31}-1$.

access_control_bits

Bits 0-6

The *access_control* bits specify the access rights and privilege level of the subspace. They also specify whether the subspace contains code or data.

TABLE 22 **Subspace Access Control Bits**

Type (3 bits)	Read/Write/Execute/Gateway (4 bits)		Usage
	1st Field (PL1)	2nd Field (PL2)	
0	Read	Not Used	Read only data page
1	Read	Write	Normal data page
2	Read/Xleast	Xmost	Normal code page
3	Read/Xleast	Write/Xmost	Dynamic code page
4	Xleast	Xmost	Gateway to PL0
5	Xleast	Xmost	Gateway to PL1
6	Xleast	Xmost	Gateway to PL2
7	Xleast	Xmost	Gateway to PL3

has_data

Bit 7

If this flag is set to one then data is defined in the SOM for this subspace.

memory_resident

Bit 8

If this flag is set to one then the subspace is to be locked in physical memory once the subspace goes into execution.

initially_frozen

Bit 9

If this flag is set to one then the subspace is to be locked in physical memory when the operating system is being booted.

new_locality

Bit 10

This flag indicates that this initialization pointer begins a new locality set. The loader can use this bit to determine which initialization pointers belong to each locality set, so that it can swap entire locality sets for improved performance.

reserved

Bits 11-31

These bits are reserved for future use.

file_loc_init_value

If *initialization_length* field is non-zero, this field contains a byte offset relative to the first byte of the SOM header. The field *file_loc_init_value* points to the data used to initialize a subspace.

If *initialization_length* is zero then this field contains a 32 bit quantity which is used as an initialization pattern for the entire subspace.

initialization_length

This field contains the size in bytes of the initialization area in the file. If this field is zero then the value contained in the field *file_loc_init_value* is used as the initialization pattern for the subspace.

space_offset

This is a byte address of where the initialization is to start relative to the beginning of a space.

7.4 Loader Fixups

The loader fixup array is an array of fixup records, grouped by space. These records are used to define fixups that are to be performed at load time. The loader fixup records for a particular space are contiguous and each record contains a back pointer to the space to which it refers.

The loader fixup records can be used only for data patches. Currently there are three types of loader fixup records available: data reference fixups, XRT reference fixups, and space reference fixups.

The data reference fixups contain information which is used by the loader to patch references to data which use absolute, rather than DP-relative addresses. The linker is responsible for building this type of loader fixup from information given in the fixup request records.

The XRT reference fixups indicate to the loader data which contains external procedure labels. The linker builds these procedure labels with XRT pointers that are relative to the beginning of the XRT segment for the SOM; the loader must add the actual address of the beginning of the XRT segment.

The space reference fixup type is used to patch references to a named space. The reference must be patched at load time with the real space ID. Fixups of this type eliminate expensive searches through the space/subspace dictionary.

Figure 7-3 shows the C language definition of the loader fixup array.

```

struct loader_fixup {
    unsigned int    fixup_type; /* type of loader fixup */
    unsigned int    space_index; /* index of space to fixup */
    unsigned int    space_offset; /* offset at which to patch */
    unsigned int    constant; /* constant used to patch the space */
};
    
```

Figure 7-40: Definition of Loader Fixups

fixup_type

This field is used to identify the type of loader fixup. There are three types of loader fixups currently defined.

TABLE 23

Loader Fixup Types

Type	Description
0	Space Reference Fixup. Used to patch references to a named space without having to search through the symbol table dictionary for an entry matching the space name. This fixup identifies the entries in the space dictionary which pertain to a particular space reference.
1	Data Reference Fixup. Used by the loader to patch data references which use absolute addresses rather than DP-relative addresses. Since DP can change at run-time, this fixup is used to track locations that may be affected by a change in DP. This loader fixup is generated by the linker if the compiler generates a fixup request record with the <i>need_data_reference</i> flag set.
2	XRT Reference Fixup. Used by the loader to relocate external procedure labels that are contained as constants in the data or literal areas of a SOM. An external procedure label is a pointer to the XRT entry (which must be on a word boundary) with the low-order bit set to indicate that the procedure label is external. The loader allocates the XRT space and must relocate procedure labels by adding the actual address of the beginning of the XRT segment for the SOM. This loader fixup is generated by the linker if the compiler generates a PLABEL fixup request record with the <i>need_data_reference</i> flag set.
3	DXRT address fixup. The constant field is the DP-relative DXRT slot.
4	Multiple DXRT slot fixup. The space_index field is the constant field, the space_offset is the DP-relative target DXRT slot, and the constant field is the source DP-relative DXRT slot. Words 2 and 3 are changed to int.

Note

The MPE/iX Loader does not support space reference loader fixups.

space_index

This field contains the index of a space definition element in the space dictionary. This element defines the space to which this fixup refers. The value of this field must be in the range 0 to 2^{31} .

space_offset

This field contains the space relative byte offset at which the patch must be made.

constant

This field's value depends on the loader fixup type. See Table 5 below for valid *constant* values.

TABLE 24**Constant Values**

Type	Meaning
0	The field contains the index of an element in the space dictionary. The element defines the space to which the space defined by <i>space_index</i> refers. The value of this field must be in the range 0 to 2^{31} .
1	The field contains the value of DP assumed when computing the absolute address of <i>space_offset</i> . The value of this field must in the range 0 to 2^{31} .
2	The field is not used and should contain zero.

7.5 Program Startup

All programs must be linked with the relocatable startup object *NRT0*. This object code defines entry points, sets up the data pointer register (DP), and initializes program variables. The Link Editor automatically links in this object file with every *LINK* performed.

The following shows an example assembly listing of a version of *NRT0* code.

MPE/iX Specifics

```
.space $TEXT$, SPNUM=0,SORT=8
.subspa $MILLICODE$, QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=8
.subspa $CODE$, QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=24
.subspa $LIT$, QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=32
.subspa $UNWIND_START$,QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=56
.subspa $UNWIND$MILLICODE$,QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=62

.space $PRIVATE$, SPNUM=1,PRIVATE,SORT=16
.subspa $GLOBAL$, QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=8
.import $global$
.subspa $SHORTDATA$,QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=16
.subspa $DATA$, QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=24
.subspa $PFA_COUNTER$,QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=64
.subspa $BSS$, QUAD=1,ALIGN=8,ACCESS=0x1f,SORT=80,ZERO

.subspa $CODE$
.export $START$,entry
.proc
.callinfo SAVE_SP,FRAME=128
.entry

$START$
ldo 128(sp),sp           ; Allocate frame, marker, & arg
depi 0,31,3,sp          ; list and doubleword align sp
.import _start
ldil L'_start,r1
ldo R'_start(r1),r1     ; Get address of _start()
stw r0,-4(sp)           ; mark last stack frame (null fm_psp)
.call
.blr r0,rp              ; store return link
.bv,n r0(r1)           ; call _start()
.break 0,0              ; should never return here

.procend

.subspa $UNWIND_START$ ; Declare subspace start symbols
.export $UNWIND_START$
$UNWIND_START$
.subspa $UNWIND_END$,QUAD=0,ALIGN=8,ACCESS=0x2c,SORT=72
.export $UNWIND_END$
$UNWIND_END$
```

```
.subspa $RECOVER_START$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=73
.export $RECOVER_START
$RECOVER_START
.subspa
$RECOVER$MILLICODE$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=78
.subspa $RECOVER$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=80
.subspa $RECOVER_END$,QUAD=0,ALIGN=4,ACCESS=0x2c,SORT=88
.export $RECOVER_END
$RECOVER_END
.space $PRIVATE$
.subspa $GLOBAL$
.export $dp$
$dp$ ; Value of dp register
.export $global$
$global$ ; Value of dp register
.subspa $PFA_COUNTER$
.export $PFA_C_START
$PFA_C_START
.subspa $PFA_COUNTER_END$,QUAD=1,ALIGN=4,ACCESS=0x1f,SORT=72
.export $PFA_C_END
$PFA_C_END
.end
```

Figure 7-4: Example Implementation of NRT0

7.5 Executable Libraries

Executable libraries (XLs) on MPE/iX contain an LST header, LST symbol table, and can have multiple SOMs. Each XL has one LST export table and header, but each SOM or load module has its own LST import table. The limit on the number of load modules per XL is currently set at 10000.

The LST import and export table uses the same structure as the LST symbol dictionary. Currently, only external code procedures are allowed in the import table. The LST import table is not created for relocatable files, only executable files.

XL modules are shared - only one copy of the code needs to exist on the system. Program files that reference a module in an XL share the same physical copy of code. Each module in an XL has its own global data area that is separate from a program file's global data. Routines in XLs cannot share global data with program files and cannot have outer blocks. External code references are allowed between modules in an XL and program files and are resolved at run time.

Figure 7-5 below contains a general layout of an XL.

LST Header
Auxiliary Header
Hash Table
SOM Directory
LST Import List
LST Symbol Table
LST Symbol Strings
Unused
SOM Header for SOM #0
SOM 0
...
SOM Header for SOM #1
SOM 1
...

Figure 7-5: General XL Layout

7.5.1 External Reference Table

Executable libraries and executable program files on MPE/iX have an External Reference Table (XRT) for external procedure calls. External procedure calls are calls that transfer control from one executable module to another, and the called procedure resides in a module outside the calling one. There is one entry in the XRT for each import stub created by the link editor for an external procedure call.

An XRT can be considered a transfer vector or table. The import stub will transfer to the procedure's entry point. At link time this entry point is not known so the stub will use the XRT entry to find the space identifier and offset of the target procedure. At run time, the loader will locate each external procedure referenced in the XRT and initialize the XRT entries with the appropriate values.

Another use of the XRT is to store the location of a load module's DP value in the XRT entry. This is necessary to enable sharing of load modules between multiple processes. All references to a load module's data must be relative to DP since data is placed at a process-dependent offset within the process's private data space. A load module's code area is assigned a unique space identifier. This space identifier is stored in the XRT entry as well.

The XRT lives in the second quadrant of the space pointed to by SR5, the Process Private Space. It is built by the loader at run time if there are external procedure calls in the program file.

The XRT contains a sub-table for every load module referenced during execution. Each sub-table for a load module contains entries for each procedure called by the load module. The layout of the XRT is shown in Figure 7-6 below.

Sub-Table Header (module A)
entry for procedure B1
entry for procedure B2
entry for procedure B3
Sub-Table Header (module B)
entry for procedure A1
entry for procedure A2

Figure 7-6: XRT Layout

The sub-table consists of an eight word header used to locate unwind tables for the module. The layout of the sub-table header is shown below.

Reserved
Reserved
Reserved
Reserved
UNWIND_START
UNWIND_END
RECOVER_START
RECOVER_END

Figure 7-7: XRT Sub-Table Layout

The XRT entry for a procedure in the sub-table is also eight words long. It contains the space id of the module to which it belongs, the entry offset for the procedure, the value of DP for the load module, the LP value of the module which contains the called procedure, the address of the CALLX routine, and three words that are not currently used.

SID of load module
Entry point offset for procedure
DP value for load module
LP value of load module
Address of CALLX routine
Reserved
Reserved
Reserved

Figure 7-8: XRT Entry Layout

7.5.2 Import and Export Stubs

Import stubs are created by the link editor for external calls. The import stub loads into a general register a pointer to the corresponding XRT entry for the called procedure. It then branches to an external procedure call millicode sequence (CALLX). CALLX locates and branches to the called procedure.

The code sequence for import stubs is shown below.

```
LDW    -4(DP), gr1           ; Load LP
STW    DP, -32(SP)          ; Save DP
ADDIL * L'XRToff, gr1       ; Add XRT offset to LP
LDO *  R'XRToff(gr1), gr1   ;
LDW    16(gr1), gr20        ; Load address of CALLX
STW    RP, -24(SP)          ; Save RP'
BE     (sr7, gr20)          ; Branch to CALLX
MFSP   sr4, gr21            ; Move sr4 to gr21
```

* Can be eliminated in cases where they would be NOPs. If eliminated, the total size of the stub is padded to 8 words because unwind descriptors assume fixed-length stubs.

Export stubs are created by the link editor for external calls. When an external procedure is called, the export stub is entered first so the procedure return/exit will return to the stub. When the stub is executed upon return, it restores DP and sr4 and returns to the caller. The code sequence for export stubs is shown below.

MPE/iX Specifics

BL	disp, gr2	; Branch to local entry point
DEP	gr31, 31, 2, gr2	; Deposit caller's Exec. Level in link
LDW	-28(SP), gr21	; Restore sr4 (part 1)
LDW	-24(SP), gr2	; Restore return address (RP')
MTSP	gr21, sr4	; Restore sr4 (part 2)
BE	0(sr4, gr2)	; Branch back to caller
LDW	-32(SP), gr27	; Restore DP

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8.1 The Debug Information Organization

The debug information are generated by the compilers, fixed up by the linker, and used by various programs (primarily the symbolic debugger(s)) to reconstruct information about the program.

On PA-RISC, a major goal was that the linker needs not know anything about the format. To this end, it was decided that the debug information be composed of several unloadable subspaces within an unloadable space (named \$DEBUG\$), and that at link time, updates to the debug information be made through the standard mechanism of a list of fixups. The linker will perform the required fixups for the debug spaces, and subspaces from separate compilation units will be concatenated. However, at exec time, the loader would know that the debug space is not to be loaded.

The debug information consists of up to eleven tables (though not all need be present in any one executable file): a header table and ten special tables. The header table will contain one header record for each compilation unit. Each header record identifies the size (in bytes) of the tables generated by that compilation unit. Two of the tables are very similar. The GNTT and LNTT both contain name and type information (NTT for Name and Type Table). The GNTT contains information about globals, and is thus limited to variables, types, and constants. The LNTT is for information about locals. The LNTT must therefore contain scoping information such as procedure nesting, begin-end blocks, etc. The GNTT and LNTT are both DNTTs (Debug Name and Type Tables), so the prefix DNTT is attached to objects (like a DNTTPOINTER) that are relevant to both the GNTT and LNTT. The SLT contains information relating source (or listing) lines to code addresses. The SLT and LNTT contain pointers between the two tables, so that the scoping information contained in the LNTT can also be used with the SLT. The VT contains ascii strings (such as variable names) and the values of named constants. Additional tables have been added for cross reference information and debug of optimized

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code. The LINES table contains DOC statement info. It is similar to the SLT in content, but not in format. The RANGE table contains DOC range records. Range records allow the address of a variable to be tracked in optimized code. The CTXT table supports inlining. The EXPR table holds expressions which evaluate to the value of a variable which has been optimized away. The tables are summarized below:

TABLE 25

Debug Table

Table	Abbr.	Contents	Points to
Global symbols	GNTT	Global name-and-type info.	GNTT, VT
Local symbols	LNTT	Local name-and-type info.	GNTT, LNTT, SLT, VT
Source lines	SLT	Source / listing line info.	LNTT, SLT
Value	VT	Names and constants	
Xref	XT	File offsets and Attributes	XT, VT
Lines	LINES	DOC line info	SRC_CTXT
lt_offset	LT_OFFSETS	offsets into LINES table	LINES
context	SRC_CTXT	DOC inline info	VT, SRC_CTXT
range	RANGE	DOC range records	
expr	EXPR	DOC expressions	

The pointers needed within the debug tables are in fact indexes into the tables. The GNTT, LNTT, and SLT each consist of a series of equal-sized entries. Some GNTT entries begin a data structure and some are extension entries. Some SLT entries are “special” (point back to the LNTT), others are “assist” (point forward in the SLT), but most are “normal” (point to code). There can be pointers from the LNTT to the GNTT, as it is common to have local variables of a global type. However, there are never pointers from the GNTT to the LNTT, as global variables are never of a local type.

The tables are defined to be as machine-independent as possible, but the debugger may need to “know” some facts about the system and language it is dealing with. The GNTT and LNTT are the only tables that require fixups to be generated by the compiler and acted upon by the linker. There are other fixups to be done, but these are all done by the pre-processor.

8.2 Compilation Unit Headers

8.2.1 Basic typedef and structure definitions

The following basic typedefs and structure definition are used through out this chapter:

```
typedef long          ADDRESS;
typedef unsigned long ADRT, *pADRT;
typedef unsigned int  LANGTYPE;
typedef unsigned long STATTYPE;      /* static-type location */
typedef long          DYNTYPE;      /* dynamic-type location */
typedef unsigned long REGTYPE;      /* register-type location */
typedef unsigned int  BASETYPE;
typedef unsigned int  BITS;
```

DNTT pointer:

```
struct DNTTP_IMMEDIATE {
    BITS      extension: 1;          /* always set to 1 */
    BITS      immediate: 1;         /* always set to 1 */
    BITS      global: 1;            /* always set to 0 */
    BASETYPE  type: 5;              /* immediate basetype */
    BITS      bitlength: 24;        /* immediate bitlength */
};

struct DNTTP_NONIMMED {
    BITS      extension: 1;          /* always set to 1 */
    BITS      immediate: 1;         /* always set to 0 */
    BITS      global: 1;            /* 1 => GNTT, 0 => LNTT */
    BITS      index: 29;            /* DNTT table index */
};

typedef union {
    struct DNTTP_IMMEDIATE  dntti;
    struct DNTTP_NONIMMED  dnttp;
    long word;              /* for generic access */
} DNTTPOINTER;            /* one word */
```

A DNTTPOINTER of DNTTNIL means a nil pointer. In the DNTTImmediate case there is always at least one zero bit (the globalbit) to distinguish that case from nil pointer (-1). In the non-immediate, non-nil case DNTTPOINTER is the block index,

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base zero, of another DNTT entry; the global bit indicates which table it is an index into, the GNTT or LNTT. Each block is 12 bytes.

Extension bits really have nothing to do with DNTT pointers, but are needed for constructing the DNTT. See the next section.

Bitlength is the MINIMUM (packed) size of the object. In lieu of other information (i.e., outside of a structure or array), the object is assumed to be right-justified in the minimum number of whole bytes required to hold the bit length.

An immediate DNTTPOINTER is only allowed if the type is a simple BASETYPE. Otherwise, a separate DNTT entry must be used.

SLT pointer:

Signed entry index, base zero, into the source line table. Each entry is eight bytes.

```
typedef long    SLTPOINTER;
```

VT pointer:

Unsigned byte offset into the value table. Note that VTNIL is not actually a nil pointer, but rather a pointer to a nil string.

```
typedef long    VTPOINTER;
```

Xref Pointer:

Signed entry index, base zero, into the cross reference table. Each entry is four bytes.

```
typedef long    XREFPOINTER;  
typedef int     KINDTYPE;
```

LT pointer:

Unsigned byte offset into the line table.

```
typedef unsigned long LTPOINTER;
```

CTXT pointer:

Unsigned byte offset into the context table.

```
typedef unsigned long CXTXTPOINTER;
```

8.2.2 XDB Header structure definition:

The header table is composed of five word header records. For each compilation unit, the compiler must generate a header record, indicating the length (in bytes) of the five tables (GNTT, LNTT, SLT, VT and XT) produced for that compilation unit.

The five tables are each contained in a separate subspace on PA-RISC and at link time, the tables from different compilation units will be concatenated separately:

GNTTs to GNTTs, SLTs to SLTs, etc.

```
struct XDB_header {
    long    gntt_length;
    long    lntt_length;
    long    slt_length;
    long    vt_length;
    long    xt_length;
};
```

The preprocessor requires the number of compilation units, and the size of each of the five tables produced by each compilation unit. The header records supply this size information, and the number of header records equals the number of compilation units.

In PA-RISC, the `header_extension` flag (MSB) is set in the `gntt_length` word in each header-record by the compilers to indicate the header contains an `xt_length` and is words long. This bit is used to distinguish SOM's that were created with the earlier version of compilers which do not have an `XT` subspace.

8.3 Name and Type Tables

The DNTT consists of a series of three-word blocks. Each starts with an "extension bit". Each structure in the union "dnttentry" begins in an "initial block" with a bit which is always zero. If a structure is more than three words (one block) long, it occupies one or more additional "extension blocks", each of which starts with a bit set to one to distinguish it from an initial block.

Note that every DNTTPOINTER has a high bit of one and that every DNTT structure bigger than one block is carefully arranged so that a DNTTPOINTER resides in the fourth and seventh words. (The extension bit is in the DNTTPOINTER to avoid wasting space due to structure packing rules.)

The second field in each structure is "kind", which acts like a Pascal variant tag to denote the type of the structure. The "unused" fields are just included for clarity.

Followings are different classes of DNTT entries. The whole union "dnttentry" is declared at the end of this section.

8.3.1 File-class ("File") DNTT Entries

- **DNTT_SRCFILE structure definition:**

```
struct DNTT_SRCFILE {          /* 3 words */
    BITS          extension: 1;
    KINDTYPE      kind: 10;
    LANGTYPE      language: 4;
    BITS          unused: 17;
    VTPOINTER     name;
    SLTPOINTER    address;
};
```

Fields definition:

extension: Always zero.
kind: always K_SRCFILE type.
language: Language type.
unused: 17 bits filler to the end of 1st word.
name: Source/listing file name.
address: Code and text locations. "address" points to a special SLT entry (for the line number only), but the code location is known from context in the SLT.

One SRCFILE is emitted for the start of each source file, the start of each included file, and the return from each included file. Additional SRCFILE entries must also be output before each DNTT_FUNC entry. This guarantees the debuggers know which file a function came from. Specifically, the definitions and rules are as follows:

Definitions

Source block: Contiguous block of one or more lines of text in a source-file, bounded by beginning or end-of-file or include directives (conceptually identical to the "basic block" in optimizer term). No distinction is made between blocks that contain compilable code and those that don't.

Code segment: Contiguous LINEAR bl/basocock of DNTT (and associated SLT) entries that are generated from the same "source block". "SLT_SRC" is used here to actually refer to an SLT_SPEC entry of type SLT_SRCFILE. Same goes for SLT_FUNC.

Rules

1. One DNTT_SRCFILE and SLT_SRC must be emitted at the head of each code segment to facilitate reading backwards through the DNTT or SLT tables from any point in the segment to determine the enclosing source file. If the source-file changes within the body of a function/subprogram, a DNTT_SRCFILE/SLT_SRC pair must be emitted prior to any additional DNTT or SLT entries generated by the remainder of that function/subprogram.
2. One DNTT_SRCFILE/SLT_SRC pair is always emitted **immediately** before any DNTT_FUNC/SLT_FUNC. Exception: a DNTT_SA and associated DNTT_XREF may appear between a DNTT_FUNC and its preceding DNTT_SRCFILE. There can be nothing between the SLT_SRC and the SLT_FUNC. The DNTT_SRCFILE (preceding the DNTT_FUNC) must name the file containing the functions declaration. The SLT_FUNC must contain the line number of the line in the function's declaration where the function's name appears. This line number must match the line number that appears in the XT record denoting the function's declaration. The SLT_END associated with the SLT_FUNC must contain the line number of the source line containing the scope-closing token (i.e. "}" or "end").
3. One DNTT_SRCFILE/SLT_SRC pair must be emitted for a source file that otherwise would not be mentioned in the DNTT i.e. source files that do not generate a code segment. This is required for static analysis only.

Notes:

Listing files and listing file line numbers may be used in place of source files and source file line numbers. A special compiler option will designate which is generated by the compiler

SRCFILE names are exactly as seen by the compiler, i.e. they may be relative, absolute, or whatever. C include file names must be given as absolute paths if found "in the usual place", i.e., /usr/include/...

8.3.2 Code-class ("Scoping") DNTT Entries

- **DNTT_MODULE structure definition:**

```
struct DNTT_MODULE {          /*5 words */
    BITS                      extension: 1;
    KINDTYPE                  kind: 10;
    BITS                      unused: 21;
    VTPOINTER                 name;
    VTPOINTER                 alias;
    DNTTPOINTER              dummy;
    SLTPOINTER                address;
};
```

Fields definition:

extension: Always zero.
kind: always K_MODULE type.
unused: 21 bits filler to the end of 1st word.
name: Module name.
alias: Alternate name, if any.

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dummy: 4th word must be DNTTPOINTER.
address: Code and text location.

One MODULE is emitted for the start of each Pascal/Modcal module or C source file (C sources are considered a nameless module). "address" points to a special SLT entry, but the code location is known from context in the SLT.

In the case of languages that do not support modules (such as FORTRAN) a DNTT_MODULE and DNTT_END pair are not used. Every MODULE must have a matching END (see below). If a Pascal/Modcal module has a module body (some code), the latter must be represented by a FUNCTION-END pair as well (see below).

For items within a module, the public bit is true if that item is exported by the module. If the public bit of an item is set, that item is visible within any module or procedure that imports the module containing the item. If the public bit of an item is not set, then the item is only visible within the module.

The "dummy" field exists only because the first word of each extension block must be a DNTTPOINTER; it is important only that the extension bit of the DNTTPOINTER be set.

The MODULE DNTT should be used only in the LNTT.

- **DNTT_FUNC structure definition:**

```
struct DNTT_FUNC {
/*0*/  BITS          extension:1;          /* always zero */
        KINDTYPE    kind: 10;           /* K_FUNCTION, K_ENTRY,
        K_BLOCKDATA, or,
        KMEMFUNC */
        BITS          public: 1;         /* 1 => globally visible */
        LANGTYPE     language: 4;       /* type of language */
        BITS          level: 5;         /* nesting level (top level =0)*/
        BITS          optimize: 2;      /* level of optimization */
        BITS          varargs: 1;       /* ellipses. Pascal/800 later */
        BITS          info: 4;          /* lang-specific stuff; F_xxxx*/
#ifdef CPLUSPLUS
        BITS          inlined: 1;
        BITS          localloc: 1;      /* 0 at top, 1 at end of block */
#endif
#ifdef TEMPLATES
        BITS          expansion: 1;     /* 1 = function expansion */
        BITS          unused: 1;
#else /* TEMPLATES */
        BITS          unused: 2;
#endif
}
```



```
#endif /* TEMPLATES */
#else
        BITS            unused: 4;
#endif
/*1*/ VTPOINTER    name;                /* name of function */
/*2*/ VTPOINTER    alias;                /* alternate name, if any */
/*3*/ DNTTPOINTER firstparam;           /* first FPARAM, if any */
/*4*/ SLTPOINTER   address;              /* code and text locations */
/*5*/ ADDRESS      entryaddr;            /* address of entry point */
/*6*/ DNTTPOINTER retval;                /* return type, if any */
/*7*/ ADDRESS      lowaddr;              /* lowest address of function */
/*8*/ ADDRESS      hiaddr;               /* highest address of function */
};                                        /* nine words */
```

Struct `DNTT_FUNC` is used for `dfunc` and `dentry`, and `dblockdata` types.

One `FUNCTION` or `ENTRY` is emitted for each formal function declaration (with a body) or secondary entry point, respectively. They are not emitted for bodyless declarations (`FORWARD`, `EXTERNAL`, "int x ();" etc.).

A `dblockdata` is emitted for Fortran `BLOCK DATA` constructs only. "address" always points to a special `SLT` entry.

For `FUNCTION` types, the "entryaddr" field is the code address of the primary entry point of the function. The "lowaddr" field is the lowest code address of the function. The "hiaddr" field is the highest code address of the function. This both gives the size of the function and helps in mapping code locations to functions when there are anonymous (non-debuggable) functions present. These three fields should be filled in by the generation of fixups.

For `ENTRY` types, the "entryaddr" field points to the proper code location for calling the function at the secondary entrypoint, and the "lowaddr" and "hiaddr" fields are nil (zero). For a `FORTRAN` subroutine with alternate entries, `DNTT_DVARS` are required to represent the parameters, see the `DNTT_FPARAM` definition for the details.

For `BLOCKDATA` types, the "public" bit should be set to 1, the "optimize" field should be set to the optimized level when compiling with `-O`, the "level", "varargs" and "info" fields should all be 0. The "firstparam" field should be `DNTTNIL`. The "entryaddr" and "lowaddr" fields should be 0, and the "highaddr" field should be `FFFFFFFFC` (-4). The "retval" field should be set to `T_UNDEFINED`, with length 0. An `SLT_FUNCTION/SNT_END` pair should be emitted for each `DNTT_FUNC` (`BLOCKDATA`).

Every `FUNCTION` or `BLOCKDATA` must have a matching `END` (see below).

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For languages in which a functions return value is set by assigning the value to the function name (such as FORTRAN & Pascal), a DVAR entry should also be emitted for the function. The address of this DVAR for the function should be the address of the answer spot for the function. This will allow the user to display the current return value while the function is executing.

The "varargs" field indicates whether the function was declared as having a variable-length parameter list. This is currently possible only via ANSI/C function-prototype "ellipses" (...). The "info" field provides additional language-specific characteristics of the function and/or its parameter-list.

The localloc (local variables location) is currently only used in the following context: If the function language is LANG_CPLUSPLUS, then 0 means that locals are at the beginning of the block, and 1 means that locals appears at the end of a block. For all other languages this bit is not used.

The FUNCTION DNTT should be used only in the LNTT.

o DNTT_DOC_FUNC structure definition

```
struct DNTT_DOC_FUNC {
/*0*/ BITS    extension: 1; /* always zero */
        KINDTYPE kind: 10; /* K_DOC_FUNCTION or */
                /* K_DOC_MEMFUNC */
        BITS    public: 1; /* 1 => globally visible */
        LANGTYPE language: 4; /* type of language */
        BITS    level: 5; /* nesting level (top level = 0)*/
        BITS    optimize: 2; /* level of optimization */
        BITS    varargs: 1; /* ellipses. Pascal/800 later */
        BITS    info: 4; /* lang-specific stuff; F_xxxx */
        BITS    inlined: 1;
        BITS    localloc: 1; /* 0 at top, 1 at end of block */
}
```

```
        BITS    expansion: 1; /* 1 = function expansion */
        BITS    doc_clone: 1;

/*1*/ VTPOINTER  name;      /* name of function */
/*2*/ VTPOINTER  alias;     /* alternate name, if any */
/*3*/ DNTTPOINTER firstparam; /* first FPARAM, if any */
/*4*/ SLTPOINTER  address;   /* code and text locations */
/*5*/ ADDRESS    entryaddr;  /* address of entry point */
/*6*/ DNTTPOINTER retval;    /* return type, if any */
/*7*/ ADDRESS    lowaddr;    /* lowest address of function */
/*8*/ ADDRESS    hiaddr;     /* highest address of function */
/*9*/ DNTTPOINTER inline_list; /* pointer to first inline */
/*10*/ LTPOINTER  lt_offset;  /* start of frag/cp line table */
/*11*/ CTXTPOINTER ctxt_offset; /* start of context table for this
                                routine */
}; /* twelve words */
```

The DNTT_DOC_FUNC is an expanded version of the DNTT_FUNC, and is generated for DOC code. It supplies additional information needed for DOC: a list of the inlined instances, and the start of the lines table and context table for the routine.

- **DNTT_BEGIN structure definition:**

```
struct DNTT_BEGIN {
```

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```
/*0*/ BITS      extension: 1; /* always zero      */
      KINDTYPE  kind: 10; /* always K_BEGIN      */
#ifdef CPLUSPLUS
      BITS      classflag : 1; /* beginning of class def'n */
      BITS      doc_bb_repos: 1; /* basic blocks repositioned */
#else
      BITS      unused1 : 1;
      BITS      doc_bb_repos: 1; /* basic blocks repositioned */
#endif
      BITS      unused2 :19;
/*1*/ SLTPOINTER address; /* code and text locations */
/*2*/ DNTTPOINTER doc_extensionptr; /* ptr to extension block */
}; /* three words */
```

BEGINs are emitted as required to open a new (nested) scope for any type of variable or label, at any level within MODULE-END and FUNCTION-END pairs. Every BEGIN must have a matching END (see below). "address" points to a special SLT entry, but the code location is known from context in the SLT. Because a DNTT BEGIN-END is used to indicate a new scope, the Pascal BEGIN-END pair does not produce a DNTT BEGIN-END, while the C { } construct does.

The BEGIN DNTT should be used only in the LNTT.

o DNTT_BEGIN_EXT structure definition

The DNTT_BEGIN_EXT record is used for blocks of code which have been moved out of their original scope. This is to support fragmentation of an originally contiguous block of code within a BEGIN/END range

caused by basic block repositioning. Each DNTT_BEGIN_EXT supports upto 3 additional statement ranges for the block.

```
struct DNTT_BEGIN_EXT {
/*0*/ BITS    extension: 1;

        KINDTYPE  kind: 10;    /* K_BEGIN_EXT */

        BITS    unused: 21;

/*1*/ DNTTPOINTER  begin_scope;    /* back ptr to ntt begin */
/*2*/ SLTPOINTER  address1;    /* pointer to SLT begin */
/*3*/ DNTTPOINTER  next_extension; /* next extension block if any */
/*4*/ SLTPOINTER  address2;
/*5*/ SLTPOINTER  address3;

};                /* six words */
```

o DNTT_INLN structure definition

The DNTT_INLN record represents an inline expansion of a routine.

Each DNTT_INLN has a matching DNTT_END. Within the DNTT_INLN / DNTT_END pair will be DNTT_FPARAMs and DNTT_DVARs representing any parameters and locals of the inlined routine. There can also be additional DNTT_INLN / DNTT_END pairs for routines that have been inlined inside of the inlined routine.

```
struct DNTT_INLN {
/*0*/ BITS    extension: 1; /* always zero    */
```

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```
        KINDTYPE   kind: 10; /* always K_INLN      */
        BITS       unused: 21;
/*1*/ SLTPOINTER  address; /* code and text locations */
/*2*/ CTXTPOINTER cxtt_tag; /* inline context tag */
/*3*/ DNTTPOINTER next_inln; /* pointer to next DNTT_INLN */
                               /* for this function (if any) */
/*4*/ ADDRESS    lowaddr; /* address of first inst of inline */
/*5*/ ADDRESS    hiaddr; /* address of last inst of inline */
}; /* six words */
```

- **DNTT_COMMON structure definition:**

```
struct DNTT_COMMON {
/*0*/  BITS          extension: 1; /* always zero */
        KINDTYPE    kind: 10; /* always K_COMMON */
        BITS        unused: 21;
/*1*/  VTPOINTER    name; /* name of common block */
/*2*/  VTPOINTER    alias; /* alternate name, if any */
}; /* three words */
```

COMMONs are used to indicate that a group of variables are members of a given FORTRAN common block. For each common block, a DNTT_COMMON is emitted, followed by a DNTT_SVAR for each member of the common block, and finally a DNTT_END. If type information is required for a member of the common block (such as an array), it may also be within the DNTT_COMMON, DNTT_END pair.

The COMMON DNTT should be used only in the LNTT.

- **DNTT_WITH structure definition:**

```
struct DNTT_WITH {
/*0*/  BITS          extension: 1; /* always zero */
        KINDTYPE    kind: 10; /* always K_WITH */
```

```
        BITS          addrtype: 2;    /* 0 => STATTYPER */
                                           /* 1 => DYNTYPER */
                                           /* 2 => REGTYPER */
        BITS          indirect: 1;    /* 1 => pointer to object */
        BITS          longaddr: 1;    /* 1 => in long pointer space */
        BITS          nestlevel: 6;   /* # of nesting levels back */
        BITS          unused: 11;
/*1*/ long          location;        /* where stored (allocated) */
/*2*/ SLTPOINTER    address;
/*3*/ DNTTPOINTER  type;            /* type of with expression */
/*4*/ VTPOINTER    name;            /* name of with expression */
/*5*/ unsigned long offset;        /* byte offset from location */
};                                  /* six words */
```

WITHs are emitted to open a with scope. Like a BEGIN, a WITH requires a matching END to close the scope. A single WITH statement possessing more than one record expression, should be handled as multiple nested withs with only one expression each.

The "addrtype" field indicates the addressing mode used for the record expression, and along with the "indirect" field, tells how to interpret the "location" and "offset" fields. Thus, depending upon the value of "addrtype", "location" may contain a short pointer, an offset from the local frame pointer, or a register number. If "nestlevel" is non-zero and "addrtype" is DYNTYPER, the address for the record expression is computed by tracing back "nestlevel" static links and using "location" as an offset from the frame pointer at that level. (This situation occurs only on the HP9000 FOCUS architecture.) The use of the "offset" field is the same as for the DNTT_SVAR entry (see below). The "type" field is the type of the record expression. The "name" field is the symbolic representation of the record expression (ex. "p[i]^"). "address" points to a special SLT, but the code location is known from context in the SLT.

The WITH DNTT should be used only in the LNTT.

- **DNTT_END structure definition:**

```
struct DNTT_END {
/*0*/ BITS          extension: 1;    /* always zero */
        KINDTYPER   kind: 10;      /* always K_END */
        KINDTYPER   endkind: 10;   /* DNTT kind closing scope for */
#ifdef CPLUSPLUS
        BITS          classflag: 1; /* end of class def'n */
        BITS          unused: 10;
#endif
```

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```
#else
        BITS          unused: 11;
#endif
/*1*/ SLTPOINTER  address;          /* code and text locations */
/*2*/ DNTTPOINTER beginscope;      /* start of scope */
};                                  /* three words */
```

ENDs are emitted as required to close a scope started by a MODULE, FUNCTION, WITH, COMMON, or BEGIN (but not an ENTRY).

Each points back to the DNTT entry that opened the scope. "endkind" indicates which kind of DNTT entry is associated with the END and is filled in by the preprocessor. "address" points to a special SLT entry, but the code location is known from context in the SLT.

The END DNTT should be used only in the LNTT.

- **DNTT_IMPORT structure definition:**

```
struct DNTT_IMPORT {
/*0*/  BITS          extension: 1;    /* always zero */
        KINDTYPE    kind: 10;       /* always K_IMPORT */
        BITS          explicit: 1;   /* module directly imported */
        BITS          unused: 20;
/*1*/  VTPOINTER    module;          /* module imported from */
/*2*/  VTPOINTER    item;            /* name of item imported */
};                                  /* three words */
```

Within a module, there is one IMPORT entry for each imported module, function, or variable. The item field is nil when an entire module is imported. Used only by Pascal/Modcal. Note that exported functions and variables have their public bits set.

The "explicit" flag indicates the module was directly imported. When not set, the module was imported by an imported module.

The IMPORT DNTT should be used only in the LNTT.

- **DNTT_LABEL structure definition:**

```
struct DNTT_LABEL {
/*0*/  BITS          extension: 1;    /* always zero */
```



```
        KINDTYPE    kind: 10; /* always K_LABEL */
        BITS        unused: 21;
/*1*/ VTPOINTER   name;      /* name of label */
/*2*/ SLTPOINTER  address;    /* code and text locations */
};                                     /* three words */
```

One LABEL is emitted for each source program statement label, referencing the matching physical line (SLT entry). An SLT pointer is used, instead of just a line-number, so a code location is known for setting a breakpoint. This is the only case of SLTPOINTER that points to a normal (not special) SLT entry.

If a label appears at the very end of a function (after all executable code), a normal SLT entry must be emitted for it anyway. In this case the SLT entry points to an exit (return) instruction.

Numeric labels are named as the equivalent character string with no leading zeroes, except in those languages where the leading zeroes are significant (i.e. COBOL).

The LABEL DNNTT should be used only in the LNNTT.

8.3.3 Storage-class ("Name") DNNTT Entries

- **DNNTT_FPARAM structure definition:**

```
struct DNNTT_FPARAM {
/*0*/ BITS        extension: 1; /* always zero */
        KINDTYPE   kind: 10; /* always K_FPARAM */
        BITS       regparam: 1; /* 1 => REGTYPE, not DYNTYPE */
        BITS       indirect: 1; /* 1 => pass by reference */
        BITS       longaddr: 1; /* 1 => in long pointer space */
        BITS       copyparam: 1; /* 1 => Copied to a local */
                        /* only for fortran strings */
#ifdef CPLUSPLUS
        BITS       dflt: 1; /* default parameter value? */
```

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```
        BITS      doc_ranges: 1; /* 1 => location is range list */
#else
        BITS      unused1: 1;

        BITS      doc_ranges: 1; /* 1 => location is range list */
#endif

        BITS      misc_kind: 1; /* 1 => misc is a dntt_ptr */

        BITS      unused2: 14;

/*1*/ VTPOINTER  name; /* name of parameter */
/*2*/ DYNTYPE    location; /* where stored */
/*3*/ DNTTPOINTER type; /* type information */
/*4*/ DNTTPOINTER nextparam; /* next FPARAM, if any */
/*5*/ int        misc; /* assorted uses */

}; /* six words */
```

FPARAMs are chained together in parameter list order (left to right) from every FUNCTION, ENTRY, or FUNCTYPE (see below), one for each parameter, whether or not the type is explicitly declared.

For unnamed parameters, the FPARAM name is "*". "regparam" implies that the storage location given is to be interpreted as a REGTYPE, not a DYNTYPE, that is, the parameter was passed in a register. "indirect" implies that the storage location given contains a data pointer to the parameter described, not the parameter itself, due to a call by reference (Pascal VAR, for instance). In the case where a call-by-value parameter is too big to be passed in the parameter list (e.g., a copied-value parameter in Pascal), the "location" must be given as the actual (post-copy) location of the parameter. "longaddr" is meaningful only for varparams, and indicates that the storage location given contains a 64 bit Spectrum long pointer. The long pointer could be in 2 consecutive words, or in the case of a regparam, two consecutive registers. "copyparam" implies that the parameter has been copied to a local, and thus the location is relative to the sp of the current procedure, not the sp of the previous procedure. "misc" is for assorted values. Currently, if the parameter is of type T_FTN_STRING_S300 then the "misc" field contains the SP relative offset of the word containing the length of the string

In the case of a FORTRAN routine with alternate entries, DNTT DVARs also must be emitted for each parameter. The reason is that with FORTRAN alternate entries, the same parameter can be in two different entry's parameter lists, in a different location (ex. the parameter "x" in "subroutine a(x,y,z)" and "entry b(v,w,x)") and yet they both represent the same parameter. Thus in order to insure a consistent address for such parameters, the compiler allocates a local temporary, and the prologue code for each entry copies the parameters into the local temps. So, to insure that the debugger can find the parameters, a DNTT DVAR must be generated for each temporary, with the name of the DVAR being the name of the FPARAM for which the temp. was allocated.

The FPARAM DNTT should be used only in the LNTT.

- **DNTT SVAR and DVAR structures definition:**

```
struct DNTT_SVAR {
/*0*/ BITS      extension: 1; /* always zero          */
      KINDTYPE   kind:    10; /* always K_SVAR          */
      BITS       public:   1; /* 1 => globally visible */
      BITS       indirect: 1; /* 1 => pointer to object */
      BITS       longaddr: 1; /* 1 => in long pointer space */
#ifdef CPLUSPLUS
      BITS       staticmem: 1; /* 1 => member of a class */
      BITS       a_union:  1; /* 1 => anonymous union member */
      BITS       doc_ranges: 1; /* 1 => location is range list */
#else
      BITS       unused1:  2;
      BITS       doc_ranges: 1; /* 1 => location is range list */
#endif
      BITS       unused2: 15;
/*1*/ VTPOINTER  name;      /* name of object (variable) */
/*2*/ STATYPE    location;  /* where stored (allocated) */
/*3*/ DNTTPOINTER type;    /* type information          */
/*4*/ unsigned long offset; /* post indirection byte offset */
/*5*/ unsigned long displacement; /* pre indirection byte offset */
};
/* six words          */

struct DNTT_DVAR {
/*0*/ BITS      extension: 1; /* always zero          */
```

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```
KINDTYPE    kind:  10; /* always K_DVAR          */
BITS        public: 1; /* 1 => globally visible */
BITS        indirect: 1; /* 1 => pointer to object */
BITS        regvar:  1; /* 1 => REGTYPE, not DYNTYPE */
#ifdef CPLUSPLUS
BITS        a_union: 1; /* 1 => anonymous union member */
BITS        doc_ranges:1; /* 1 => location is range list */
#else
BITS        unused1: 1;
BITS        doc_ranges:1; /* 1 => location is range list */
#endif
BITS        unused2: 16;
/*1*/ VTPOINTER  name;      /* name of object (variable) */
/*2*/ DYNTYPE    location;  /* where stored (allocated) */
/*3*/ DNTTPOINTER type;     /* type information          */
/*4*/ unsigned long offset; /* post indirection byte offset */
                               /* for use in cobol structures */
/*5*/ unsigned long future; /* padding to 3-word block end */
};                               /* six words                */
```

SVARs describe static variables (with respect to storage, not visibility) and DVARs describe dynamic variables, and also describe register variables. Note that SVARs have an extra word, "offset", not needed for the other types. This provides for direct data which is indexed from a base, and indirect data which is accessed through a pointer, then indexed.

The "location" field of an SVAR will require a fixup. An example of when the offset field can be useful, is a FORTRAN common block. In a common block declaration such as "common /marx/ groucho, harpo, chico", the symbol "marx" is the only global symbol. If "marx" is accessed indirectly, then the address of "harpo" would contain the address of "marx" in the location field (with the indirect bit on), and the offset of "harpo" from "marx" in the offset field. If "marx" is not indirect, then location field can be filled in by a fixup of the form address(marx) + offset of harpo, and the offset field is not needed.

If a variable is defined in a shared library and referenced by the main program, the SVAR in the main program will have its "location" field point to the data-linkage table (DLT) entry for the variable. The SVAR consumer will know implicitly that the reference is indirect because the "location" field address falls within the bounds of the

DLT.

The compilers must emit SVARs even for data objects the linker does not know about by name, such as variables in common blocks.

As in the FPARAM entry, the longaddr field indicates the use of a Spectrum long pointer, and is valid only if the indirect flag is true. The "regvar" field also has the same meaning as in the FPARAM case.

For languages in which a functions return value is set by assigning the value to the function name (such as FORTRAN & Pascal), a DVAR entry should also be emitted for the function. The address of this DVAR for the function should be the address of the answer spot for the function. This will allow the user to display the current return value while the function is executing.

For a FORTRAN subroutine with alternate entries, DNNT_DVARs are required to represent the parameters, see the DNNT_FPARAM definition for the details.

The SVAR can be used in both the GNNT and LNNT, while the DVAR is only applicable to the LNNT.

- **DNNT_CONST structure definition:**

```
struct DNNT_CONST {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10;       /* always K_CONST */
        BITS        public:1;      /* 1 => globally visible */
        BITS        indirect:1;    /* 1 => pointer to object */
        LOCDESCTYPE locdesc:3;     /* meaning of location field */
#ifdef CPLUSPLUS
        BITS        classmem:1;    /* 1 => member of a class */
        BITS        unused:15;
#else
        BITS        unused:16;
#endif
/*1*/  VTPOINTER    name;           /* name of object */
/*2*/  STATYPE     location;        /* where stored */
/*3*/  DNNTPOINTER type;           /* type information */
/*4*/  unsigned long offset;        /* post indirection byte offset */
/*5*/  unsigned long displacement; /* pre indirection byte offset */
}
```

```
}; /* six words */
```

The value of `locdesc` determines the meaning of location. Compilers are free to use any of the three types (`LOC_IMMED`, `LOC_PTR`, `LOC_VT`) as feasible and appropriate. They might, for example, merely dump all `CONST` values into the VT, with some redundancy, if they could do no better. Ideally, each compiler would use all three types according to whether the constant is stored in an immediate instruction (so a copy is needed here), in code or data space, or nowhere else, respectively.

If `locdesc == LOC_PTR`, `CONST` is very much like an `SVAR`, and the indirect and offset values are relevant.

The `CONST DNTT` can be used in both the `GNTT` and `LNTT`.

8.3.4 Type-class ("Type") DNTT Entries

- **DNTT_TYPE structure definition:**

```
struct DNTT_TYPE {
/*0*/  BITS          extension:1; /* always zero */
      KINDTYPE      kind:10;     /* either K_TPEDEF or */
                                      /* K_TAGDEF */
      BITS          public:1;    /* 1 => globally visible */
      BITS          typeinfo:1;  /* 1 => type info available */
      BITS          unused:19;
/*1*/  VTPOINTER    name;        /* name of type or tag */
/*2*/  DNTTPOINTER type;        /* type information */
}; /* three words */
```

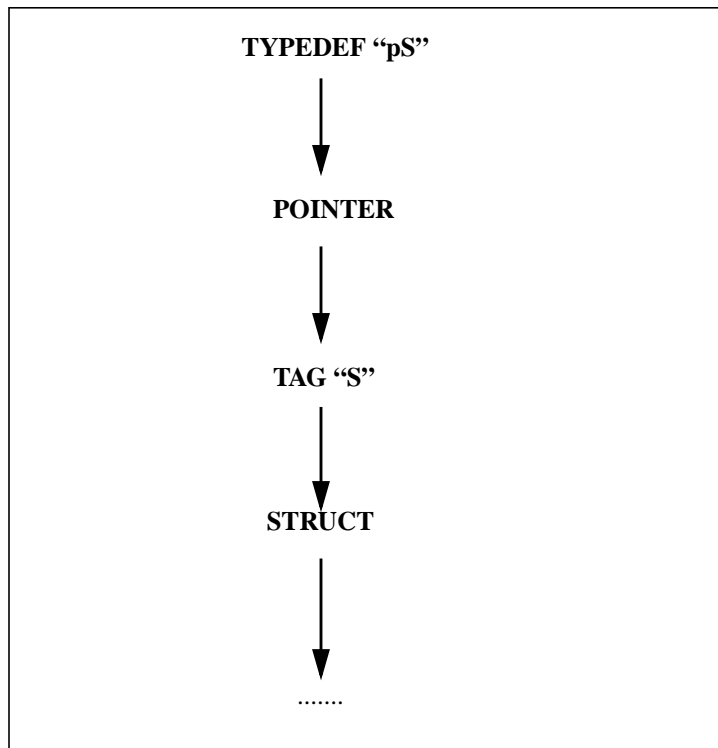
The `DNTT_TYPE` type is used for `dtype` and `dtag` entries. `TPEDEFs` are just a way of remembering names associated with types declared in Pascal, via "type" sections, or in C, via "typedef"s. `TAGDEFs` are used for C "struct", "union", and "enum" tags, which may be named identically to "typedef"s in the same scope. `TAGDEFs` always point at `STRUCTs`, `UNIONS`, or `ENUMs` (see below), and provide a way to "hang" a name onto a subtree.

Note that named types point directly to the underlying structures, not to intervening `TPEDEFs` or `TAGDEFs`. Type information in `TPEDEFs` and `TAGDEFs` point to the same structures independent of named instantiations of the types.

For example:

typedef struct S {...} *pS;

would generate something like this:



And:

```
typedef enum E { ... } EEE;
```

would generate something like this:

TYPDEF “EEE”



TAG “E”



ENUM



....

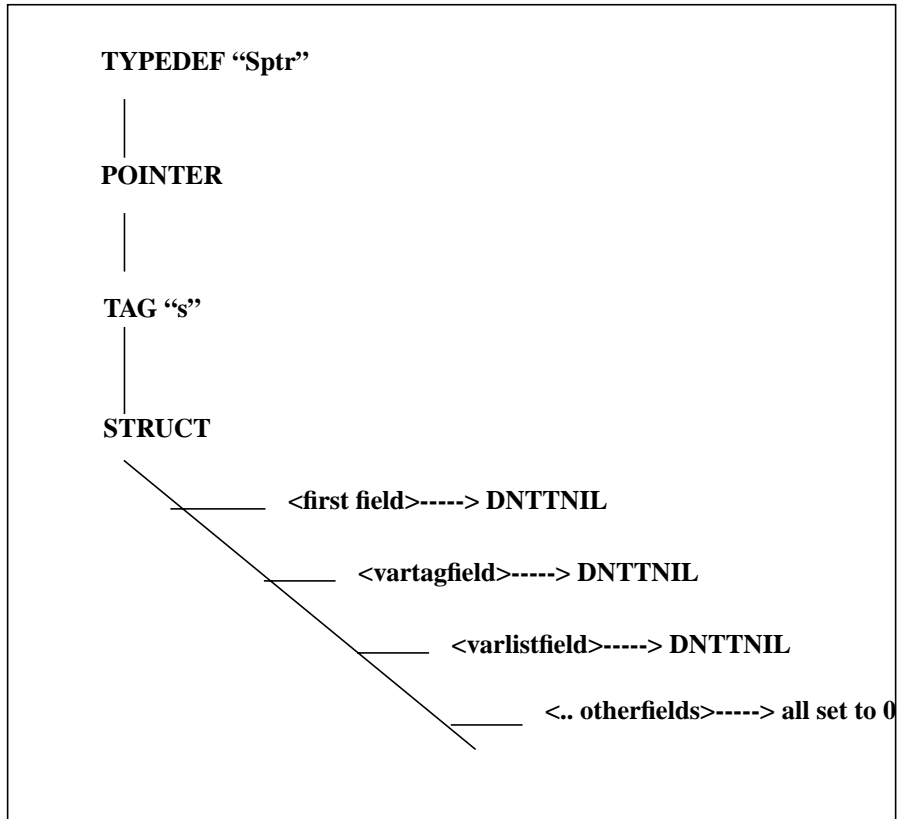
Note also that variables (of a named non-base type) must point to TYPEDEF or TAGDEF dntt, and not the underlying structures. If this is not done, the removal of duplicate global information is impossible.

The "typeinfo" flag only applies to TAGDEFs. When not set, it is used to indicate that an underlying struct, union, or enum is named, but the actual type is not declared. In general, "typeinfo" will be set to 1. It will be set to a 0 if the type subtree is not available. Consider the C file

```
*typedef struct s *Sptr;  
  
*main(){}
```

which is a valid compilation unit with "struct s" defined in another file. For this case, the "typeinfo" for TAGDEF "s" will be set to 0, and "type" points to a "nil" DNTT_STRUCT (i.e. a DNTT_STRUCT entry with its "firstfield", "vartagfield", and "varlist" fields set to DNTTNIL and its "declaration" and "bitlength" fields set to 0).

Graphically:



Thus, whenever "typeinfo" is 0, "type" must point to an appropriate DNTT entry which has all its fields correctly NIL'ed. This applies to *named* DNTT_STRUCT's, DNTT_UNION's, and DNTT_ENUM's.

The TYPEDEF and TAGDEF DNTTs may be used in both the GNTT and LNTT.

- **DNTT_POINTER structure definition:**

```
struct DNTT_POINTER {
/*0*/  BITS          extension: 1;    /* always zero */
#ifdef CPLUSPLUS
        KINDTYPE    kind:  10;     /* K_POINTER or K_REFERENCE */
#else
        KINDTYPE    kind:  10;     /* always K_POINTER */
#endif
        BITS        unused: 21;
/*1*/  DNTTPOINTER pointsto;        /* type of object */
/*2*/  unsigned long bitlength;     /* size of pointer, not object */
};                                     /* three words */
```

- **DNTT_ENUM and MEMENUM structures definition:**

```
struct DNTT_ENUM {
/*0*/  BITS          extension: 1;    /* always zero */
        KINDTYPE    kind:  10;     /* always K_ENUM */
        BITS        unused: 21;
/*1*/  DNTTPOINTER firstmem;        /* first MEMENUM (member) */
/*2*/  unsigned long bitlength;     /* packed size */
};                                     /* three words */
```

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```
struct DNTT_MEMENUM {
/*0*/  BITS          extension: 1;    /* always zero */
        KINDTYPE    kind: 10;       /* always K_MEMENUM */
#ifdef CPLUSPLUS
        BITS          classmem: 1;   /* 1 => member of a class */
        BITS          unused: 20;
#else
        BITS          unused: 21;
#endif
/*1*/  VTPOINTER    name;           /* name of member */
/*2*/  unsigned long value;         /* equivalent number */
/*3*/  DNTTPOINTER nextmem;        /* next MEMENUM, else */
                                           /* ENUM type */
};                                       /* four words */
```

Each ENUM begins a chain of (name, value) pairs. The nextmem field of the last memenum, should be DNTT NIL. The POINTER, ENUM, and MEMENUM DNTTs can all be used in both the GNTT and LNTT.

- **DNTT SET, SUBRANGE, and ARRAY structures definition:**

```
struct DNTT_SET {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10;       /* always K_SET */
        BITS          declaration:2; /* normal, packed, or crunched */
        BITS          unused:19;
/*1*/  DNTTPOINTER subtype;        /* type implies bounds of set */
/*2*/  unsigned long bitlength;    /* packed size */
};                                       /* three words */

struct DNTT_SUBRANGE {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10;       /* always K_SUBRANGE */
        BITS          dyn_low:2;    /* >0 => nonconstant low bound */
};
```

```
        BITS          dyn_high:2;    /* >0 => nonconstant high bound */
        BITS          unused: 17;
/*1*/ long          lowbound;      /* meaning depends on subtype */
/*2*/ long          highbound;     /* meaning depends on subtype */
/*3*/ DNTTPOINTER  subtype;       /* immediate type or ENUM */
/*4*/ unsigned long bitlength;     /* packed size */
};                                  /* five words */

struct DNTT_ARRAY {
/*0*/ BITS          extension:1;    /* always zero */
        KINDTYPE     kind: 10;      /* always K_ARRAY */
        BITS          declaration: 2; /* normal, packed, or crunched */
        BITS          dyn_low: 2;    /* >0 => nonconstant low bound */
        BITS          dyn_high: 2;   /* >0 => nonconstant high bound */
        BITS          arrayisbytes:1; /* 1 => array size is in bytes */
        BITS          elemisbytes: 1; /* 1 => elem. size is in bytes */
        BITS          elemorder: 1;  /* 0 => in increasing order */
        BITS          justified: 1;   /* 0 => left justified */
        BITS          unused: 11;
/*1*/ unsigned long arraylength;    /* size of whole array */
/*2*/ DNTTPOINTER  indextype;      /* how to index the array */
/*3*/ DNTTPOINTER  elemtype;       /* type of each array element */
/*4*/ unsigned long elemlength;    /* size of one element */
};                                  /* five words */
```

The `dyn_low` and `dyn_high` fields are non-zero only if the `DNTT_SUBRANGE` is defining the range of an array index, otherwise they are always zero. The `dyn_low` and `dyn_high` bits are duplicated in the `DNTT_SUBRANGE` defining the range of the array index (so `sllic` can fix the pointers). "dyn_low" indicates whether the lower bound for the subscript of the array is dynamic. If the `dyn_low` field is zero, then the `lowbound` field of the `DNTT_SUBRANGE` entry, pointed to by the `indextype` field in the `DNTT_ARRAY` entry, is interpreted as a constant lower bound. If the `dyn_low` field is 1, then the `lowbound` field of the `DNTT SUBRANGE` is interpreted as a `DYNTYPE` giving a local address where the lower bound can be found. If the `dyn_low` field is 2, then the `lowbound` field of the `DNTT_SUBRANGE` is interpreted as a `DNTTPOINTER` to a variable whose value is the lower bound (needed if the lower bound is a static variable). The `dyn_low` value of 3 is not used. The "dyn_high" bit has a similar meaning relating to the upper bound. If an upper bound for an array parameter is not given (like assumed size arrays in FORTRAN, or "char foo[]" in C) then the upper bound in the `DNTT_SUBRANGE` should be the largest integer that fits in a long integer, so that any value the user can give is legal.

"arrayisbytes" indicates that the field "arraylength" contains the length in bytes rather than bits. This is needed on Spectrum where an array could be up to 2**32 bytes. A value of zero for bitsize will be used to represent 2**32.

"elemisbytes" indicates that the field "elemlength" contains the elem. length in bytes rather than bits. The "elemlength" field contains the not the "true" size of an array element, but the size allocated to each element within the array (the "true" size plus any wasted bits on the left or right). As an example for a

Pascal array of a 13 bit structure, the array element size might equal 16, with the justified field equal to 0 to indicate the structure is left justified within the 16 bits. The "true" size of the structure would be found in the size field of the

DNTT_STRUCT pointed to by the "elemtype" field of the DNTT_ARRAY.

"indextype" typically points to a SUBRANGE for bounds.

"elemtype" may point to another ARRAY for multi-dimensional arrays. Row or column precedence in the language is reflected in the order of the ARRAY entries on the chain. For example, in Pascal, which is row-precedent, an array declared [1..2, 3..4, 5..6] would result in "array 1..2 of array 3..4 of array 5..6 of ...". The same declaration in FORTRAN, which is column-precedent, would result in "array 5..6 of array 3..4 of array 1..2 of ...". This makes index-to-address conversion much easier. Either way an expression handler must know the precedence for the language.

The SET, SUBRANGE, and ARRAY DNTTs can be used in both the GNTT and LNTT.

- **DNTT STRUCT structure definition:**

```
struct DNTT_STRUCT {
/*0*/  BITS           extension:1;    /* always zero */
        KINDTYPE     kind:10;       /* always K_STRUCT */
        BITS         declaration:2;  /* normal, packed, or crunched */
        BITS         unused:19;
/*1*/  DNTTPOINTER  firstfield;     /* first FIELD, if any */
/*2*/  DNTTPOINTER  vartagfield;    /* variant tag FIELD, or type */
/*3*/  DNTTPOINTER  varlist;        /* first VARIANT, if any */
/*4*/  unsigned long bitlength;     /* total at this level */
};                                     /* five words */
```

The "declaration", "vartagfield", and "varlist" fields apply to Pascal/Modcal records only and are nil for record structures in other languages. If there is a tag, then the "vart-

agfield" points to the FIELD DNTT describing the tag. Otherwise, the "vartagfield" points to the tag type.

The STRUCT DNTT may be used in both the GNTT and LNTT.

- **DNTT UNION structure definition:**

```
struct DNTT_UNION {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10;       /* always K_UNION */
        BITS          unused: 21;
/*1*/  DNTTPOINTER firstfield;     /* first FIELD entry */
/*2*/  unsigned long  bitlength;    /* total at this level */
};                                       /* three words */
```

This type of DNTT_UNION supports C unions only and is not used otherwise.

Since STRUCTUREs and UNIONs are not packable inside of outer STRUCTUREs and UNIONs, their bitlengths tell their actual (not necessarily packed) size, according only as to how they are internally packed.

The UNION DNTT may be used in both the GNTT and LNTT.

- **DNTT FIELD structure definition:**

```
struct DNTT_FIELD {
/*0*/  BITS          extension: 1;    /* always zero */
        KINDTYPE    kind: 10;       /* always K_FIELD */
#ifdef CPLUSPLUS
        BITS          visibility:2;   /* pub = 0, prot = 1, priv = 2 */
        BITS          a_union:1;     /* 1 => anonymous union member */
        #ifdef TEMPLATES
        BITS          staticMem:1;   /* 1 -> static member of a template */
        BITS          unused:17;
        #else /* TEMPLATES */

```

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```
        BITS            unused:18;
        #endif /* TEMPLATES */

#else /* normal code, not C++ support */
        BITS            unused:21;
#endif
/*1*/  VTPOINTER    name;           /* name of field, if any */
/*2*/  unsigned long bitoffset;     /* of object itself in STRUCT */
/*3*/  DNTTPOINTER type;           /* type information */
/*4*/  unsigned long bitlength;    /* size at this level */
/*5*/  DNTTPOINTER nextfield;      /* next FIELD in STRUCT, if any */
};                                   /* six words */
```

This type describes the fields in Pascal records and C structures and unions. The bitoffset is from the start of the STRUCT or UNION that started the chain, to the start of the object itself, ignoring any padding. Note that bitoffset does not have to be on a byte boundary. For unions, each bitoffset should be zero since all fields overlap.

The bitlength field is the same as that of the type except for C bit fields, which may be a different size than the base type.

The FIELD DNTT can be used in both the GNTT and LNTT.

- **DNTT VARIANT structure definition:**

```
struct DNTT_VARIANT {
/*0*/  BITS            extension: 1;  /* always zero */
        KINDTYPE     kind: 10;      /* always K_VARIANT */
        BITS            unused: 21;
/*1*/  long            lowvarvalue;   /* meaning depends on vartype */
/*2*/  long            hivarvalue;    /* meaning depends on vartype */
/*3*/  DNTTPOINTER varstruct;        /* this variant STRUCT, if any */
/*4*/  unsigned long  bitoffset;     /* of variant, in outer STRUCT */
/*5*/  DNTTPOINTER nextvar;         /* next VARIANT, if any */
};                                   /* six words */
```


"varstruct" points to the STRUCT which in turn describes the contents of the variant. The latter might in turn point to VARIANTS of its own, and to FIELDS which point to other STRUCTs.

"lowvarvalue" and "hivarvalue" are the range of values for which this variant applies; more than one dntt VARIANT may be necessary to describe the range (e.g., 'a'..'n','q:'). A type field is unnecessary, as the type can be obtained from the "vartagfield" field of the STRUCT DNTT.

The VARIANT DNTT can be used in both the GNTT and LNTT.

- **DNTT FILE structure definition:**

```
struct DNTT_FILE {
/*0*/  BITS           extension:1;    /* always zero */
        KINDTYPE     kind:10;       /* always K_FILE */
        BITS         ispacked: 1;   /* 1 => file is packed */
        BITS         unused: 20;
/*1*/  unsigned long  bitlength;     /* of whole element buffer */
/*2*/  unsigned long  bitoffset;     /* of current element in buffer */
/*3*/  DNTTPOINTER  elemtype;       /* type and size of element */
};                                       /* four words */
```

Pascal/Modcal is the only language of interest with built-in file buffering. For Pascal/Modcal files, the symbol table tells the file element type, the sizes of the current element (via "elemtype") and the whole buffer (via "bitlength"), and the locations of the element buffer (from the parent "NAME" entry) and the element itself within the buffer, following header information (from "bitoffset").

The FILE DNTT can be used in both the GNTT and LNTT.

- **DNTT FUNCTTYPE structure definition:**

```
struct DNTT_FUNCTYPE {
/*0*/  BITS           extension:1;    /* always zero */
        KINDTYPE     kind:10;       /* always K_FUNCTYPE */
        BITS         varargs:1;     /* func-PROTO ellipses. */
        BITS         info:4;        /* lang-specific stuff; F_xxxx */
        BITS         unused:16;
};
```

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```
/*1*/ unsigned long   bitlength;      /* size of function pointer */
/*2*/ DNTTPOINTER firstparam;        /* first FPARAM, if any */
/*3*/ DNTTPOINTER retval;           /* return type, if any */
};                                     /* four words */
```

This type supports function variables in a limited way, including the parameter types (if any) and the return value type (if any).

See DNTT_FUNC for discussion of various fields.

The FUNCTYPE DNTT can be used in both the GNTT and LNTT.

- **DNTT COBSTRUCT structure definition:**

```
struct DNTT_COBSTRUCT {
/*0*/  BITS           extension:1;      /* always zero */
      KINDTYPE      kind: 10;         /* always K_COBSTRUCT */
      BITS          hasoccurs:1;      /* descendant has OCCURS clause */
      BITS          istable: 1;       /* is a table item? */
      BITS          unused:19;
/*1*/  DNTTPOINTER parent;            /* next higher data item */
/*2*/  DNTTPOINTER child;            /* 1st descendant data item */
/*3*/  DNTTPOINTER sibling;          /* next data item at this level */
/*4*/  DNTTPOINTER synonym;         /* next data item w/ same name */
/*5*/  BITS          catusage: 6;     /* category or usage of item */
      BITS          pointloc:8;      /* location of decimal point */
      BITS          numdigits:10;    /* number of digits */
      BITS          unused2:8;
/*6*/  DNTTPOINTER table;            /* array entry describing table */
/*7*/  VTPOINTER    editpgm;         /* name of edit subprogram */
/*8*/  unsigned long bitlength;      /* size of item in bits */
};                                     /* nine words */
```

This entry is used to describe COBOL data items and table items.

A Cobol variable will begin with a DNTT_SVAR, DNTT_DVAR, or DNTT_FPARAM whose "type" field is a DNTTPOINTER to a DNTT_COBSTRUCT.

"parent", "child", "sibling", and "synonym" are DNTTPOINTER to other DNTT_SVAR, DNTT_DVAR, or DNTT_FPARAMs having these particular relationships with the current DNTT_COBSTRUCT (or are set to DNTTNIL if no such relationship exists).

"hasoccurs" is set to 1 if the descendent of this COBOL element (pointed to by "child") has an OCCURS ... DEPENDING ON clause.

"istable" is set to 1 if this COBOL data item is a table. In this case, "table" will point to a DNTT_ARRAY entry describing the table.

The COBSTRUCT DNTT can be used in both the GNTT and LNTT.

- **DNTT MODIFIER structure definition:**

```
struct DNTT_MODIFIER {
/*0*/  BITS          extension:1;          /* always zero */
        KINDTYPE    kind: 10;           /* always K_MODIFIER */
        BITS        m_const:1;         /* const */
        BITS        m_static:1;       /* static */
        BITS        m_void:1;        /* void */
        BITS        m_volatile: 1;    /* volatile */
        BITS        m_duplicate:1;    /* duplicate */
        BITS        unused:16;
/*1*/  DNTTPOINTER type;              /* subtype */
};                                     /* 2 words */
```

- **The following DNTTs :**

**DNTT_GENFIELD,
DNTT_MEMACCESS,
DNTT_VFUNC,
DNTT_CLASS_SCOPE,
DNTT_FRIEND_CLASS,
DNTT_FRIEND_FUNC,
DNTT_CLASS,
DNTT_TEMPLATE,
DNTT_TEMPL_ARG,
DNTT_PTRMEM,
DNTT_INHERITANCE,
DNTT_OBJECT_ID**

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are defined to support C++ and template.

```
struct DNTT_GENFIELD {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10;       /* always K_GENFIELD */
        BITS          visibility:2; /* pub = 0, prot = 1, priv = 2 */
        BITS          a_union:1;    /* 1 => anonymous union member */
        BITS          unused:18;
/*1*/  DNTTPOINTER  field;          /* pointer to field or qualifier */
/*2*/  DNTTPOINTER  nextfield;     /* pointer to next field */
};                                       /* three words */
```

```
struct DNTT_MEMACCESS {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10; /      /* always K_MEMACCESS */
        BITS          unused:21;
/*1*/  DNTTPOINTER  classptr;      /* pointer to base class */
/*2*/  DNTTPOINTER  field;         /* pointer field */
};                                       /* three words */
```

```
struct DNTT_VFUNC {
/*0*/  BITS          extension: 1;  /* always zero */
        KINDTYPE    kind:10;       /* always K_VFUNCTION */
        BITS          pure:1;       /* pure virtual function ? */
        BITS          unused:20;
/*1*/  DNTTPOINTER  funcptr;       /* function name */
/*2*/  unsigned long vtbl_offset;  /* offset into vtbl for virtual */
};                                       /* three words */
```

```
struct DNTT_CLASS_SCOPE {
/*0*/  BITS          extension:1;    /* always zero */
        KINDTYPE    kind:10;       /* always K_CLASS_SCOPE */
        BITS          unused:21;
/*1*/  SLTPOINTER   address;       /* pointer to SLT entry */
/*2*/  DNTTPOINTER  type;         /* pointer to class type DNTT */
};                                       /* three words */
```

```
struct DNTT_FRIEND_CLASS {
/*0*/  BITS          extension:1;    /* always zero */
      KINDTYPE     kind: 10;        /* always K_FRIEND_CLASS */
      BITS          unused: 21;
/*1*/  DNTTPOINTER classptr;       /* pointer to class DNTT */
/*2*/  DNTTPOINTER next;           /* next DNTT_FRIEND */
};                                     /* three words */

struct DNTT_FRIEND_FUNC {
/*0*/  BITS          extension:1;    /* always zero */
      KINDTYPE     kind:10;         /* always K_FRIEND_FUNC */
      BITS          unused:21;
/*1*/  DNTTPOINTER funcptr;        /* pointer to function */
/*2*/  DNTTPOINTER classptr;       /* pointer to class DNTT */
/*3*/  DNTTPOINTER next;           /* next DNTT_FRIEND */
};                                     /* four words */

struct DNTT_CLASS {
/*0*/  BITS          extension:1;    /* always zero */
      KINDTYPE     kind:10;         /* always K_CLASS */
      BITS          abstract:1;     /* is this an abstract class? */
      BITS          class_decl:2;   /* 0=class,1=union,2=struct */
#ifdef TEMPLATES
      BITS          expansion:1;     /* 1=template expansion */
      BITS          unused:17;
#else /* TEMPLATES */
      BITS          unused:18;
#endif /* TEMPLATES */
/*1*/  DNTTPOINTER memberlist;      /* ptr to chain of K_[GEN]FIELDS */
/*2*/  unsigned long  vtbl_loc;      /* offset in obj of ptr to vtbl */
/*3*/  DNTTPOINTER parentlist;      /* ptr to K_INHERITANCE list */
/*4*/  unsigned long  bitlength;     /* total at this level */
/*5*/  DNTTPOINTER identlist;       /* ptr to chain of class ident's */
/*6*/  DNTTPOINTER friendlist;      /* ptr to K_FRIEND list */
#ifdef TEMPLATES
```

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```
/*7*/ DNTTPOINTER templateptr; /* ptr to template */
/*8*/ DNTTPOINTER nextexp; /* ptr to next expansion */
#else /* TEMPLATES */
/*7*/ unsigned long future2;
/*8*/ unsigned long future3;
#endif /* TEMPLATES */
}; /* nine words */

struct DNTT_TEMPLATE {
/*0*/ BITS extension:1; /* always zero */
      KINDTYPE kind:10; /* always K_TEMPLATE */
      BITS abstract:1; /* is this an abstract class? */
      BITS class_decl: 2; /* 0=class,1=union,2=struct */
      BITS unused:18;
/*1*/ DNTTPOINTER memberlist; /* ptr to chain of K_[GEN]FIELDs */
/*2*/ long unused2; /* offset in obj of ptr to vtbl */
/*3*/ DNTTPOINTER parentlist; /* ptr to K_INHERITANCE list */
/*4*/ unsigned long bitlength; /* total at this level */
/*5*/ DNTTPOINTER identlist; /* ptr to chain of class ident's */
/*6*/ DNTTPOINTER friendlist; /* ptr to K_FRIEND list */
/*7*/ DNTTPOINTER arglist; /* ptr to argument list */
/*8*/ DNTTPOINTER expansions; /* ptr to expansion list */
}; /* 9 words */
```

DNTT_TEMPLATEs only appear in the GNTT. Functions and classes templates cannot be local. (Their instantiations may be).

```
struct DNTT_TEMPL_ARG {
/*0*/ BITS extension: 1; /* always zero */
      KINDTYPE kind:10; /* always K_TEMPL_ARG */
      BITS usagetype:1; /* 0 type-name 1 expression */
      BITS unused: 20;
/*1*/ VTPOINTER name; /* name of argument */
/*2*/ DNTTPOINTER type; /* for non type arguments */
/*3*/ DNTTPOINTER nextarg; /* Next argument if any */
/*4*/ long unused2[2];
}; /* 6 words */
```

Pxdb fills in the prevexp, and nextexp in the DNTT_CLASS. Pxdb also fills in the expansions field in the DNTT_TEMPLATE.

```
struct DNTT_PTRMEM {
/*0*/  BITS          extension:1;    /* always zero */
      KINDTYPE     kind:10;        /* K_PTRMEM or
      /* K_PTRMEMFUNC */
      BITS          unused:21;
/*1*/  DNTTPOINTER pointsto;      /* pointer to class DNTT */
/*2*/  DNTTPOINTER memtype;      /* type of member */
};                                     /* three words */

struct DNTT_INHERITANCE {
/*0*/  BITS          extension:1;    /* always zero */
      KINDTYPE     kind:10;        /* K_INHERITANCE */
      BITS          Virtual:1;     /* virtual base class ? */
      BITS          visibility:2;   /* pub = 0, prot = 1, priv = 2 */
      BITS          unused:18;
/*1*/  DNTTPOINTER classname;     /* first parent class, if any */
/*2*/  unsigned long  offset;      /* offset to start of base class */
/*3*/  DNTTPOINTER next;         /* pointer to next K_INHERITANCE */
};                                     /* four words */

struct DNTT_OBJECT_ID {
/*0*/  BITS          extension:1;    /* always zero */
      KINDTYPE     kind:10;        /* K_OBJECT_ID */
      BITS          unused:21;
/*1*/  unsigned long  object_ident; /* object identifier */
/*2*/  unsigned long  offset;      /* offset to start of base class */
/*3*/  DNTTPOINTER next;         /* pointer to next K_OBJECT_ID */
/*4*/  unsigned long  segoffset;   /* for linker fixup */
};                                     /* five words */
```

8.3.5 General ("overall") DNTT Entry Format

- **Generic Entry for Easy Access:**

```
struct DNTT_GENERIC {
```

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```
        unsigned long    word [9];        /* rounded up to
};                                           /* whole number of blocks */

struct DNNT_BLOCK {                          /* easy way to deal with one block */
/*0*/  BITS              extension: 1;    /* always zero */
        KINDTYPE        kind:10;        /* kind of dnttentry */
        BITS            unused:21;
/*1*/  unsigned long    word [2];
};
```

- **Overall DNNT entry:**

```
union dnttentry {
    struct DNNT_SRCFILE    dsfile;

    struct DNNT_MODULE    dmodule;
    struct DNNT_FUNC      dfunc;
    struct DNNT_FUNC      dentry;
    struct DNNT_FUNC      dblockdata;
    struct DNNT_DOC_FUNC  doptfunc;
    struct DNNT_BEGIN    dbegin;
    struct DNNT_BEGIN_EXT dbeginext;
    struct DNNT_END      dend;
    struct DNNT_IMPORT    dimport;
    struct DNNT_LABEL     dlabel;
    struct DNNT_WITH      dwith;
    struct DNNT_COMMON    dcommon;

    struct DNNT_FPARAM    dfparam;
    struct DNNT_SVAR      dsvar;
    struct DNNT_DVAR      ddvar;
    struct DNNT_CONST     dconst;

    struct DNNT_TYPE      dtype;
    struct DNNT_TYPE      dtag;
    struct DNNT_POINTER   dptr;
    struct DNNT_ENUM      denum;
    struct DNNT_MEMENUM   dmember;
    struct DNNT_SET       dset;
```



```
struct DNNT_SUBRANGE  dsubr;
struct DNNT_ARRAY     darray;
struct DNNT_STRUCT    dstruct;
struct DNNT_UNION     dunion;
struct DNNT_FIELD     dfield;
struct DNNT_VARIANT   dvariant;
struct DNNT_FILE      dfile;
struct DNNT_FUNCTYPE  dfunctype;
struct DNNT_COBSTRUCT dcobstruct;
struct DNNT_MODIFIER  dmodifier;
struct DNNT_DYN_ARRAY_DESC darraydesc;
struct DNNT_DESC_SUBRANGE ddescsubr;
#ifdef CPLUSPLUS
struct DNNT_CLASS_SCOPE dclass_scope;
struct DNNT_POINTER     dreference;
struct DNNT_PTRMEM     dptrmem;
struct DNNT_PTRMEM     dptrmemfunc;
struct DNNT_CLASS      dclass;
struct DNNT_GENFIELD   dgenfield;
struct DNNT_VFUNC      dvfunc;
struct DNNT_MEMACCESS  dmemaccess;
struct DNNT_INHERITANCE dinheritance;
struct DNNT_FRIEND_CLASS dfriend_class;
struct DNNT_FRIEND_FUNC dfriend_func;
struct DNNT_OBJECT_ID  dobject_id;
struct DNNT_FUNC       dmemfunc;
struct DNNT_TEMPLATE   dtemplate;
struct DNNT_TEMPL_ARG  dtempl_arg;
struct DNNT_FUNC_TEMPLATE dfunctempl;
struct DNNT_LINK       dlink;    /* generic */
struct DNNT_TFUNC_LINK dtflink;
#endif /* CPLUSPLUS */

struct DNNT_INLN      dinln;
struct DNNT_INLN_LIST dinlnlist;
struct DNNT_ALIAS     dalias;

struct DNNT_XREF      dxref;
struct DNNT_SA        dsa;
```

```
    struct DNTT_GENERIC  dgeneric;
    struct DNTT_BLOCK   dblock;
};
```

8.4 Static Analysis Information

8.4.1 XREF Table (XT) Entry Format

This table contains static information about each named object in a compilation unit. It consists of a collection of lists, each list associated with a DNTT object via the DNTT_XREF that follows the object. The DNTT_XREF contains an XREF-POINTER which is an offset into the XT table, and denotes the beginning of the reference list.

Each list is actually one or more of linear sub-list that are linked together. Each sub-list begins with an XREFNAME entry, which names a (current) source file. Following the XREFNAME is one or more XREFINFO entries, one for each appearance of the object's name in the current file. These entries list what type of reference and the line no. within the file. Column numbers are currently unsupported. The XREFINFO1 structure is normally used.

The XREFINFO2A/B structure pair is only used for compilers which support line numbers greater than 16 bits long. An XREFLINK marks the end of a sublist, so a typical sequence looks like:

```
XREFNAME, XREFINFO1, XREFINFO1, ... , XREFLINK
```

Note that all elements of a sublist must appear in sequence (linearly). If the list must be continued, the XREFLINK serves as a continuation pointer from one sublist to the next, and contains another offset into the XT where the next sublist is found for the same named object. If there is no additional sublist, the XREFLINK contains a 0 index, denoting the end of the current list.

Lists for the same named object may appear in different compilation units. It is the responsibility of PXDB to link these together.

```
struct XREFINFO1 {
    BITS    tag: 3;                /* always XINFO1 */
    BITS    definition: 1;        /* True => definition*/
    BITS    declaration:1;       /* True => declaration*/
};
```

```
        BITS    modification:1;        /* True => modification*/
        BITS    use:1;                /* True => use*/
        BITS    call:1;               /* True => call */
        BITS    column:8;             /* Unsigned Byte for Column
                                        /* within line */
        BITS    line:16;              /* Unsigned 16-bits for line # relative */
                                        /* to beginning of current include file. */
};

struct XREFINFO2A {
    /* first word */
        BITS    tag:3;                /* always XINFO2A */
        BITS    definition:1;         /* True => definition*/
        BITS    declaration: ;        /* True => declaration*/
        BITS    modification:1;       /* True => modification*/
        BITS    use:1;                /* True => use */
        BITS    call:1;               /* True => call */
        BITS    extra:16;
        BITS    column:8;
};

struct XREFINFO2B {
    /* second word */
        BITS    line:32;              /* Unsigned 32-bits for line # relative */
                                        /* to beginning of current file. */
};

struct XREFLINK {
        BITS    tag:3;                /* always XLINK for XREFLINK */
        BITS    next:29;              /* index of next list. If */
                                        /* zero then this is the end of line. */
                                        /* a.k.a. continuation pointer */
};

struct XREFNAME {
        BITS    tag:3;                /* always XNAME for XREFNAME */
        BITS    filename:29;          /* VTPOINTER to file name */
};

union xrefentry {
        struct XREFINFO1    xrefshort;
```

```
    struct XREFINFO2A    xreflong;
    struct XREFINFO2B    xrefline;
    struct XREFLINK      xlink;
    struct XREFNAME      xfname;
};
```

8.4.2 Static Analysis Support DNTT Entries

Static analysis support consists of two DNTT entries:

- **DNTT XREF Entry:**

```
struct DNTT_XREF {
/*0*/  BITS          extension: 1;    /* always zero */
        KINDTYPE    kind:10;        /* always K_XREF */
        BITS          language:4;    /* language of DNTT object */
        BITS          unused: 17;
/*1*/  XREFPOINTER  xreflist;        /* index into XREF subspace */
/*2*/  long          extra;          /* free */
};                                       /* three words */
```

This entry is used to retrieve cross-reference information from the XREF Table (XT). A DNTT_XREF entry immediately follows the DNTT_SVAR, DNTT_DVAR, DNTT_TYPE, etc. entry to which it pertains.

The XREFPOINTER points into the XT table where the information about the previous DNTT entry is contained. If no entries are generated in the XT table, the xreflist field should contain XREFNIL. The language field contains the source language (LANG_xxx) value of the DNTT object.

The XREF DNTT can be used in both the GNTT and LNTT.

- **DNTT SA Entry:**

```
struct DNTT_SA {
/*0*/  BITS          extension: 1;    /* always zero */
        KINDTYPE    kind: 10;        /* always K_SA */
        KINDTYPE    base_kind:10;    /* K_FUNCTION, K_LABEL, etc */
};
```

```
        BITS          unused: 11;
/*1*/  VTPOINTER    name;
/*2*/  long          extra;          /* free */
};
```

This entry is used with static analysis info. It supplies the name and kind for a few special cases not currently handled by a DNTT_SVAR, DNTT_DVAR, DNTT_TYPE, etc. It is used for a local entity that has a global scope.

Example:

If a function, has a DNTT_FUNCTION entry in the LNTT; but it can be seen globally, then a K_SA will be emitted in the GNTT, with the functions name and a base_kind of K_FUNCTION; the DNTT_XREF will follow the DNTT_SA, not the DNTT_FUNCTION.

The DNTT_SA is also used for C macros.

The XREF DNTT can be used in both the GNTT and LNTT.

8.5 Source Line Table

8.5.1 SLT Entry Format

This table consists of a series of entries, each of which is either normal, special, or assist according to the sltdesc field of the first word. Normal entries contain an address (actually a code offset relative to the beginning of the current function) and a source/listing line (by line number). Listing line numbers may be used in place of source line numbers based upon a compiler option. This will also be reflected in the DNTT_SRCFLE entries. Special entries also provide a line number (where something was declared) and point back to the DNTT which references them. This is used for quick determination of scope, including source/listing file, after an interrupt. Even if there are multiple source/listing files, all source/listing line information is accumulated in this one table.

The SLT was originally designed to be unnested, even for those languages whose LNTT must reflect their nesting. The debuggers depend upon this. For those languages that are nested the SLT must now be nested and an SLT_ASST must immediately follow each SLT_SPEC of type FUNC. The "address" field will be filled in by the compiler back-ends to point forward to the first SLT_NORM in the FUNC's scope. The "first-

norm" is set to one if this SLT_NORM is the first SLT_NORM looking sequentially forward in the SLT.

The one exception to the normal/special/assist rule is the EXIT SLT. The EXIT SLT is used to identify exit points for a routine. The EXIT SLT is a special only in the sense that the sltdesc field is not equal to SLT_NORMAL. However, it contains a line number and address like a normal SLT. The EXIT SLT is used in place of a NORMAL SLT for all exit statements (such as "return" in C and FORTRAN, or the "end" of a procedure body in Pascal).

The SLT_MARKER is for use in "Chunk-Per-Som". The address field contains a new base address (replacing the current procedure's low-address field. This new base address will be added to succeeding SLT_NORMALs and SLT_EXITs to produce an absolute address.

To distinguish prologue (function setup) code emitted at the END of a function from the last line (normal SLT) of the function, a normal SLT entry with a line number of SLT_LN_PRLOGUE is used. Such SLT entries are only emitted if there is trailing prologue code, and they are always the last SLT emitted for the function except for the special SLT entry for the function END. For compilers that emit the prologue code before the main body, no special prologue SLT entry is required.

One SLT entry is emitted for (the FIRST physical line of) each executable statement, for each construct that generates a DNTT entry which points to an SLT entry, and for the prologue code, if any. The user cannot set a breakpoint without a corresponding SLT entry. Compilers must emit multiple SLT entries for parts of a composite statement (such as FOR) and for multiple statements appearing on one source line.

For compatibility, the high bits of DNTTPOINTERS in SLT entries are also set to 1, even though they are not needed here.

The global bit on DNTTPOINTERS in SLT entries should always be 0, as the LNTT contains all the scoping information.

8.5.2 SLT Types and Data Structure

Sizeof SLTTYPE is 4 bits, for a maximum of 16 possible special slttypes.

Current available SLT types are:

```
#define SLT_NORMAL 0          /* note that the field is unsigned */
#define SLT_SRCFILE 1
#define SLT_MODULE 2
#define SLT_FUNCTION 3
#define SLT_ENTRY 4
#define SLT_BEGIN 5
#define SLT_END 6
```

```
#define SLT_WITH          7
#define SLT_EXIT          8
#define SLT_ASSIST        9
#define SLT_MARKER        10
#define SLT_CLASS_SCOPE  11    /* For C++ use only */

struct SLT_NORM {
    SLTTYPE      sldesc: 4;      /* always zero */
    BITS         line: 28;      /* where in source text */
    ADDRESS      address;       /* where in function */
};                               /* two words */

struct SLT_SPEC {
    SLTTYPE      sldesc: 4;      /* special entry type */
    BITS         line: 28;      /* where in source text */
    DNTTPOINTER backptr;       /* where in DNTT */
};                               /* two words */

struct SLT_ASST {
    SLTTYPE      sldesc: 4;      /* always nine */
    BITS         unused: 28;
    SLTPOINTER   address;       /* first SLT normal */
};                               /* two words */

struct SLT_GENERIC {
    unsigned long word[2];
};                               /* two words */

union sltentry {
    struct SLT_NORM      snorm;
    struct SLT_SPEC      sspec;
    struct SLT_ASST      sasst;
    struct SLT_GENERIC   sgeneric;
};                               /* two words */
```

8.6 Value Table (VT)

This table contains symbol names plus values for DNNT_CONST entries of type LOC_VT. All strings are null-terminated, as in C. There are no restrictions on the lengths of values nor the order in which they may appear. All symbol names are exactly as given by the user, e.g. there are no prepended underscores.

CONST values are not (and need not be) terminated in any way. They may be forced to word boundaries if necessary, with resulting wasted bytes.

The first byte of the table must be zero (a null string terminator), so that the null VTPOINTER results in a null name.

8.7 Ordering of Table Entries

LNTT and SLT entries must be emitted and kept in source file order wherever possible. As a minimum, named LNTT entries must be emitted and kept within the proper scope, though some compilers may emit them at the end of a scope instead of the beginning. In general, the debugger must know the emission rules for the language it is dealing with, and search the LNTT accordingly, or else always search in both directions.

Items in the GNTT are all global, so the public bit must always be set. Within the LNTT, the public bit indicates that the item is exported by the module in which it resides, and is visible within a module or procedure that imports the containing module.

Compilers and linkers are encouraged to make multiple references to DNNT, SLT, and VT entries (even chains of DNNT entries) where possible to reduce redundancy with no loss of data. They are also encouraged to emit entries grouped so that related entries are physically close, as long as no scope rules are violated.

SLT entries must be emitted in sorted line number order within each file, except for special SLT entries for ENTRYs and FUNCTIONs only. They may be out of line number order (due to nested functions, etc.) so long as the next normal SLT entry is the proper place to breakpoint the entity. For example, there can be numerous ENTRY types after a FUNCTION, all referring to the same code location. (If there are no normal SLT entries before the next FUNCTION or MODULE entry and a SLT_ASST does not immediately follow the SLT_SPEC for a FUNC, the entity has no breakpointable locations.)

SLT entries must be sorted in ascending code address order WITHIN EACH MODULE or FUNCTION body. It is impossible to require that they be sorted both by file line number and code address because function object code may be emitted or linked out of source order in a segment.

It is reasonable to expect sequential SLT entries may have the same line numbers or code locations (but not both, as that would be redundant). This might be due to multiple statements on one source line or several scope levels starting at one place in the code.

Thus, for nested languages like Pascal and Modcal, the LNTT entries must be nested to reflect the program's scope. The SLT entries should also be nested with an SLT_ASST entry following each SLT_SPEC of type FUNC.

8.8 Postprocessing

Linker postprocessing or XDB's preprocessor (**PXDB**) must be run on the debug info in the executable program file to massage the debug info so that the debugger may start up and run more efficiently.

Some of the tasks performed by PXDB are: remove duplicate global type and variable information from the GNTT, append the GNTT onto the end of the LNTT and place both back in the LNTT section, build quick look-up tables for files, procedures, modules, and paragraphs (for Cobol), placing these in the GNTT section, and reconstruct the header appearing in the header section to access this information.

- **PXDB Header and Support Data Structures:**

```
struct PXDB_header {
    int    pd_entries;    /* # of entries in function look-up table */
    int    fd_entries;    /* # of entries in file look-up table */
    int    md_entries;    /* # of entries in module look-up table */
    BITS   pxdbed : 1;    /* 1 => file has been preprocessed */
    BITS   bighdr : 1;    /* 1 => this header contains 'time' word */
    BITS   sa_header : 1; /* 1 => created by SA version of pxdb */
                                /* used for version check in xdb */

#ifdef CPLUSPLUS
    BITS   inlined: 1;    /* one or more functions have been inlined */
    BITS   spare:12;
    short  version;      /* pxdb header version */
#else /* CPLUSPLUS */
    BITS   spare:29;
#endif
}
```

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```
#endif /* CPLUSPLUS */
    int    globals;          /* index into the DNTT where GNTT begins */
    BITS   time;             /* modify time of file before being pxdbed */
    int    pg_entries;       /* # of entries in label look-up table */
    int    functions;        /* actual number of functions */
    int    files;            /* actual number of files */
#ifdef CPLUSPLUS
    int    cd_entries;       /* # of entries in class look-up table */
    int    aa_entries;       /* # of entries in addr alias look-up table */
    int    oi_entries;       /* # of entries in object id look-up table */
#endif
};
```

Source File Descriptor:

An element of the source file quick look-up table

```
typedef struct FDS {
    long    isym;            /* first symbol for file */
    ADRT    adrStart;        /* mem adr of start of file's code */
    ADRT    adrEnd;         /* mem adr of end of file's code */
    char    *sbFile;        /* name of source file */
    BITS    fHasDecl: 1;    /* do we have a .d file? */
    BITS    fWarned: 1;    /* have warned about age problems? */
    unsigned short ilnMac;  /* lines in file (0 if don't know) */
    int     ipd;            /* first proc for file, in PD [] */
    BITS    *rgLn;         /* line pointer array, if any */
} FDR, *pFDR;
```

Procedure Descriptor:

An element of the procedure quick look-up table

```
typedef struct PDS {
    long    isym;            /* first symbol for proc*/
    ADRT    adrStart;        /* memory adr of start of proc*/
    ADRT    adrEnd;         /* memory adr of end of proc*/
    char    *sbAlias;        /* alias name of procedure*/
    char    *sbProc;         /* real name of procedure*/
    ADRT    adrBp;          /* address of entry breakpoint */
    ADRT    adrExitBp;      /* address of exit breakpoint */
#ifdef CPLUSPLUS
```

```
        int          icd;          /* member of this class */
#else /* CPLUSPLUS */
        BITS          inst;        /* instruction at entry */
#endif /* CPLUSPLUS */
#ifdef TEMPLATES
        BITS          ipd;        /* index of template for this function */
#else /* TEMPLATES */
        BITS          instExit;    /* instruction at exit */
#endif /* TEMPLATES */
#ifdef CPLUSPLUS
#ifdef TEMPLATES
        BITS          unused: 6;
        BITS          fTemplate: 1; /* function template*/
        BITS          fExpansion: 1; /* function expansion*/
        BITS          linked : 1; /* linked with other expansions*/
#else /* TEMPLATES */
        BITS          unused: 9;
#endif /* TEMPLATES */
        BITS          duplicate: 1; /* clone of another procedure */
        BITS          overloaded:1; /* overloaded function */
        BITS          member: 1; /* class member function */
        BITS          constructor:1; /* constructor function */
        BITS          destructor:1; /* destructor function */
        BITS          Static: 1; /* static function */
        BITS          Virtual: 1; /* virtual function */
        BITS          constant: 1; /* constant function */
        BITS          pure: 1; /* pure (virtual) function */
        BITS          language: 4; /* procedure's language */
        BITS          inlined: 1; /* function has been inlined */
        BITS          Operator: 1; /* operator function */
        BITS          stub: 1; /* bodyless function */
#else
        BITS          unused1: 18;
        BITS          language: 4; /* procedure's language */
        BITS          unused2: 3;
#endif
        BITS          optimize: 2; /* optimization level */
        BITS          level: 5; /* nesting level (top=0)*/
} PDR, *pPDR;
```

Module Descriptor:

An element of the module quick reference table

```
typedef struct MDS {
    long    isym;           /* first symbol for module*/
    ADRT    adrStart;      /* adr of start of mod.*/
    ADRT    adrEnd;        /* adr of end of mod.*/
    char    *sbAlias;      /* alias name of module */
    char    *sbMod;        /* real name of module*/
    BITS    imports: 1;    /* module have any imports? */
    BITS    vars_in_front: 1; /* module globals in front? */
    BITS    vars_in_gaps: 1; /* module globals in gaps? */
    BITS    unused : 29;
    BITS    unused2;       /* space for future stuff*/
} MDR, *pMDR;
```

Paragraph Descriptor:

An element of the paragraph quick look-up table

```
typedef struct PGS {
    long    isym;           /* first symbol for label */
    ADRT    adrStart;      /* memory adr of start of label */
    ADRT    adrEnd;        /* memory adr of end of label */
    char    *sbLab;        /* name of label */
    BITS    inst;          /* Used in xdb to store inst @ bp */
    BITS    sect: 1;       /* true = section, false = parag. */
    BITS    unused: 31;    /* future use */
} PGR, *pPGR;
```

Class Descriptor:

An element of the class quick look-up table for C++ support.

```
typedef struct CDS {
    char    *sbClass;      /* name of class */
    long    isym;          /* class symbol (tag) */
    BITS    type : 2;      /* 0=class, 1=union, 2=struct */
#ifdef TEMPLATES
    BITS    fTemplate : 1; /* class template */
#endif
```

```
        BITS          expansion : 1;    /* template expansion */
        BITS          unused    :28;
#else /* TEMPLATES */
        BITS          unused    : 30;
#endif /* TEMPLATES */
        SLTPOINTER    lowscope;      /* beginning of defined scope */
        SLTPOINTER    hiscope;      /* end of defined scope */
} CDR, *pCDR;
```

Address Alias Entry:

An element of the address alias quick look-up table for C++ support.

```
typedef struct AAS {
    ADRT    low;
    ADRT    high;
    int     index;
    BITS    unused : 31;
    BITS    alternate : 1;    /* alternate unnamed aliases? */
} AAR, *pAAR;
```

Object Identification Entry

An element of the object identification quick look-up table for C++ support.

```
typedef struct OIS {
    ADRT    obj_ident;    /* class identifie */
    long    isym;        /* class symbol */
    long    offset;      /* offset to object start */
} OIR, *pOIR;
```

8.9 Debug Format Changes for Debugging of Optimized Code (DOC)

8.9.1 Debug Format Changes

The following describes the changes to the debug format for HP-UX 10.0. The primary change to the debug format is the addition of a new debug space and debug subspaces. For code compiled with `-g` and `-O`, the debug information will be generated into a new space named `$PINFO$` (after processing with `pxdb --` prior to `pxdb` processing the

debug information will be generated into the \$DEBUG\$ space). All the standard xdb-format subspaces will be placed into the \$PINFO\$ space along with the two new subspaces: \$LINE\$, and \$LT_OFFSET\$.

This document has now been updated to also describe those changes made to improve DOC support at the HP-UX 10.20 release.

8.9.2 Object File Format Details

When a file is compiled with debug and optimization specified, the compilers build a \$DEBUG\$ space and a \$LT_OFFSET\$ subspace within the \$DEBUG\$ space. As of HP-UX 10.20, the \$LT_OFFSET\$ subspace is obsolete. The linker builds the \$LINE\$ subspace within the \$DEBUG\$ space when debug info is seen in any object file being linked. When pxdB processes the executable file, the \$DEBUG\$ space is renamed \$PINFO\$ if it detects DOC format debug info in the file.

The compilers supply line table information to the linker in the form of fixup requests. Two new fixup requests have been defined to signal the building of DOC line tables (which includes information to be included in the first entry of the line table) and to generate special line table escape entries. The information for the line number tables is supplied by the fixup request, R_LINETAB.

The compilers generate the R_LINETAB fixup to request that DOC line tables be built. This fixup passes in a version number and subspace index and subspace offset of a location which must be patched with the offset of the line table which is about to be built. The R_LINETAB fixup request is a 9-byte with the following fields:

Offset	Length	Field
0	1	R_LINETAB
1	1	version number
2	3	symbol index (symbol-relative loc to patch w/line table offset)
5	4	offset (symbol + offset = location to patch w/line table offset)

The first parameter is a 1-byte version number which identifies the line table version (format). The actual value is not important to the linker. The second parameter is a symbol index to be used in conjunction with the third parameter, an offset, as a location which is to be filled with the offset (relative to the \$LINE\$ subspace) of the line table about to be built.

The line number information is passed to the linker via the R_STATEMENT fixup request, which is embedded within the fixups for the code at statement boundaries. The R_STATEMENT fixup has three variants to handle one, two and three byte statement of line numbers as necessary. The actual meaning assigned to the number, whether it be

statement numbers of line numbers, is irrelevant to the linker, and needs to be agreed upon only by the compiler and the end user of the line table information.

The R_LINETAB_ESC fixup is a 3-byte fixup defined as follows:

Offset	Length	Field
0	1	R_LINETAB_ESC (0xDB)
1	1	escape code
2	1	number of following R_STATEMENT fixups containing escape data.

This fixup request is used to place escape entries into the line table. There are several escape entries defined in the line table format which are used by the debugger and other tools when processing the line table. Some of these escapes must be generated by the linker, the others are generated by the compiler and the linker does not need to know the details of these escapes. The escapes entries which are not generated by the linker are entered into the line table via a combination of the R_LINETAB_ESC and R_STATEMENT fixups.

The first parameter contains the actual escape code which is to be placed into a 1-byte entry in the line table. The second parameter specifies how many of the following R_STATEMENT entries contain data to be entered directly into the line table (these statement fixups will not contain line numbers -- instead they hold data which is to be placed directly into the line number table as part of the escape sequence). With the currently defined escapes, the value of the second parameter will be in the range [0,4].

8.9.3 Building the Line Tables

All line tables will be placed into the \$LINES\$ subspace of the executable file. The linker must create a new line table each time an R_LINETAB fixup is processed. If a line table is in progress then it must be completed by entering a dst_in_end escape and the final pc delta entry. Each line table is terminated when 1) a new R_LINETAB fixup is seen or 2) when the end of the current code subspace is reached.

When a new line table is started the version number passed as a parameter to the fixup is used as the first one-byte entry in the table. The symbol and offset parameters passed in the R_LINETAB fixup must be saved along with the corresponding line table offset as 'fixups' to be applied to the symbol+offset location when that symbol's subspace is processed. The first R_STATEMENT entry processed after an R_LINETAB fixup will generate a four-byte entry containing the absolute code address associated with the fixup.

The size of the next entry (in bytes) is determined by the absolute line number value (the value passed to the R_STATEMENT fixup). The linker must emit the absolute line number into the table using the minimum number of bytes required by the line number value. For example, if the line number is less than 256, then the absolute line number entry will be one byte; if the line number is greater than 255 and less than 65536, then

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the line number entry will be 2 bytes, etc. Each subsequent R_STATEMENT entry will cause one entry (consisting of one or more bytes) to be generated into the line table.

The linker needs to be aware of, and generate, some of the escape codes defined for the DOC line table. These escape codes are as follows:

Table entry for ESC	ESC Name	Description
	dst_ln_end	end escape; final entry follows. The final entry contains the code size of the last statement in high 4 bits (i.e. the last PC delta); the low 4 bits are 0
	dst_ln_pad	This byte is padding
	dst_ln_dpc1_dln1	The next table entry is a one byte pc delta followed by a one byte line delta.
	dst_ln_dpc2_dln2	The next table entry is a two byte pc delta followed by a two byte line delta.
	dst_ln_pc4_ln4	The next table entry is a four byte absolute pc followed by a 4-byte absolute line number.
	dst_ln_dpc0_dln1	The next table entry is a one byte line delta; the pc delta is zero.

The linkers must use the multi-byte line delta and pc-delta escapes whenever the line or code delta values exceed the range that can be expressed in a 1-byte entry. There must be one line table entry to express each R_STATEMENT fixup. For example, if either the line number delta or code delta falls outside of the range [-8,7] (line delta) or [0,11] (code delta), but is less than the byte-range [-127,128] (line delta) or [0,255] (code delta) then a **dst_ln_dpc1_dln1** must be generated. Similarly, if the delta range for either line or code delta cannot be described in the 1-byte format, then a **dst_ln_dpc2_dln2** (two-byte line and pc delta escape format) must be used. Finally, if the code and line deltas exceed the 2-byte format, then a **dst_ln_pc4_ln4** absolute line number and code address must be used.

The R_LINETAB_ESC fixup directs the linker to treat <n> following R_STATEMENT fixups as absolute data entries. The R_LINETAB_ESC causes the linker to generate a one-byte entry into the table which contains the data value passed in as the first argument. The second R_LINETAB_ESC argument specifies the number of following R_STATEMENT entries which contain data to be directly entered into the line-table. These R_STATEMENT entries will not cause the normal pc-delta/line-delta entries to be generated; Instead, the argument passed to the R_STATEMENT fixups will be used as absolute data for a one-byte entry in the line table.

8.9.4 Debug Format Changes

The new subspace, \$LT_OFFSET\$, will be placed into the \$DEBUG\$ space by the compilers when optimization is specified with debug (-g and -O). The format and the \$LT_OFFSET\$ table is a list of 1-word entries; each entry contains a line table offset which corresponds to the beginning of each line table in the \$LINES\$ subspace (in order). One line table will be emitted for each NTT_FUNC debug entry. This subspace is temporary for UX10.0 xdb-DOC transition and will be obsoleted in post-UX10.0 releases.

As of HP-UX 10.20, the LT_OFFSET subspace is now obsolete. The DNTT_DOC_FUNC for a routine includes an offset into the LINES table.

Xdb-style \$GNTT\$, \$LNTT\$, \$SLT\$ and \$VT\$ will be placed into the \$DEBUG\$ space by the compilers when optimization and debug are specified together on the command line. If no optimization is requested (plain -g) then the standard xdb debug information will be generated into the \$DEBUG\$ debug space.

The xdb-style \$HEADER\$ subspace will be modified to include new fields when both debug and optimization are specified (the \$DEBUG\$ space and xdb format will be unchanged when -g is used without optimization, or when static analysis (-y) is used).

The DOC information header is defined as follows:

```
struct DOC_info_header {
    unsigned int xdb_header: 1; /* bit set if this is post-3.1 xdb */
    unsigned int doc_header: 1; /* bit set if this is doc-style header*/
    unsigned int version: 8; /* version of debug/header
                             format. For 10.0 the value
                             will be 1. For "Davis" the
                             value is 2.
                             */
    unsigned int reserved_for_flags: 18; /* for future use; -- must be
                                         set to zero
                                         */
    unsigned int has_range_table: 1; /* space contains a $RANGES$
                                       subspace for variable ranges.
                                       */
    unsigned int has_context_table: 1; /* space contains a $CTXT$
                                       subspace for context/inline
                                       table.
                                       */
    unsigned int has_lines_table: 1; /* space contains a $LINES$
                                       subspace for line tables.
                                       */
}
```

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```
    unsigned int has_lt_offset_map: 1; /* space contains an lt_offset
                                       subspace for line table mapping
                                       */

    long  gntt_length; /* same as old header */
    long  Intt_length; /* same as old header */
    long  slt_length; /* same as old header */
    long  vt_length; /* same as old header */
    long  xt_length; /* same as old header */
    long  ctxt_length; /* present only if version >= 2 */
    long  range_length; /* present only if version >= 2 */
    long  expr_length; /* present only if version >= 2 */

};
```

Similarly, the pxdB header must be modified to include the DOC fields when emitted into the \$PINFO\$ space of an executable.

The DOC pxdB header is defined as follows:

```
struct DOC_info_PXDB_header {
    unsigned int xdb_header: 1; /* bit set if this is post-3.1 xdb */
    unsigned int doc_header: 1; /* bit set if this is doc-style header */
    unsigned int version: 8; /* version of pxdB see defines
                              * PXDB_VERSION_* in this file */
    unsigned int reserved_for_flags: 16; /* for future use; -- must be
                                          * set to zero
                                          */

    unsigned int has_aux_pd_table: 1; /* $GNTT$ has aux PD table */
    unsigned int has_expr_table: 1; /* space has $EXPR$ */
    unsigned int has_range_table: 1; /* space has $RANGES$ */
    unsigned int has_context_table: 1; /* space has $SRC_CTXT$ */
    unsigned int has_lines_table: 1; /* space contains a $LINES$
                                       * subspace for line tables.
                                       */

    unsigned int has_lt_offset_map: 1; /* space contains an lt_offset
                                       * subspace for line table mapping
                                       */

    /* the following fields are the same as those in the PXDB_header in $DEBUG$ */
    int  pd_entries; /* # of entries in function look-up table */
    int  fd_entries; /* # of entries in file look-up table */
    int  md_entries; /* # of entries in module look-up table */
    BITS pxdbed : 1; /* 1 => file has been preprocessed */
};
```

```
    BITS    bighdr : 1; /* 1 => this header contains 'time' word */
    BITS    sa_header : 1; /* 1 => created by SA version of pxdbe */
           /* used for version check in xdb */
    BITS    inlined: 1; /* one or more functions have been inlined */
    BITS    spare : 28;
    int     globals; /* index into the DNTT where GNTT begins */
    BITS    time; /* modify time of file before being pxdbe */
    int     pg_entries; /* # of entries in label look-up table */
    int     functions; /* actual number of functions */
    int     files; /* actual number of files */
    int     cd_entries; /* # of entries in class look-up table */
    int     aa_entries; /* # of entries in addr alias look-up table */
    int     oi_entries; /* # of entries in object id look-up table */
};
```

For example, the \$PINFO\$ debug space will contain the following subspaces when -g and -O are specified together on the command line:

```
$PINFO$
$HEADERS$
$GNTT$
$LNNTT$
$SLT$
$VT$
$LINES$
$LT_OFFSETS$
$RANGES$
$CTXT$
$EXPR$
```

Note: there will be no \$XT\$ table for static analysis. Static analysis (-y) and optimization is incompatible for UX10.0.

8.9.5 Line Number Table Definition

The line number definition is based on the DST (Domain DDE Symbol Table) .lines definition. Although there were changes to support additional escape codes, all existing DST .lines escapes have been retained. The line table format is defined as a stream of nibble pairs, where the first nibble represents a PC delta, and the second a line number

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delta. The PC delta is unsigned, and runs from 0..15. The PC delta values 12..15 are used for special escape handling. PC delta values 12 and 13 are used to signify short-form context switches. PC delta values 14 and 15 are used to signify two sets of 16 escape codes in the line number delta field.

PC Delta	Line Delta or Bit #	Interpretation
0..11	-8..7	interpreted as line delta
12	4 bits - rrcc	interpreted as context switch: rr (0..3) is run length in entries, interpreted as 1..4. cc (0..3) is context index number.
13	4 bits - rrdd	interpreted as context switch: rr (0..3) is run length in entries, interpreted as 1..4. dd (0..3) is context index number minus 4, so is interpreted as contexts 4..7.
14	0..15	interpreted as new escape codes (set #2)
15	0..15	interpreted as DST escape codes (set #1).

Note that it is possible to have entries with PC deltas of 0. This will be used to associate multiple source lines to a single block of code.

The image table is a structure intended to be used in the presence of inlining. It defines the full source file context of inlined code. It also provides a starting line number from which subsequent line number deltas are applied, within the life of the run length. The code which interprets the delta stream will obtain the starting line number for a context from the image table at the first encounter of it's index number. The interpreter must then maintain a running count of the context's current line number. Note that a context switch does not signify creation of a line number table entry, but rather is used to set up the context to which subsequent deltas are applied.

The PC and line number bases to which subsequent deltas are applied are set forth in the table via special escapes. This escape and starting bases must appear prior to any applicable delta pairs, and the bases may be reset at any time. Once the bases are set, the interpreter will generate a line number table entry whenever it encounters a PC/number delta pair (which may take 1, 2, 5 or 9-byte forms).

Set #1 Escape codes (same as DST)

decimal	name	function
0	dst_ln_pad	pad type
1	dst_ln_file	pad byte fill escape
2	dst_ln_dpc1_dln1	1 byte pc delta, 1 byte line delta
3	dst_ln_dpc2_dln2	2 byte pc delta, 2 byte line delta
4	dst_ln_pc4_ln4	4 byte absolute pc number, 4 byte abs. line
5	dst_ln_dpc0_dln1	pc delta = 0, 1 byte line delta
6	dst_ln_ln_ff_1	statement escape, stmt # = 1
7	dst_ln_ln_off	statement escape, stmt # = next byte
8	dst_ln_entry	entry escape, next byte is entry number
9	dst_ln_exi	exit escape
10	dst_ln_stmt_end	gap escape, 4 bytes pc delta
11	dst_ln_escape_11	reserved
12	dst_ln_escape_12	reserved
13	dst_ln_escape_13	reserved
14	dst_ln_nxt_byte	next byte contains real escape code
15	dst_ln_end	end escape, final entry follows

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Set #2 Escape Codes (additional to DST ones)

decimal	name	function
0	dst_ln_ctx_1	next byte describes context switch with 5-bit index into the image table and 3-bit run length. If run length is 0, the context is considered active until context end switch or new context switch are encountered.
1	dst_ln_ctx_2	next 2 bytes describe context switch with 13-bit index and 3-bit run length. If run length is 0, the context is considered active until context and switch or new context switch are encountered.
2	dst_ln_ctx_4	next 4 bytes describe context switch with 29-bit index and 3-bit run length. If run length is 0, the context is considered active until context and switch or new context switch are encountered.
3	dst_ln_ctx_end	end current context.
4	dst_ln_col_run_1	next byte is a column position marking the beginning of the next statement, following byte is length of statement.
5	dst_ln_col_run_2	next 2 bytes are a column position marking the beginning of the next statement, following two bytes are length of a statement.
6	dst_ln_init_base1	next 4 bytes are an absolute PC base address. Immediately following is a 1-byte starting line number.
7	dst_ln_init_base2	next 4 bytes are an absolute PC base address. Immediately following is a 2-byte starting line number.
8	dst_ln_init_base3	next 4 bytes are an absolute PC base address. Immediately following is a 3-byte starting line number.
9-15	reserved	for future use.

8.9.6 Range Table(RANGE)

This information is HP proprietary and was removed from this document.

8.9.7 View/modify globals and arguments when safe

Globals may be set and viewed safely at procedure entry and exit for C, C++ and FORTRAN code. For Pascal, however, the Pascal front end is intelligent enough to recognize some instances in which a global may be safely promoted across procedure boundaries.

Thus, viewing and setting of globals must be considered unsafe at all times for Pascal code. Arguments may be viewed and set safely at procedure entry for C, C++, FORTRAN and Pascal. The 10.0 functionality will permit setting and viewing of globals and arguments at unsafe times, but DDE will generate a warning of unreliability for these operations. Further, setting of locals will also be allowed, but will always cause a warning.

As of HP-UX 10.20, DDE now tracks scalar variables in the C language. This paragraph is applicable only to C programs. Scalars can be safely printed anywhere. DDE will either print the correct value, or print a warning that the address/value is unknown. However, a variable may not be settable in all places that it is printable, as the variable may have been replaced with a constant value. Non-scalars such as arrays, array elements, structures and structure elements are not tracked, so the limitations from the previous paragraph still apply.

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9.1 Overview

Stack unwinding refers to the processes of procedure trace-back and context restoration, both of which have several possible system and user-level applications. A software stack unwinding convention is necessary on PA-RISC because in the event of an interruption of execution, there is insufficient information directly available to perform a comprehensive stack trace. The stack trace is the basic operation performed in context restoration.

Some important tools are heavily dependent on the presence of the stack unwinding facility. For example, system dump analysis tools examine all system processes that were running at the time of a system crash, an operation which involves multiple stack traces. Symbolic debuggers require the ability to display the state of the call stack at any point during a program's execution. Many language-specific features such as the *ESCAPE* mechanism in HP Pascal, *C++ exception handling* also require stack unwinding capabilities.

The stack unwind information is generated once at compile time via fixups and stored in a static data structure called the *unwind table*. An unwind table is automatically built into each program file by the linker.

Each entry in the unwind table contains two addresses which describe a region of code, typically the starting and ending address of a procedure. Each entry also contains an *unwind descriptor* which holds information about the frame and register usage of that region. When an unwind operation is required, the unwind table is searched to find the region containing the instruction where the exception or interrupt occurred.

9.2 Requirements for Stack Unwinding

Unwind depends crucially on the ability to determine, for any given instruction, the state of the stack and whether that instruction is part of a procedure entry or exit sequence. In particular, instructions that modify SP or RP must be made known to the unwind routines. Furthermore, it is necessary that all the callee-saves registers be saved at the dedicated locations on the stack following the procedure calling conventions.

To guarantee that a routine is unwindable, the assembly programmer should strictly adhere to the stack and register usage conventions described in the Run-time Architecture document. It is mandatory that the procedure entry and exit sequences conform to the standard specifications. All procedures generated by HP's compilers will automatically meet all these requirements and hence will be unwindable.

The assembler provides several directives that help in making routines completely unwindable. The `“.ENTER”` and `“.LEAVE”` directives will automatically generate the standard entry and exit sequences. The code sequences generated by these directives are determined by the options specified in the `“.CALLINFO”` directive. In rare cases, it may be necessary to generate non-standard stack frames or to create multiple unwind regions for the same routine. These cases can be handled with proper use of the `“.CALLINFO”`, `“.ENTRY”`, `“.EXIT”`, `“.PROC”` and `“.PROCEND”` directives as documented in the PA-RISC Assembly Language Reference Manual.

To successfully perform a stack trace from any given instruction in a program, the following requirements must be met:

- The specified instruction must lie within a standard code sequence, as specified above.
- Caller-save registers must be saved and restored across a call (if their contents are live across a call).
- Unwind table entries must be generated for each routine, and for any discontinuous regions of code.
- The frame size for each routine must be the same as is stated in the unwind descriptor for that routine.
- The use of RP (or MRP) in each routine must conform to the specifications stated in the unwind descriptor for the specifications stated in the unwind descriptor for that routine.

The minimum requirements for a successful context restoration are:

- All requirements for a stack trace (as above) must be met.
- The use of the callee-saves registers in each routine must conform to the specifications given in the unwind descriptor for that routine.

The assembler generates fixup requests for the linker based on the information made available to it by the programmer in the various procedure entry, exit, and call directives. The linker builds the unwind descriptors based on these fixup requests. The unwind descriptors describe the stack and register usage information for a particular address

range and the length of the entry and exit sequences. The unwind descriptors are four word entities with the following format:

word #1	.PROC (start address of the procedure)
word #2	.PROCEND (end address of the procedure)
word #3	.CALLINFO (unwind descriptor)
word #4	

The linker sorts all the unwind descriptors according to the address range they refer to and places them in a separate subspace. Most stack unwind functions depend on the unwind entries being sorted properly.

9.2.1 Unwinding Across an Interrupt Marker

Information such as machine state (i.e., register contents) are pushed on stack when interrupt or trap occurs. This area of stack is called the interrupt marker and is different from the normal stack marker. The routine *_sigreturn()* marks the interrupt marker by having the `HP_UX_interrupt_marker` bit of its unwind descriptor set. Unwind tool must check this bit when unwinding through each frame. When the `HP_UX_interrupt_marker` bit is set, register contents must be restored from the interrupt marker. The interrupt marker is defined in the *sigcontext* structure.

9.2.2 Unwinding from Stubs on HP-UX

A few HP-UX specific stubs have been designed to support the shared library mechanism. Calls to external routines in HP-UX will return via an export stub. The call itself will go through an import stub as described in Section 6.3.16 on page 146.

In the HP-UX shared library implementation, GR 19 points to a shared library descriptor. This descriptor contains a pointer to the location where the unwind tables and the stub tables are located. Each shared library has its own tables.

When unwinding through the HP-UX export stub, the PC return register (RP) and GR 19 are restored from the stack (SP-24 for RP and SP-32 for GR 19).

9.2.3 Unwinding from Millicode

The one type of standard call from which unwindability cannot be guaranteed is the millicode call. This is because the assembler cannot automatically generate the standard entry and exit sequences for millicode routines that allocate additional stack space. Fortunately, relatively few millicode routines require the creation of a stack frame. It is possible, however, to support unwinding from such routines (i.e., nested millicode calls), provided that the millicode routine which allocates the stack space is written so that it

uses the correct entry and exit sequences. It is the responsibility of the author of the specific routine to incorporate these provisions into the actual code.

9.2.4 Instances in Which Unwinding May Fail

A successful stack trace may not be possible in the following situations:

- Procedures that have multiple (secondary) entry points.
- Code sequences in which DP (GR 27) is modified. Note that DP should never be altered by user code, only by system code as is absolutely necessary.

9.2.5 Callee-Saves Register Spill

For a procedure to be unwindable, the callee-saves registers must be stored in the correct location within the stack frame. The registers will be stored in the correct locations when the standard entry and exit sequences generated by the `.ENTER` and `.LEAVE` are used. The stack unwinding utilities may fail if an interrupt occurs on an instruction in a non-standard entry or exit sequence. For this reason, it is advisable that assembly programmers use `.ENTER` and `.LEAVE` rather than create their own entry and exit sequences.

If you do not use the `.ENTER` and `.LEAVE` directives, then callee-saves registers should be saved within the procedure's stack frame as follows:

- Any floating-point registers are saved starting at the double-word at the bottom of the current stack frame, the address in `SP` on entry to the procedure. Register `fr12` should be stored at this location, with subsequent callee-saves registers saved in numeric order in the double-words immediately following.
- Any general registers are saved starting at the first word after the last callee-saves floating-point register is saved. Register `gr3` should be stored first, with subsequent registers saved in numeric order in the words immediately following.
- Callee-saves space register `sr3` is saved by moving its contents to a general register with an `MFSP` instruction and then storing it in the first double-word aligned word immediately following the last callee-saves general register.

9.2.6 Sample entry and exit code

This example illustrates how the stack gets laid out at the entry code with the callee-saves registers. Note that the `.CALLINFO` requests that `gr3 .. gr5` and `fr12 .. fr15` get stored in the stack. It also allocates 24 bytes of space for local variables. The entire frame size including the frame marker is 128 bytes. Note that this is the exact sequence of code that should be happening for procedure entry and exit, the unwinding utilities may fail if an interrupt occurs on an instruction in a non-standard entry or exit sequence.

```
.SPACE $TEXT$
.SUBSPA $CODE$,QUAD=0,ALIGN=4,ACCESS=44,CODE_ONLY, SORT=24
initboard
.PROC
.CALLINFO CALLER,FRAME=24,ENTRY_FR=15,ENTRY_GR=5,SAVE_RP
```

```
.ENTRY
STW rp,-20(sp)
FSTDS,MA fr12,8(sp)
FSTDS,MA fr13,8(sp)
FSTDS,MA fr14,8(sp)
FSTDS,MA fr15,8(sp)
STWM r3,96(sp)
STW r4,-92(sp)
STW r5,-88(sp)

;; procedure body

LDW -88(sp),r5
LDW -92(sp),r4
LDWM -96(sp),r3
FLDDS,MB -8(sp),fr15
FLDDS,MB -8(sp),fr14
FLDDS,MB -8(sp),fr13
BV r0(rp)
.EXIT
FLDDS,MB -8(sp),fr12
.PROCEND ;
```

9.3 Role of Stubs in Unwinding

The stub unwind region (also called the linker stub table) contains unwind descriptors for linker-generated stubs. Stubs are usually generated by the linker when a procedure makes an external call. Although there are various kinds of stubs, all of them save some data about the current location and then branch to some other location. Since it is necessary to unwind from stubs, it is necessary to describe these regions in the unwind table. To do this, the linker generates two-word unwind descriptors for stubs. If a procedure needs to return through a parameter relocation stub, the unwind mechanism needs to know that the extra `rp` value is saved in the stack marker. If execution is stopped in the middle of a stub, unwind needs to know that, especially if inside a parameter relocation stub, where the stack pointer may have been bumped by 8 bytes to create a temporary storage area. The stub-unwind descriptors have the following format:

```
struct stub_desc {
unsigned int  addr;           /* address of the first instruction of the stub */
unsigned int  mbz1: 4;       /* must be zero - reserved */
unsigned int  type: 4;       /* stub type */
unsigned int  mbz2: 3;       /* must be zero - reserved */
unsigned int  reloclen: 5;   /* used only for parameter relocation stubs;
                             contains the number of the instruction which
                             stores RP on the stack in the stub. */
unsigned int  length: 16;    /* length (# of words) of stub area */
};
```

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In some cases, a contiguous sequence of calling, called, or long branch stubs or milli-code long branch can be covered by a single unwind descriptor.

The UNWIND and RECOVER subspaces point to the unwind, stub, and recover tables. These tables are arranged in code space as follows:

\$UNWIND_START\$	at beginning of unwind table
\$UNWIND_END\$	at beginning of stub table
\$RECOVER_START\$	at beginning of recover table
\$RECOVER_END\$	at end of recover table

The three tables mentioned above, namely the unwind, stub and recover tables, are required to be contiguous. In a shared library, the DLT slot at 0 (gr 19) contains a self-relative pointer to a four-word descriptor containing the four pointers to the unwind tables corresponding to the four symbols above.

9.3.1 The Stub Unwind Types

The following table describes the stub-unwind types in bits 4..7 of the second word of the two-word unwind descriptors for stubs:

Stub Names	Value	Description
NULL	0	not used
LONG_BRANCH_STUB	1	stubs generated for branches beyond 256K-bytes offset.
LOCAL_RELOC_STUB	2	parameter relocation stub
EXTERN_IMPORT_STUB	3	MPE shared library import stub
EXTERN_EXPORT_STUB	4	calls entry point, handles inter-quad return; deposits caller's exec level in rp
LONG_LOAD_STUB	5	not used
HPUX_IMPORT_STUB_NO_RP	6	o signal to the unwind library and all other unwind users that this is an HP-UX shared library import stub (in either a program file or a shared library) that does not save RP before branching to the callee.

Stub Names	Value	Description
MILLILONG_BRANCH_STUB	7	like LONG_BRANCH_STUB, used to reach millicode routines
INTERQUAD_IMPORT_STUB	8	loads r22 with address of routine in quad0 and branches to _sr4export
HPUX_EXPORT_STUB_NO_RP	9	o signal to the unwind library and all other unwind users that this is an HP-UX shared library export stub (in either a program file or a shared library) that does not save RP before branching to the entry point; and in fact does not trap the return from the entry before control passes back to the caller.
HPUX_EXPORT_STUB	10	HP-UX shared library export stub, like DL_EXPORT_STUB
HPUX_IMPORT_STUB	11	HP-UX shared library import stub used in an incomplete executable. Loads r19 required by callee, makes inter-quad branch, stores rp at -24 (sp).
SHLIB_IMPORT_STUB	12	HP-UX shared library import stub used in a shared library, see HPUX_IMPORT_STUB.
LONG_SHLIB_IMPORT_STUB	13	like SHLIB_IMPORT_STUB except PLT entry is too far from r19.
SHL_LONG_BRANCH_STUB	14	PC-relative long branch stub used in a shared library.
FDP_COUNTING_STUB	15	Stub generated to count branches for feedback directed positioning.

9.3.2 Unwinding from Parameter Relocation Stub

A parameter relocation stub creates its own temporary 8-byte stack frame while it's executing, so the stack unwind mechanism needs to understand where the stack pointer gets incremented and decremented. There are two forms of parameter relocation stub. The

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first form saves `rp` and catches the return path so it can relocate the return value; the second form is one way, so it does not have to save `rp`.

In the following two examples, assembly code are shown to handle `arg1/arg0` to `farg1` and `arg3/arg2` to `farg3` parameter relocation.

With return relocation:

```
a:                                     ; relocate parameters
    stws,ma    arg1, 8(sp)             ; create temporary stack frame
    stws      arg0, -4(sp)
    fldds     -8(sp), farg1
    stws      arg3, -8(sp)
    stws      arg2, -4(sp)
    fldds,mb  -8(sp),farg3           ; destroy temporary frame
b:                                     ; save rp and call the function
    stw       rp, -8(sp)
    bl,n     func,rp
    nop
                                     ; function returns here
                                     ; relocate the return value
c:                                     ; create temporary stack frame
    fstds, ma  fret0, 8(sp)
    ldws      -4(sp), ret1
    ldws, mb  -8(sp), ret0           ;destroy temporary frame
d:
    ldw       -8(sp), rp
    bv,n     0(rp)
e:
```

Without return relocation:

```
a:                                     ; relocate parameters
    stws,ma    arg1, 8(sp)             ; create temporary stack frame
    stws      arg0, -4(sp)
    fldds     -8(sp), farg1
    stws      arg3, -8(sp)
    stws      arg2, -4(sp)
    fldds,mb  -8(sp),farg3           ; destroy temporary frame
b:                                     ; branch to the function
    b,n      .+8
c:
d:
e:
```

For parameter relocation stubs (type 2) and export stubs (types 9 and 10), the size (in instructions) of the argument relocation code $((b - a)/4)$ is recorded in the *relocLen* field, and the total size (in instructions) of the stub $((e - a)/4)$ in the *length* field.

If there is no return relocation path, the value $(length - relocLen)$ will be 1.

If $(length - reloclen)$ is greater than 1, the relative positions of the labels *c* and *d* can be inferred from the values of *reloclen* and *length* as follows:

$$c = b + 12 = a + (reloclen * 4) + 12$$
$$d = e - 8 = a + (length * 4) - 8$$

When unwinding, use the following table to determine how to find the next frame, based on the current *pc*:

<i>pc</i>	return ptr	<i>psp</i>
<i>pc</i> == <i>a</i>	<i>rp</i>	<i>sp</i>
<i>a</i> < <i>pc</i> < <i>b</i>	<i>rp</i>	<i>sp</i> - 8
<i>pc</i> == <i>b</i>	<i>rp</i>	<i>sp</i>
<i>b</i> < <i>pc</i> <= <i>c</i>	-8(<i>sp</i>)	<i>sp</i>
<i>c</i> < <i>pc</i> < <i>d</i>	-8(<i>psp</i>)	<i>sp</i> - 8
<i>d</i> <= <i>pc</i> < <i>e</i>	-8(<i>sp</i>)	<i>sp</i>

For export stubs (types 9 and 10), the calculations of positions *c* and *d* are different because the stubs are different:

$$c = b + 8 = a + (reloclen * 4) + 8$$
$$d = e - 16 = a + (length * 4) - 16$$

9.4 External Interface

9.4.1 The Unwind Descriptor

When the assembler sees procedure directives such as “.ENTER” or “.LEAVE”, it builds fixup requests for the linker. Using the information in these fixup requests, the linker builds a 4-word unwind descriptor for each unwind region. These descriptors monitor a particular code address range, typically an entire procedure. The unwind descriptors provide information about the stack size, registers usage, and the lengths of the entry and exit sequences. The linker sorts these entries in the increasing order of code addresses and places them in a separate subspace.

Following is a C language declaration of the unwind descriptor:

```
struct unwind_table_entry {
    unsigned int region_start;          /* Word 1 */
    unsigned int region_end;           /* Word 2. */
    unsigned int Cannot_unwind:1;     /* Word 3. */
    unsigned int Millicode:1;
    unsigned int Millicode_save_sr0:1;
    unsigned int Region_description:2;
    unsigned int reserved:1;
    unsigned int Entry_SR:1;
    unsigned int Entry_FR:4;
    unsigned int Entry_GR:5;
```

```
    unsigned int Args_stored:1;
    unsigned int Variable_Frame:1;
    unsigned int Separate_Package_Body:1;
    unsigned int Frame_Extension_Millicode:1;
    unsigned int Stack_Overflow_Check:1;
    unsigned int Two_Instruction_SP_Increment:1;
    unsigned int sr4export:1;
    unsigned int cxx_info:1;
    unsigned int cxx_try_catch:1;
    unsigned int sched_entry_seq:1;
    unsigned int reserved1:1;
    unsigned int Save_SP:1;
    unsigned int Save_RP:1;
    unsigned int Save_MRP_in_frame:1;
    unsigned int save_r19:1;
    unsigned int Cleanup_defined:1;
    unsigned int MPE_XL_interrupt_marker:1; /* Word 4 */
    unsigned int HP_UX_interrupt_marker:1;
    unsigned int Large_frame_r3:1;
    unsigned int alloca_frame:1;
    unsigned int reserved2:1;
    unsigned int Total_frame_size:27;
};
```

region_start

This is the starting address of the unwind region.

region_end

This is the end address of the unwind region.

word # 3 and word #4: Flags

The 3rd and the 4th word of the unwind descriptor contains bit flags and stack frame size that are used by the unwind utility routines. The number in the following brackets are only used for identifying purpose.

1. ***Cannot_unwind*** (bit 0): One (1) if this region does not follow unwind conventions and is therefore not unwindable; zero otherwise. (Creation of non-unwindable assembly code is strongly discouraged.)
2. ***Millicode*** (bit 1): One if this region is a millicode routine; zero otherwise.
3. ***Millicode_save_sr0*** (bit 2): One if this (millicode) routine saves sr0 in its frame (at `current_SP - 16`); zero otherwise.
4. ***Region_description*** (bits 3-4): Describes the code between the starting and ending offsets of this region:

00: Normal (entry point at start of region, exit point at end; contains no other entry/exit points)

01: Entry point only (contains no exit point)

10: Exit point only (contains no entry point)

11: Discontinuous (contains no entry or exit point)

Normal context is code that falls between the last entry point and first exit point of a routine.

Entry point only context is code that makes up an alternate entry point. It consists of entry code inserted by the assembler or compiler as well as user code. It does not contain exit code.

Exit point only context is code that makes up an alternate exit point. It consists of exit code inserted by the assembler or compiler as well as user code. It does not contain entry code.

Discontinuous context is code within an assembled or compiled routine that is either not preceded by some entry point or not followed by some exit point.

One unwind table entry is generated per routine, plus one for each additional entry point, exit point, and discontinuous region. Normally, all unwind descriptors are identical except for the `Region_description` field. The entry and exit points to any region are marked using the `“.ENTRY”` and `“.EXIT”` assembler directives.

5. **Entry_SR** (bit 6): One if the sole entry-save space register `sr3` is saved/restored by the associated entry/exit code sequence; zero otherwise.
6. **Entry_FR** (bit 7-10): The number of entry-save floating-point registers saved/restored by the associated entry/exit code sequence.
7. **Entry_GR** (bit 11-15): The number of entry-save general registers saved/restored by the associated entry/exit code sequence. Note that the semantics of this field are different from those of the similarly named field of the `.CALLINFO` directive to the assembler. For example, a value of 5 in this field would mean that `gr3` through `gr7` (inclusive) have been saved in the entry save code.
8. **Args_stored** (bit 16): One if this region’s prologue includes storing any arguments to the routine in memory in the architected locations; zero otherwise. (Note: this bit may not be correct if the associated routine was compiled with optimization, as the optimizer may remove initial stores of arguments, but will never clear this bit.)
9. **Variable_Frame** (bit 17): Indicates that this region’s frame may be expanded during the region’s execution (using the Ada dynamic frame facility). Such frames require different unwinding techniques.
10. **Separate_Package_Body** (bit 18): Indicates the associated region is an Ada separate package body. It has no frame of its own, but uses space in a parent frame to save RP and spill any entry save registers.
11. **Frame_Extension_Millicode** (bit 19): Indicates the associated region is a special millicode routine which implements the Ada frame extension operation.

12. **Stack_Overflow_Check** (bit 20): Indicates the associated region has an Ada stack overflow check in its entry sequence(s).
13. **Two_Instruction_SP_Increment** (bit 21): Indicates the associated (Ada) region had a large frame such that two instructions were necessary to produce that portion of the frame increment which cannot be deduced from the frame size field in the unwind descriptor.
14. **sr4export** (bit 22): Indicates hand written sr4 export stub.
15. **cxx_info** (bit 23): This bit is used to indicate one or both of the followings:
 - (a) the associated function or region has a C++ exception specification.
 - (b) the associated function or region has objects which might require cleanup (destruction).
16. **cxx_try_catch** (bit 24): This bit is used to indicate that the associated function or region has one or more C++ try/catch constructs.
17. **sched_entry_seq** (bit 25): This bit indicates optimizer may have scheduled entry code. `U_get_previous` frame emits a warning message in this case indicating that context restoring unwind is not possible.
18. **Save_SP** (bit 27): One if the entry value of SP is saved by this region's entry sequence in the current frame marker (`current_SP - 4`); zero otherwise.
19. **Save_RP** (bit 28): For non-millicode, one if the entry value of RP is saved by the entry sequence in the previous frame (at `previous_SP - 20`); zero otherwise. For millicode, one if the entry values of MRP and sr0 are saved by the entry sequence in the current frame (at `current_SP - 20` and `current_SP - 16`, respectively); zero otherwise. If this bit is one, the `Save_MRP_in_frame` and `Millicode_save_sr0` bits are ignored.
20. **Save_MRP_in_frame** (bit 29): One if the entry value of MRP is saved by the entry code in the current frame (at `current_SP - 20`); zero otherwise. Applies only to millicode.
21. **Save_r19** (bit 30): One if gr19 is saved for shared library tables.
22. **Cleanup_defined** (bit 31): The interpretation of this field is dependent upon the language processor which compiled the routine.
23. **MPE_XL_interrupt_marker** (bit 32): One if the frame layout corresponds to that of an MPE XL interrupt marker.
24. **HP_UX_interrupt_marker** (bit 33): One if the frame layout corresponds to that of an HP-UX interrupt marker.
25. **Large_frame_r3** (bit 34): One if gr3 is changed during the entry sequence to contain the address of the base of the (new) frame.
26. **alloca_frame** (bit 35): This bit is set if `alloca()` is used and has been inlined. This indicates gr3 or gr4 may contain the previous sp value.
27. **Total_frame_size** (bit 37-63): The amount of space, in 8-byte units, added to SP by the entry sequence of this region. This space includes register save and spill areas, as well as padding. This quantity is needed during unwinding to locate the entry-save register save area. It is also used to determine the value of `previous_SP` if it was not saved in the stack marker.

9.4.2 Unwind Utility Routines

The unwind utility routines currently reside in the libcl.a (libcl.sl for shared library). The following section describes these routines and their interfaces.

- **U_get_unwind_table**

```
struct utable {
    unsigned unwind_table_start;
    unsigned unwind_table_end;
};
```

```
struct utable U_get_unwind_table(unsigned int dp_value);
```

This routine returns the code offsets of the start and end of the unwind table of a given object module. The unwind table is word-aligned. It takes the DP value for the object module where the unwind table is stored. It returns the offset of the start of the unwind table, and the offset of the first word beyond the unwind table.

ARG0: DP value of routine being unwound to. (only used on MPE/iX)

RET0: Offset (in space of routine being unwound to) of start of unwind table.

RET1: Offset (in space of routine being unwound to) of first word beyond end of unwind table.

- **U_get_unwind_entry**

```
int U_get_unwind_entry(
    unsigned int PC;
    unsigned int Space_id;
    unsigned int table_start;
    unsigned int table_end );
```

Given the PC_offset value of interest and the start and end of the associated unwind table, this routine returns the code offset (in PC_space) of the associated unwind table entry. If no unwind table entry exists, -1 is returned. Typically the table_start and table_end is found using the *U_get_unwind_table* routine.

ARG0: PC value to look up.

ARG1: Space id of table.

ARG2: Offset of start of unwind table.

ARG3: Offset of first word beyond end of unwind table.

RET0: Offset of unwind table entry associated with PC value; -1 if none exists.

This routine requires that the unwind table is sorted in increasing order of starting addresses. It does a binary search of the table to get to the entry corresponding to the input PC value.

- **U_get_previous_frame**

```
struct current_frame_def {  
  
    unsigned curr_frame_size;    /* Frame size of current routine. */  
    unsigned curr_sp;           /* The current value of stack pointer. */  
    unsigned curr_pcspace;      /* PC-space of the calling routine. */  
    unsigned curr_pcoffset;     /* PC-offset of the calling routine. */  
    unsigned curr_dp;           /* Data Pointer of the current routine. */  
    unsigned curr_rp;           /* Initial value of RP. */  
    unsigned curr_mrp;          /* Initial value of MRP. */  
    unsigned curr_sr0;          /* Initial value of sr0. */  
    unsigned curr_sr4;          /* Initial value of sr4 */  
    unsigned r3;                /* Initial value of gr3 */  
    unsigned cur_r19;           /* GR19 value of the calling routine,  
                                used only in shared library HP-UX. */  
  
    int r4;                     /* for alloca run-time stack memory  
                                allocation */  
  
    reserved;                   /* may have values in future releases */  
  
};  
  
struct previous_frame_def {  
  
    unsigned prev_frame_size;   /* frame size of calling routine. */  
    unsigned prev_sp;           /* SP of calling routine. */  
    unsigned prev_pcspace;      /* PC_space of calling routine's caller. */  
    unsigned prev_pcoffset;     /* PC_offset of calling routine's caller. */  
    unsigned prev_dp;           /* DP of calling routine. */  
    unsigned udescr0;           /* low word of calling routine's unwind */  
                                /* descriptor. */  
    unsigned udescr1;           /* high word of calling routine's unwind */  
                                /* descriptor. */  
  
    unsigned ustart;            /* start of the unwind region. */  
    unsigned uend;              /* end of the unwind region. */  
    unsigned uw_index;         /* index into the unwind table. */  
  
    unsigned prev_r19;          /* GR19 value of the caller's caller. */  
    int r3;                     /* value for gr3, for run-time-stack  
                                memory allocation */  
  
    int r4;                     /* value for gr4, for run-time-stack  
                                memory allocatoin */  
  
};
```

```
int U_get_previous_frame (  
    struct current_frame_def *curr_frame;  
    struct previous_frame_def *prev_frame );
```

Given a `PC_space`, a `PC_offset` value that is a return link to the caller, the frame size, and the `DP` and `SP` values of the called routine, this routine returns the frame size, the `DP` and `SP` values of the caller's frame, and the `(PC_space, PC_offset)` value that is a return link to the caller's caller.

The return value of this function means:

0: normal;

Negative:

-1: if `curr_pcspace`, `curr_pcoffset` is nil, indicating stack was fully unwound;

-4: if error occurs during linker stub unwinding other negative values less than -1 may be used in the future to indicate additional unexpected (internal) errors.

Positive: The frame is not unwindable for some reason.

1: no unwind_descriptor

0x7fffffff: cannot_unwind bit on in previous unwind descriptor

Assembly interface:

ARG0: Pointer to an eleven-word area of memory that contains the current frame info.

ARG1: Pointer to an eleven-word area of memory defined on exit as per definition of the `previous_frame_info` structure.

RET0: Return value defined on exit.

This routine is designed to enable access to the previous frame on the stack with input information about the current state. You may call this iteratively by setting the `cur` fields to the appropriate machine state, and then copying the first five `prev` values into the corresponding fields for successive calls, until end-of-stack is reached.

When a nonzero value is returned, the fields that would normally get defined on exit are undefined.

If the frame of the called routine is the topmost frame on the stack when unwinding commences, `cur_frsz` should be zero on the initial call.

- **U_get_previous_frame_x**

```
int U_get_previous_frame_x (  
    struct current_frame_def *curr_frame;  
    struct previous_frame_def *prev_frame );
```

```
struct current_frame_def *curr_frame;
struct previous_frame_def *prev_frame;
int size);
```

The functionality of this routine is the same as `U_get_previous_frame`. The only difference is the addition of the third parameter. This routine is introduced to allow for new fields to be added to the `current_frame_def` and `previous_frame_def`. With the `alloca` support, the data structures have to be extended to include new fields for `alloca` run-time stack memory information. The `size` field is used to specify the number of bytes used for the `previous_frame_def`. Starting at 10.0, users should start using `U_get_previous_frame_x` instead of `U_get_previous_frame` to access to the previous frame on stack.

- **U_get_recover_table**

```
struct recover_table_entry {
    unsigned TRY_start;           /* Starting offset (from sr4) of TRY region.*/
    unsigned TRY_end;           /* Ending offset (from sr4) of the
                                instruction following TRY region. */
    unsigned RECOVER_start;     /* RECOVER block offset for associated
                                TRY region (execution resumes here). */
};

struct rtable {
    unsigned recover_table_start;
    unsigned recover_table_end;
};
```

```
struct rtable U_get_recover_table (unsigned int dp_value);
```

This function returns the code offsets of the start and end of the recover table of a given object module.

This routine and the one describes below (`U_get_recover_address`) can be used to resume execution at a specific point if something unexpected happens. The HP Pascal run-time libraries use these routines to recover from traps and to execute non-local ESCAPE statement.

The recover table has three word entries containing the beginning and the end addresses of the unwind region and the resume address. It is word-aligned.

This function takes the DP value for the object module where the recover table is stored. It returns the offset of the start of the recover table, and the offset of the first word beyond the recover table.

This is the interface for assembly programmers:

ARG0: DP value of routine associated with PC value of interest.

RET0: Offset (in space of routine being unwound to) of start of recover table.

RET1: Offset (in space of routine being unwound to) of first word beyond end of recover table.

- **U_get_recover_address**

Given the PC_offset value of interest and the location of the associated recover table, returns the code offset (in PC_space) of the associated recover block. If the PC_offset does not point to a try block, an -1 is returned.

```
int U_get_recover_address( unsigned int PC;
                          unsigned int Space_id;
                          unsigned int rtable_start;
                          unsigned int rtable_end );
```

This is the interface for assembly programmers:

ARG0: PC_offset to look up.

ARG1: Offset (in space of routine being unwound to) of start of recover table.

ARG2: Offset (in space of routine being unwound to) of first word beyond end of recover table.

ARG3: Space id of recover table.

RET0: Recover address with actual execution level, or -1 if not found.

- **U_STACK_TRACE**

```
U_STACK_TRACE();
```

Applications can obtain stack traces easily using the U_STACK_TRACE() routine. This routine can be called from any place without any arguments. It will print the stack trace from the caller's frame onwards onto the standard output stream.

- **U_get_shLib_text_addr**

```
int U_get_shLib_text_addr(int GR19);
```

Given the GR 19 value, this routine will return -1 if the corresponding code is not in the HP-UX shared library, otherwise it will return the text address of the shared library.

- **U_get_shLib_unw_tbl**

```
struct utable U_get_shLib_unw_tbl(int GR19);
```

Given the GR 19 value, this routine will return -1 if the corresponding code is not in the HP-UX shared library, otherwise it will return the address of unwind start and unwind end of the shared library.

- **U_get_shLib_recv_tbl**

```
struct rtable U_get_shLib_recv_tbl(int GR19);
```

Given the GR 19 value, this routine will return -1 if the corresponding code is not in the HP-UX shared library, otherwise it will return the address of recover start and recover end of the shared library.

9.4.3 Unwind Examples: Using U_get_previous_frame

This following example illustrates how to make use of the U_get_previous_frame routine to write a stack trace into a character string. This example demonstrates that trace mechanism works for both archived and shared library routines.

Since a full stack trace requires access to the symbol tables in the program file, we have omitted the symbols from the output.

To try out the example, do:

```
make unwind_example
```

U_get_previous_frame is designed to enable access to the previous frame on the stack with input information about the current state. You may call this iteratively by setting the curr_frame to the appropriate machine state, and then copying the first five prev_frame fields into the corresponding fields for successive calls, until end of stack is reached. The initial set-up of curr_frame is done using a supported low-level routine which HP has written. This assembly level routine **MUST** be in the same image as the routine which uses it. This is the method we recommend using when priming the initial curr_frame for U_get_previous_frame. **NOTE:** the curr_frame and prev_frame fields are subject to change across releases. Thus, you should always extract the low-level routine from the system on which the executable will be built for (the location of the routine is explained in trace.c below).

```
=====  
Makefile  
=====
```

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```
unwind_example: example.out example.sl trace.sl output.txt
output.txt: example.out
             example.out 1>output.txt 2>&1

example.out: test_unwind.c example.sl trace.sl
             cc -Aa -o example.out test_unwind.c example.sl trace.sl -lcl
example.sl: test_shl.c
            cc -c -Ae +z test_shl.c
            ld -o example.sl -b test_shl.o
            rm test_shl.o

trace.sl: trace.c unwind.h ugetfram.s
          cc -c -Aa +z trace.c ugetfram.s
          ld -o trace.sl -b trace.o ugetfram.o
          rm trace.o ugetfram.o

clean:
        rm -f *.o *.out *.sl *.txt

=====
unwind.h
=====

#ifndef UNWIND_HEADER_FILE
#define UNWIND_HEADER_FILE

typedef struct cframe_info {
    unsigned cur_frsize;      /* frame size */
    unsigned cursp;          /* stack pointer */
    unsigned currls;         /* PC-space of CALLING routine */
    unsigned currlo;         /* PC-offset of CALLING routine */
    unsigned curdp;          /* data pointer */
    unsigned toprp;          /* return pointer */
    unsigned topmrp;          /* millicode return pointer */
    unsigned topsr0;         /* sr0 */
    unsigned topsr4;         /* sr4 */
    unsigned r3;             /* gr3 */
    unsigned cur_r19;        /* linkage-table pointer (gr19) - for PIC code */
} cframe_info;

typedef struct pframe_info {
    unsigned prev_frsize;    /* frame size */
    unsigned prevsp;         /* stack pointer */
    unsigned prevrls;        /* PC-space of CALLING routine */
    unsigned prevrlo;        /* PC-offset of CALLING routine */
    unsigned prevdp;         /* data pointer */
    unsigned udescr0;        /* first half of unwind descriptor */
    unsigned udescr1;        /* second half of unwind descriptor */
    unsigned ustart;         /* start of the unwind region */
    unsigned uend;           /* end of the unwind region */
    unsigned uw_index;       /* index into the unwind table */
    unsigned prev_r19;       /* linkage-table pointer (gr19) - for PIC code */
} pframe_info;

#endif /* UNWIND_HEADER_FILE */

=====
trace.c
=====
```

Stack Unwind Library

```
#include <stdio.h>
#include "unwind.h"

static void copy_prev_to_curr (cframe_info *curr_frame,
                               pframe_info *prev_frame);

void unwind_trace (char *stack_trace)
{
    cframe_info curr_frame;
    pframe_info prev_frame;
    unsigned stack_ptr, space_reg, offset_reg;
    unsigned data_ptr, linkage_ptr;
    unsigned sp20, depth;
    unsigned status;

    /* set up a valid curr_frame by calling an assembly routine.
     * This assembly routine is not exported by HP, but can
     * be extracted from /usr/lib/libcl.a ... it is called
     * ugetfram.o. The U_get_frame_info routine MUST be put into
     * the same image as this routine. It can then set up a dummy
     * curr_frame that has the correct values set.
     */
    U_get_frame_info (&curr_frame);

    /* U_get_frame_info doesn't zero sr0 and sr4 ... so do them explicitly
     */
    curr_frame.topsr0 = 0;
    curr_frame.topsr4 = 0;

    /* throw away the first frame ... since its a dummy frame
     * created by the call to U_get_frame_info.
     */
    status = U_get_previous_frame (&curr_frame, &prev_frame);

    /* Check to make sure everything is okay */
    if (status)
    {
        fprintf(stderr, "Stack_Trace: error while unwinding stack\n");
        return;
    }

    /* copy the prev_frame to the curr_frame */
    copy_prev_to_curr (&curr_frame, &prev_frame);

    /* Now for the real work. Initialize the trace string, and then
     * loop, unwinding a frame at a time until there are no more frames
     * to unwind (i.e. the offset portion of the return address is 0).
     */
    *stack_trace=0;

    for (depth = 0; curr_frame.currlo; depth++)
    {
        status = U_get_previous_frame (&curr_frame, &prev_frame);

        /* Check to make sure everything is okay */
        if (status)
        {
            fprintf(stderr, "Stack_Trace: error while unwinding stack\n");
            return;
        }
    }
}
```

```
    }

    /* Now, we'd like to print out the return pointer.  However,
     * U_get_previous_frame returns the prev_frame for the 1st NON-STUB
     * frame in the call chain.  It may be the case that the return
     * pointer for this frame points into another stub.  What we'd
     * really like to see is the return point for all NON-STUBS.
     * U_get_previous_frame updates curr_frame so that it contains
     * a frame whose return point is a NON-STUB.  Print out this value
     * before copying over prev_frame into curr_frame.
     */
    sprintf(stack_trace + strlen(stack_trace),
            "(%2d) 0x%x\n", depth, (curr_frame.currlo & ~3));

    copy_prev_to_curr (&curr_frame, &prev_frame);
}

static void copy_prev_to_curr (cframe_info *curr_frame,
                              pframe_info *prev_frame)
{
    /* Update curr_frame with values returned in prev_frame */
    curr_frame->cur_frsize = prev_frame->prev_frsize;
    curr_frame->currsp = prev_frame->prevrsp;
    curr_frame->currpls = prev_frame->prevpls;
    curr_frame->currlo = prev_frame->prevrlo;
    curr_frame->curdp = prev_frame->prevdp;

    /* don't update curr_frame.cur_r19 because U_get_previous_frame does
     * it directly.
     */
}

=====
test_unwind.c
=====
#include <stdio.h>

/* This file is built into an archived executable.  Traces in here
 * should prove that our trace mechanism works with archived routines.
 */

/* A prototype for a function that is in a shared library */
void foobar (void (* funcptr) (void));

/* This routine shows that our trace works when a shared library
 * routine calls back into the archived executable (2 levels deep)
 */
void foofoo (void)
{
    char trace_string[1025];

    unwind_trace (trace_string);

    fprintf(stderr, "\n\n\nIn foofoo, our trace gives: \n%s\n",
            trace_string);
    fprintf(stderr, "and U_STACK_TRACE gives: \n");
    U_STACK_TRACE();
}
}
```

Stack Unwind Library

```
/* This routine shows that our trace works when a shared library
 * routine calls back into the archived executable (1 levels deep)
 */
void barfoo (void)
{
    char trace_string[1025];

    unwind_trace (trace_string);

    fprintf(stderr, "\n\n\nIn barfoo, our trace gives: \n%s\n",
            trace_string);
    fprintf(stderr, "and U_STACK_TRACE gives: \n");
    U_STACK_TRACE();

    foofoo();
}

/* This routine shows that our trace works for archived functions */
void bar (void)
{
    char trace_string[1025];

    unwind_trace (trace_string);

    fprintf(stderr, "\n\n\nIn bar, our trace gives: \n%s\n", trace_string);
    fprintf(stderr, "and U_STACK_TRACE gives: \n");
    U_STACK_TRACE();

    foobar(barfoo);
}

void foo (void)
{
    bar();
}

main()
{
    foo();
}

=====
Ugetfram.s
=====

.CODE
;-----
;
;                               U_get_frame_info
;
; U_get_frame_info loads the value of the caller's SP, PCspace, PCoffset
;
; and DP into a record, a pointer to which has been passed into
; this routine in arg0. The format of this record is that required by the
; unwind routine
; "U_get_previous_frame".
;
;
;                               offset contents
;
```

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```
;      0      cur_frsize      framesize of called routine      :
;      4      curSP           SP of called routine              :
;      8      curRLS          PC_space of calling routine          :
;      12     curRLO          PC_offset of calling                  :
;                                     routine                      :
;      16     curDP           DP of called routine                :
;      20     topRP           RP (reg. 2) of called routine        :
;
;      24     topMRP          MRP (reg. 31) of called routine      :
;
;      28     cufSR0          :
;      32     cufSR4          :
;      36     curR3           :
;      40     cur_r19(new offset) :
;endif
;
; INPUT PARAMETERS:
;      arg0 : pointer to a 11-word structure with the above
;            layout
;
; OUTPUT PARAMETERS:
;      the fields curSP, curRLS, curRLO,curDP
;
;-----
;
U_get_frame_info
    .PROC
    .CALLINFO
    .ENTRY
    stw    sp,4(arg0)        ; store caller's SP
    mfsp   sr4,r20
    stw    r20,8(arg0)      ; store caller's PC space
    stw    rp,12(arg0)     ; store caller's PC offset
    stw    dp,16(arg0)     ; store caller's DP
    stw    r3,36(arg0)     ; store caller's R3
    stw    r0,0(arg0)      ; initialize rest of fields
    stw    r0,20(arg0)     ; --
    stw    r19,40(arg0)    ; fetch r19
    bv     r0(rp)          ; return, after restoring SP
    .EXIT
    stw    r0,24(arg0)     ; --
    .PROCEND

    .EXPORT U_get_frame_info, CODE, PRIV_LEV=3
    .END
```

```
=====  
output.txt  
=====
```

In bar, our trace gives:

```
( 0) 0x2044  
( 1) 0x20c0  
( 2) 0x20f8  
( 3) 0x800419a4  
( 4) 0x18fc
```

and U_STACK_TRACE gives:

```
( 0) 0x0000208c  bar + 0x60 [./example.out]
```

Stack Unwind Library

```
( 1) 0x000020c0 foo + 0x14 [./example.out]
( 2) 0x000020f8 main + 0x14 [./example.out]
( 3) 0x800419a4 start + 0x70 [/lib/libc.sl]
( 4) 0x000018fc $START$ + 0x9c [./example.out]
```

In foobar, our trace gives:

```
( 0) 0x8084844c
( 1) 0x20a0
( 2) 0x20c0
( 3) 0x20f8
( 4) 0x800419a4
( 5) 0x18fc
```

and U_STACK_TRACE gives:

```
( 0) 0x808484d0 foobar + 0xe0 [/tmp/unwind_example/example.sl]
( 1) 0x000020a0 bar + 0x74 [./example.out]
( 2) 0x000020c0 foo + 0x14 [./example.out]
( 3) 0x000020f8 main + 0x14 [./example.out]
( 4) 0x800419a4 start + 0x70 [/lib/libc.sl]
( 5) 0x000018fc $START$ + 0x9c [./example.out]
```

In barfoo, our trace gives:

```
( 0) 0x1fb4
( 1) 0x808484f4
( 2) 0x20a0
( 3) 0x20c0
( 4) 0x20f8
( 5) 0x800419a4
( 6) 0x18fc
```

and U_STACK_TRACE gives:

```
( 0) 0x00001ffc barfoo + 0x60 [./example.out]
( 1) 0x808484f4 foobar + 0x104 [/tmp/unwind_example/example.sl]
( 2) 0x000020a0 bar + 0x74 [./example.out]
( 3) 0x000020c0 foo + 0x14 [./example.out]
( 4) 0x000020f8 main + 0x14 [./example.out]
( 5) 0x800419a4 start + 0x70 [/lib/libc.sl]
( 6) 0x000018fc $START$ + 0x9c [./example.out]
```

In foofoo, our trace gives:

```
( 0) 0x1f30
( 1) 0x2008
( 2) 0x808484f4
( 3) 0x20a0
( 4) 0x20c0
( 5) 0x20f8
( 6) 0x800419a4
( 7) 0x18fc
```

and U_STACK_TRACE gives:

```
( 0) 0x00001f78 foofoo + 0x60 [./example.out]
( 1) 0x00002008 barfoo + 0x6c [./example.out]
( 2) 0x808484f4 foobar + 0x104 [/tmp/unwind_example/example.sl]
( 3) 0x000020a0 bar + 0x74 [./example.out]
```



```
( 4) 0x000020c0 foo + 0x14 [./example.out]
( 5) 0x000020f8 main + 0x14 [./example.out]
( 6) 0x800419a4 start + 0x70 [/lib/libc.sl]
( 7) 0x000018fc $START$ + 0x9c [./example.out]
```

In `sig_hand`, our trace gives:

```
( 0) 0x8084830c
( 1) 0x800ab3e8
( 2) 0x808484fc
( 3) 0x20a0
( 4) 0x20c0
( 5) 0x20f8
( 6) 0x800419a4
( 7) 0x18fc
```

and `U_STACK_TRACE` gives:

```
( 0) 0x8084838c sig_hand + 0xb4 [/tmp/unwind_example/example.sl]
( 1) 0x800ab3e8 sigreturn [/lib/libc.sl]
( 2) 0x808484fc foobar + 0x10c [/tmp/unwind_example/example.sl]
( 3) 0x000020a0 bar + 0x74 [./example.out]
( 4) 0x000020c0 foo + 0x14 [./example.out]
( 5) 0x000020f8 main + 0x14 [./example.out]
( 6) 0x800419a4 start + 0x70 [/lib/libc.sl]
( 7) 0x000018fc $START$ + 0x9c [./example.out]
```

9.5 Setjmp and longjmp jmp_buf

`Setjmp` and `longjmp` functions are useful for dealing with errors and interrupts encountered in a low-level subroutine of a program. `Setjmp` saves its stack environment in `env` (`jmp_buf` type) for later use by `longjmp`. `Longjmp` restores the environment saved by the last call of `setjmp` with the corresponding `env` argument. After `longjmp` is completed, program execution continues as if the corresponding call of `setjmp` had just returned the value `val`.

```
#include <setjmp.h>
```

```
int setjmp (env)
jmp_buf env;
```

```
void longjmp (env, val)
jmp_buf env;
int val;
```

```
struct jump_buffer {
    int jb_rp;           /* Return Pointer */
    int jb_sp;           /* Marker SP */
    int jb_sm;           /* Signal Mask */
    int jb_os;           /* On Sigstack */
    int jb_gr3;          /* Entry Save General Registers */
    int jb_gr4;
    int jb_gr5;
    int jb_gr6;
    int jb_gr7;
```

```
int jb_gr8;
int jb_gr9;
int jb_gr10;
int jb_gr11;
int jb_gr12;
int jb_gr13;
int jb_gr14;
int jb_gr15;
int jb_gr16;
int jb_gr17;
int jb_gr18;
int jb_gr19;
int jb_sr3; /* Entry Save Space Register */
double jb_fr12; /* Entry Save Floating Point Registers */
double jb_fr13;
double jb_fr14;
double jb_fr15; /* Second word for Signal Mask */
int jb_sm2;
double jb_fr16;
double jb_fr17;
double jb_fr18;
double jb_fr19;
double jb_fr20;
double jb_fr21;
int jb_rp_prime; /* rp prime from frame marker */
int jb_ext_dp; /* external_dp from frame marker */
};

typedef struct jump_buffer jmp_buf;
```

9.6 Process Context

This section discusses exception handling in Ada and C++.

9.6.1 Ada Exception handling

The exception handling semantics of the Ada/800 runtime are implemented in the package `EXCEPTION_MANAGER`, which is nested in the package `ADA_RUNTIME`, and its subunits.

The code generator generates instructions to raise exceptions along with tables that describe the actions to be taken when an exception is raised. There are two methods to enter `RAISE_EXCEPTION`, the procedure that handles exceptions. One is through system traps and the signal handler of the runtime system, the other one is by invoking `RAISE_EXCEPTION` directly. The trap instructions are used for checks. When a check fails, it will trap, and the signal catcher of the runtime system will receive a HP-UX signal. It then decodes the trap and calls `EXCEPTION_MANAGER.RAISE_EXCEPTION` to treat the exception. For explicit raise statements, the code generator will emit direct calls to `RAISE_EXCEPTION`. The `RAISE_EXCEPTION` routine can also be called by other routines in the runtime system.

RAISE_EXCEPTION takes two pieces of information from its caller: the exception code and the program counter where the exception occurred.

Exception Through Traps and Signals

The operation to handle signals is as follows:

- exception occurs
- system trap occurs
- signal generated
- signal handler entered
- RAISE_EXCEPTION called

The exception manager looks up the exception in a set of tables, depending on the place where the exception occurred and what exception it was, and tries to find a handler. If a handler is found, the exception manager does all cleanups necessary (all cleanup actions in scopes from the scope that raised the error down to, but not including the destination scope) and then passes control to the handler. The necessary cleanups include waiting for dependent tasks, freeing heap memory, and cutting back the stack to reclaim the space for dynamic objects. If no handler is found, the exception is propagated.

Exception Tables

The object code contains scope and handler tables which are searched by the exception manager. The linker emits the scope table from information in the the relocatable object (SOM) files. The code generator emits the handler table directly.

There is a scope table created by the linker for a program. The scope table consists of scope entries. There are two symbols (beginning and ending symbols) provided by the linker to delimit the scope entries. The beginning and ending symbols point to the first entry and the entry past the last one (first byte not in the table) respectively. The structures of a scope table and a scope table entry are as follows:

Scope Table
entry #1
entry #2
...

Scope Table Entry
scope_begin
scope_end
handler_tbl_addr

The *scope_begin* and *scope_end* are the beginning and ending offsets associated with the current scope. The *handler_tbl_addr* is the code address of the handler table for this scope.

The scope entries need to be sorted in the order of the code generator encountering the end of scope. This means that in the table, the "scope_end" values will be monotonically increasing. The linker has to be changed to allow stacked scopes, i.e., an inner scope is totally nested within an outer scope.

We only need a scope entry for the statement region of a scope that has a handler. This is a great simplification from previous schemes. We do not need scope entries for separate package bodies, since unwind will be able to unwind through a separate package body and find the invocation location.

When an exception is raised in a block which is nested in another block, if the handler of the inner scope doesn't handle it, it will be propagated to the outer scope. It means that the "scope_begin" and "scope_end" of the outer scope has to enclose those of the inner scope. The current UCODE implementation unnests scope entries such that entries do not have overlapping "scope_begin" and "scope_end". An Ada option will be added to the UCODE such that entries will not be unnested. It also has the advantage of having less scope entries than entries which are unnested.

The exception parts are placed in line, to follow immediately after the statement part of the scopes. While this introduces a branch over the exception part in the normal case, it makes the tables simpler, because a table entry is not needed to know how to propagate out of the exception scope. This decision was also necessary due to the requirements imposed by existing HP-PA utilities that demand that a procedure have only one exit, and this exit must be the last instruction in the procedure. This requirement precludes putting exception parts in the "dead space" after the procedure exit.

There is a one-to-one correspondence between scope table entries and handler tables. This means that the handler table is basically an extension of the information in the scope table entry. It would be possible to merge the two tables, and eliminate the word necessary for the "handler_tbl_addr". For now, the tables are kept separate, to be consistent with Pascal's method of handling try/recover information, which uses a similar 3 word scheme to describe try/recover scopes. Pascal does not need the handler table information, so their 3rd word is simply the code address of the recover part. In order to stop Pascal from executing code in the handler table, a special trap instruction is needed at the beginning of the handler table and its trap handler will stop the program. The special trap instruction is necessary because the handler table is not in the unwind region. The handler table is put in the code space and is right after the code for a procedure. As unwind regions only cover code and the handler table is between the code for different procedures, the handler table is not in the unwind region.

A handler table consists of a header and an array of handler entries. The code address in the scope table entry points to the handler table header. This header describes the scope which has an exception part. Following this header are entries which describe each individual exception which has a handler, and the code address of that handler.

The structures of a handler table, a handler table header and a handler entry are as follows:

Handler Table
handler_table_header
handler_table_entry #1
handler_table_entry #2
...

Handler Table Header
trap_instruction
number_of_entries
scope_kind
anonymous_raise_save_offset
sp_save_location
cleanup_stop_point

Handler Table Entry
exception_code
handler_code_addr

The *number_of_entries* field simply denotes how many handler table entries follow this header.

The *scope_kind* denotes the kind of scope we have, such as procedure, function, package, accept body, etc. This is necessary in the case where we have an exception occurring in the statements covered by these handlers, but the exception we have is not handled here. We therefore need to propagate, and the propagation is different depending on the *scope_kind*. If the scope is an inline package or block, we simply need to look for a handler in the scope tables immediately following the current scope table entry. We continue this linear search till we either find an enclosing entry or we get to a subprogram type entry which starts after the exception raising offset. The *scope_kind* field is necessary to terminate this search. If the scope is a subprogram or separate package body, we need to call unwind to determine the call or invocation location.

The *anonymous_raise_save_offset* is an offset to a frame location used to save the current exception code before giving control to the handler. It is also used to restore the exception code when any anonymous raise is executed. It has the value of undefined off-

set unless one of the handlers contains an anonymous raise.

The *sp_save_location* is an offset to a frame location used to restore the stack pointer before transferring control to one of the handlers. The object code stored the stack pointer into this frame location at entry to the statement region covered by this exception part. It has the value of an invalid frame offset if the unit does not contain further blocks which have dynamic variables. If it is the invalid frame offset, no stack cut back is necessary. The *cleanup_stop_point* is an offset to a frame location that describes where to stop the process of tasking and heap cleanups. Before transferring control to one of the handlers, we need to wait for all dependent tasks on the chain above *cleanup_stop_point*, and after that, free all heap objects on the chain above *cleanup_stop_point*. The code generator will set *cleanup_stop_point* to be the top of the logical frame for the block that has the handler. This will cause cleanup of all objects on the chain above those of this particular block (and NOT including this block). Note that it doesn't matter if the block has cleanups or not, since we have only a top of frame point, and not the location of the cleanup list entries for the block. All the offsets in the handler table header (*anonymous_raise_save_offset*, *sp_save_location*, and *cleanup_stop_point*) are always offsets from PSP even on static frames.

The *exception_code* is the value of an exception handled here, or a special value to represent a "when others". The *handler_code_addr* is a subprogram symbol plus an offset which points to the handler code area for the particular exception code. As the handler table is put in the code space and is right after the end of a procedure, *handler_code_addr* is relocation fixup. In the case of nested blocks, the handler code is inline but the handler table is moved out of the line (to right after the end of a procedure). The reason for this is that the unwind regions delimit the "begin" and "end" of code which should not have any data, otherwise, the linker may do undesired fixups. Here is an example of code layout :

```
begin
  statements #1
  begin
    statements #2
  exception
    handlers # 2
  end;
exception
  handlers #1
end;
```

The layout of generated code and table is as follow:

```
code for statements #1
code for statements #2
code for handlers #2
code for handlers #1
handler table for the inner scope
handler table for the outer scope
```

When `RAISE_EXCEPTION` is called, it calls various routines to perform the following operations:

1. `FIND_SCOPE_ENTRY` routine uses two steps to locate the desired scope entry. It first does a binary search to find the first entry that ends on or after the raising offset, and then a linear search from there to find the first entry including the raising offset. This algorithm works because the entries are emitted in order of the code generator encountering the end-of-scopes. This means that entries from inner blocks will come before entries from outer blocks.
2. If no scope entry is found, then there is no local handler within the current scope, and we need to propagate by calling `unwind` to go back one scope, and then repeat step 1.
3. If the scope entry is found, `FIND_HANDLER_TABLE` routine finds the handler table based on the handler table offset in the scope entry.
4. The `FIND_HANDLER` routine loops through the handler table to search for the handler entry whose exception code matches with the exception raised.
5. If a handler is found, save the current exception at the handler table's `anonymous_raise_save_offset` if necessary, do any necessary cleanups, and pass control to the handler; otherwise, propagate the exception. If we need to propagate, and the scope kind is either a procedure or a separate package body, then call `unwind` to go back one scope, and then start this entire search process again. If we need to propagate from a block or inline package, simply keep searching forward in the scope table starting with the next entry after the current one. In this way, if there is an enclosing block or procedure with a handler, we will find it based on the original offset.

Unwind Mechanism

The exception handling routines need to call lower level utilities to unwind through a scope. The existing unwind mechanism for Spectrum is used for this purpose, with some extensions to allow handling of variable sized scopes and separate packages. The primary routine provided by the unwind utilities is the `u_get_previous_frame` routine. Given a PC value, this routine gets the appropriate unwind entry for this scope from the unwind table. If a scope is a subprogram, then its previous scope is its call; if a scope is a separate package body, then its previous scope is its invocation point. The information kept and updated by the unwind routines reflects the program state in that scope. This information consists of the SP, DP, PC space, PC offset and the size of the current scope. When running under HP-UX, DP and the PC space values do not change.

The unwind utilities find out the scope size of any scope by looking at the unwind descriptor for that scope. In Ada, the scope size is not known at compile time for procedures that either allocate dynamic objects or have separate packages. Thus, the scope size cannot be looked up in the unwind descriptor. A boolean flag will be set in the unwind descriptor to indicate a variable sized scope. For such procedures, the previous stack pointer (PSP) will be stored in the frame marker upon entry to a procedure. This

stored PSP will be used to get the SP for the previous (caller's) frame.

When a procedure allocates a dynamic object, the size of the frame is increased at that point. The frame marker is also moved out. This extension of the frame is done by a special millicode routine. Within this routine the SP changes in value. The unwind descriptor of the frame extension millicode routine is specially marked, so that the unwind utilities can recognize the fact that SP changes value within the routine and can unwind appropriately. This implies that the unwind utilities have to know about the sequence of instructions in the millicode routine completely.

On exit from a block that allocates dynamic objects, the frame has to be shrunk to the correct size. This is again done through a special millicode routine. However, no special treatment is needed to unwind through this frame size reduction millicode. The SP and the frame marker are in a valid state at each instruction in the routine.

The elaboration code of a separate package is in the same frame as the parent unit. The entry and exit sequences of this code are different from ordinary procedures. The unwind descriptor for a separate package elaboration has to indicate that it is part of a parent frame. However, the base of the frame contribution of the package must be stored in the descriptor so that the spill locations for the separate package can be identified.

There is one thing we have to be extremely careful about while propagating exceptions. The meaning of offsets into the code may be different depending on the situation. If we are starting to unwind from a trap, we will have the actual trapping offset. If we are unwinding through a procedure call, the return point is two instructions past the call branch. The reason it is two past and not one past is that the instruction immediately following the call branch is executed before the call actually occurs, in the delay slot of the branch.

Cleanups for Dependent Tasks, Heap Objects, and Stack Space

There are three separate cleanups necessary before transferring control to any handler. These are for tasks, heap objects, and stack space used by dynamic variables. For tasks and heaps, there are two chains that contain cleanup information. The cleanups necessary are for entries on these lists above the frame contribution for the scope of the destination exception handler. This assumes that frame contributions are sorted, in that a nested scope's frame contribution will always be above the contributions of scopes that it is nested within. This scheme is described in detail in another memo.

To cut the stack back to reclaim space used for dynamic variables, use `sp_save_location` field as the offset to a frame location containing the value of SP that we need to restore. This is necessary only for scopes that contain blocks with dynamic variables. If `sp_save_location` contains the `invalid_offset` then we do not need to restore SP. Note that we must change SP and then copy the frame marker back to correspond to the new SP value. This means that we need to modify the value of SP in our saved register image and also move the stack marker. Note that this cleanup scheme only handles cleaning up dynamic variables in the frame of the handler. This works since the unwind procedure will get rid of dynamic objects in frames above the destination, since their dynamic objects will disappear when their frame disappears.

Note that we must do the tasking cleanups before the heap cleanups or stack reclamation, since the tasks may be using the heap objects or dynamic variables.

Procedure Traceback Tables and Mechanism

When an exception is raised but not handled, we want to give a stack traceback, which provides information about the path of exception propagation through active scopes. The traceback routine prints the exception name, followed by the stack trace which prints the compilation unit name(s), scope name(s), scope kind(s), and line number(s) of each scope it encounters. This information all comes from the unwind and auxiliary unwind tables (generated by the linker), the name tables (generated for each compilation unit by code generator), and the exception name table (generated for the entire program by the binder). For traceback, we do not use information from the exception tables themselves. The scope part is not printed, since it would take more space in the auxiliary unwind table to support it, and we are unsure that the user really wants to see it. Also, we decided to suppress the tracing of blocks and local packages, so there will be no entries in the unwind tables for them. There will, however, be entries for separate packages, so the user will see trace propagation through separate packages.

When the exception manager goes all the way to the base of the stack and cannot find any applicable handler, then it knows that the current task will terminate. At this point, we will print a traceback. The exception manager will call the traceback routine, passing the original raising offset.

The linker generates the unwind and auxiliary unwind tables, and these two tables are parallel. For each entry in the unwind table, there is a corresponding entry in the auxiliary unwind table. Their structures are as follows:

Unwind Table
unwind entry #1
unwind entry #2
...

Unwind entry
scope_begin
scope_end
flags
frame_size

aux_unwind_table
aux unwind entry #1
aux unwind entry #2
...

aux unwind entry
cu_name_ptr
scope_name_ptr
scope_kind
line_number_tbl_ptr

The unwind table is similar to the scope table for exception handling, except that the unwind table has more entries and entries are unnested. It has an entry for each subprogram level scope as well as library level packages and separate packages. There are no entries for local packages as it would require multiple unwind entries for a subprogram level scope. In other words, we forgo having traceback for any scopes smaller than subprograms (ie: blocks and local packages). The *scope_begin* and *scope_end* have the same meaning as the exception tables, and are sorted in the same order. The *flags* can include a boolean indicating the presence of a variable sized frame.

Both *cu_name_ptr* and *scope_name_ptr* point to the name table which contains the string literals emitted by code generator. A null pointer for *cu_name_ptr* or *scope_name_ptr* indicates "unknown" which may occur when units are compiled with traceback off. If the value of *scope_name_ptr* is 1, it indicates that it is a "<type support subprogram>". The *line_number_tbl_ptr* points to the line number table generated by the linker. The linker uses the information from the start of statement fixups to emit the line number table. The code generator provides *cu_name_ptr*, *scope_name_ptr* and *scope_kind* to let the linker emit the auxiliary unwind table. Ada will use an option to pass these to Ucode, and there is a new fixup called R_AUX_UNWIND that Ucode will use to communicate these items to the linker.

The traceback routine calls **u_get_previous_frame** which takes an offset to get the appropriate unwind entry from the unwind table. Once the unwind entry is located, the corresponding entry in the auxiliary unwind table can be located easily as both tables consist of parallel arrays of entries. A unwind utility routine will return either an index or offset from the beginning of the unwind table such that the runtime routine can find the associated auxiliary unwind entry.

The name table generated by the code generator consists of compilation unit names and scope names pointed by *cu_name_ptr* and *scope_name_ptr* in the auxiliary unwind table. The string literals in the name table end with a null character. There is one name table for each compilation unit (not just a single one for the entire program). There is no need to ever traverse the name tables, so we do not need pointers or symbols to the start of them. The only action supported by these tables is direct access to a name pointed to by an entry in the auxiliary unwind table.

The structure of a name table is as follows:

Name Table of a cu
cu_name
scope_names

The exception names table has a different format, however. We need to be able to search this table, looking for an entry with a given exception value. We do not have direct pointers into entries in this table. The binder will write out a single exception names table for the entire program, using information provided by the code generator. Note that if we are suppressing traceback, we do not need to produce either the exception names table or the names tables.

The structure of the exception names table is as follows:

Exception names table
exception name entry #1
exception name entry #2
...

Exception names entry
exception_value
exception_name_length
exception_name_text

The exception names table is thus a table containing entries of varying lengths. Each entry starts with an exception value, and then supplies the length and the characters of the name of that exception. All exceptions will have entries in this table, including the predefined and I/O exceptions.

The structure of line_number_table is as follows:

Line Number Table
version_number
start_code_offset
start_line_number

code_diff	line_diff	code_diff	line_diff
code_diff	line_diff	code_diff	line_diff
...

The `line_number_table` starts with a header that contains three words of information: `version_number`, `start_code_offset` and `start_line_number`. The first word contains the version number, as a 32-bit integer. It is initially 1 (one), and is here to support the possibility of changing the table format sometime in the future. If we ever change the format, the runtime would have to look at the version number, and interpret the tables based on the format that corresponded to that version. This would allow the intermixing of old format and new format SOMs into one executable.

The second word gives the offset (in BYTES) from the beginning of the unwind region to the start of the code for the first numbered line in the region. The third word gives the line number of that first line of code. After that, the `line_number_table` contains any number of elements, each of which has a pair of `code_diff` and `line_diff` which are usually the differences of code offsets and line numbers between the previous and current elements. The `code_diff` values are word offsets (not byte offsets), and are unsigned (range 0 .. 255). The `line_diff` values are signed, range (-128 .. 127). Both entries in this pair (`code_diff` and `line_diff`) occupy only one byte each. For entries with too large a span to fit into one byte fields, the table simply uses additional entries, in the standard format. Note that since the first line of code is covered by the information in the two-word header, the first pair of (`code_diff`, `line_diff`) gives the information for the second line of code.

The meaning of each pair in the table is determined by the value of `code_diff`, as shown in the table below.

Code_diff_value	Meaning
0 to 250	Normal entry, representing differences.
251	The next 3 bytes (the <code>line_diff</code> , and the following <code>code_diff</code> and <code>line_diff</code>) contain a secondary line number.
252	This is the short form of a secondary line number. The following (signed) <code>line_diff</code> gives the difference between the last secondary line number and the value of the current one.
253	The next 3 bytes (the <code>line_diff</code> , and the following <code>code_diff</code> and <code>line_diff</code>) contain an absolute line number. This is used in place of many difference entries, when the difference between two line numbers is large. This must follow an entry with a <code>line_diff</code> of zero (see below).

254	Ignore this pair and the following two pairs (the 254 and the following line_diff, code_diff, line_diff, code_diff, and line_diff). This is for future expansion.
255	End of the table. Stop searching. On this entry, the value of line_diff is meaningless

The special code value of 251 means that a secondary line number follows in the next three bytes. These entries give an extra line number for lines that are the result of instantiations or inlinings. In this case, the regular table entries give the line number of the inlining or instantiation, and the secondary line number gives the original line number of the source (before it was inlined or instantiated).

The special code value of 252 is the short form of the above. Instead of taking three bytes to give the absolute value of a secondary line number, this form gives one byte which when added to the value of the last secondary line number, gives the value of this secondary line number. The following byte is signed, so the secondary line number can go either up or down. The following byte can be zero, which means this secondary line number is exactly the same as the last one. Note that the previous secondary line number (that we base the value on) can be either a short form or a long form).

The special code value of 253 is an absolute line number. When encountering one of these, we disregard our line number value we have built using the line_diffs, and use this new value. From then on, new line_diffs apply to the new value. Note that since this form does not have a code_diff field, it is equivalent to a (code_diff, line_diff) pair with a code_diff value of zero. Entries like this have the effect of hiding the line that comes before it. To prevent this, before the code 253 special entry, we need a regular entry with a zero value for line_diff, and a code_diff value giving the length of the previous line (see example).

Because a code 253 entry takes up 6 extra bytes, we should only use it when we would otherwise have to use more than 4 regular entries to span a large gap in line numbers.

During the traversal of the table, we do not use the secondary line number entries (with codes of 251 or 252) as we attempt to find the line number for a given code offset. After we find the line number, we look at the following entry, to see if it is a secondary line number entry. If so, it applies to the line we just found. If not, there is no secondary line number for that line, which means the line was not involved in inlining or generic instantiation.

This line number table, and the associated auxiliary unwind tables are now a CLL standard, and will be produced by the linker. So far, Ada is the only language to use the secondary line numbers, and no language uses the special code 254. Code 253 can be used by any language, but BASIC is the language that will probably use it the most. The design of the tables is such that when there are no secondary line numbers (such as for the other languages), there is very little overhead to support them.

It is likely that any future use of the code 254 would have to change the number of bytes to skip. This is OK, since if we made that change we would also change the version

Stack Unwind Library

number, so the runtime could use the new method.

The best way to demonstrate this method is by example. Suppose you have some code with the following characteristics (all starting positions and sizes in the following table are in WORDS):

Line #	Secondary Line #	Start at:	Size
1	-	0	10
2	-	10	20
3		30	400
4	-	430	10
200	-	440	10
205	-	450	10
180	-	460	300
30	4000	760	10
30	4001	770	20
30	4005	790	15
3000	-	805	22
3010	-	827	25

Note that the above example has line numbers which are not monotonically increasing. The line numbers are also not very regular. There is some code at lines 1, 2, 3, and 4, and then a lot of comments, so the next line of code is at line 200. Furthermore, after line 205, we have some unnested exception handlers, with lines at 180 and then at 30. Finally, we have lots of comments, followed some final lines at line numbers 3000 and 3010. Line 3 is an inlining of a single-line subprogram (originally at line 95), and line 30 is an instantiation of a 3 line generic (originally at line 4000 to 4005). The code offsets are monotonically increasing, as you would expect.

Here is the line number table that would represent the above situation. The picture below shows the actual table content in the first two columns only. The last columns indicate the meaning of that entry.

start_code_offset	start_line_number	Means	Actual Offset	Line #
0	1	= >	0	1

code_diff	line_diff	Means	Actual Offset	Line #
10	1	= >	10	2
20	1	= >	30	3

code_diff	extra info	Means	secondary line number
251	0, 0, 95	= >	95

code_diff	line_diff	Means	Actual Offset	Line #
250	0	= >	280	3

code_diff	extra info	Means	secondary line number
252	0	= >	95

code_diff	line_diff	Means	Actual Offset	Line #
150	1	= >	430	4
10	127	= >	440	131
0	69	= >	440	200
10	5	= >	450	205
10	-25	= >	460	180
250	0	= >	710	180
50	-128	= >	760	52
0	-22	= >	760	30

code_diff	extra info	Means	secondary line number
251	0, 15, 160	= >	4000

code_diff	line_diff	Means	Actual Offset	Line #
10	0	= >	770	30

code_diff	extra info	Means	secondary line number
252	1	= >	4001

code_diff	line_diff	Means	Actual Offset	Line #
20	0	= >	790	30

code_diff	extra info	Means	secondary line number
252	4	= >	4005

code_diff	line_diff	Means	Actual Offset	Line #
15	0	= >	805	30

code_diff	extra info	Means	Actual Offset	Line #
253	0, 11, 184	= >	805	3000

code_diff	line_diff	Means	Actual Offset	Line #
22	10	= >	827	3010
255	0	= >	stop	stop

The algorithm for traversing the tables is as follows. You start with the offset of code that was active at the time of the traceback. The goal is to find the line number whose code contains this offset. As you traverse the table, you start with `Start_code_offset` and `Start_line_number`. When you encounter a regular table entry pair (one with a `code_diff` in the range 0 .. 250), add its code offset difference to your code offset counter, and its line number difference to your line number counter. When you encounter a code 253 entry, update your line number from the next three bytes in the table. The last two columns of the table above shows the value of these two counters after encountering each such entry in the table.

The algorithm stops when it finds the last actual code offset (the one furthest along in the table) that is less than or equal to the offset you are looking for. In practical terms, this means find the first actual code offset bigger than the one you are looking for, and then back up one entry in the table.

Let's look at a few examples:

Example 1. If you are looking for offset 90, you find line 3, since 30 is the last offset \leq 90. You then notice that this piece of line 3 has a (long form) secondary line number of 95.

Example 2. If you are looking for offset 300, you also find line 3, but you find its second entry, since 280 is the last offset \leq 300. Here also, this piece of line 3 has a (short form) secondary line number of 95.

Example 3. If you are looking for offset 440, you find line 200, since its offset of 440 is the last offset \leq 440. Note that the entry for line 131 (there really is no line 131) is not reachable, since its actual offset of 440 is the same as the next entry's actual offset. Note that there is no secondary line number on this line.

Example 4. If you are looking for offset 805, you find line 3000, since its offset of 805 is the last offset \leq 805. Once again, there is a hidden line before it, also with an offset of 805, which is just necessary to establish the code offset for the absolute line entry for line 3000. Since line 3000 shares the same code offset as the last entry for line 3, that last entry for line 3 is not reachable. This unreachable entry must exist, to establish the starting offset for the line 3000 entry.

This method uses only two bytes per line in most cases. If the size of an individual line is bigger than 250 words, or the difference in line numbers is not in the range -128 .. 127, then you will end up with extra regular entries in the table. You may end up with

many extra regular entries on unusual cases. For example, a line containing 1100 words of object code would need five regular table entries.

Any line with a secondary line number will also use more space, to hold the extra information.

Any extra regular entries inserted in the table will be of one of two types:

1. A duplicate entry for a given line number, to get around the limit of 250 words of object code per line (as shown by lines 3 and 180 in the example). Note that if the long line also has a secondary line number, we need a secondary line number entry to follow each piece of the original line in the table (as shown by line 3 in the example). Note that after the first secondary line number entry, the duplicate ones can be the short form (code 252) with a difference value of 0.

2. A hidden entry with an unused line number, to either get around the limit on the span between line numbers (as shown by lines 131 and 52 in the example), or to precede an absolute line number entry (as shown by the last entry for line 3 in the example). These entries can never show up in a traceback because they share the same actual offset with the entry that follows them. Note that in this case we do not need secondary line numbers on these hidden lines.

Note that if any line needs both classes of extra regular entries (if it has more than 250 words of code AND has a line number that differs from the next one by an amount other than -128 .. 127), then all the class 1 extra entries must precede the class 2 ones. This is necessary, since you must first take into account all the offsets for the given line number, before you start changing the line number for the next line. This is shown by line 180 in the example.

The advantages of this method are that it is very compact, in that most lines will have only one entry, occupying 2 bytes total, and that the necessary extensions are simple, and don't effect the processing speed very much.

9.6.2 C++ Exception handling

The C++ exception handling can be broken down into four functional areas:

1. Transfer of Control

When an exception is encountered, the exception handling mechanism must suspend execution at the throw point, and resume execution at the appropriate catch point. When execution is resumed, global and local variables must have correct values.

2. Exception Identification

The exception handling run-time support (henceforth simply the "run-time") must have type information available which describes various characteristics of a type; for example, this information is used to determine if a thrown exception is handled by a catch

clause. The mechanism for emitting and utilizing this information is called “Exception Identification”.

3. Object Cleanup

When an exception occurs, the exception handling mechanism should attempt to destroy all fully and partially constructed automatic objects between the throw point and the catch point. If an exception occurs in the construction of a heap object, the heap object should be destroyed and any memory allocated for the object should be deallocated. When *exit* is called, fully and partially constructed static objects should be destroyed.

4. Storage Management

The run-time must maintain a copy of a thrown object. There can be multiple thrown objects which are simultaneously active, and the run-time must manage the memory necessary to store such objects.

Implementation Scheme

The exception handling scheme can be summarized as follows:

- Use `setjmp/longjmp` to transfer control from a *throw* to the appropriate *catch* clause.
- Use a linked list of “markers” running through the stack to record the execution of try blocks, functions with exception specifications, and functions which require object cleanup.
- The translator emits *typeinfo* objects to store useful information about a type (such as the list of base classes). This information is used by the exception mechanism to determine if a catch clause can handle the thrown object, and to check for exception specification violations. The *typeinfo* information is also used to determine how to destroy partially constructed objects.
- Upon entry into a function which requires object cleanup in the event of an exception, a “cleanup marker” is chained into the chain of markers. This cleanup marker will point to a statically generated table which describes the cleanup actions required by this function.
- The chain of markers is also used to handle functions with exception specifications; this is done by adding a “specification marker” to the marker chain upon entry to a function with an exception specification.

10.1 Content of the Millicode Library

The Millicode library contains special purpose routines that are tailored for performance. These routines are written in the PA-RISC assembly language and follow only the millicode calling conventions. Each Millicode routine determines exactly what registers are preserved and which are destroyed, and the compiler has this information hardcoded into it.

There are four kinds of millicode routine:

Languages Support Millicode:

These are packed and unpacked decimal arithmetic operations, decimal conversions, or strings comparison. By convention, routines that begin with \$\$g... manipulate unpacked decimal and those begin with \$\$d... manipulate packed decimal numbers.

Arithmetic Instructions:

These instructions are not supported in a typical RISC processor such as divide or remainder.

Compiler Back End Support routines:

These include address manipulation and moves, ripple, stack frame extension etc...

Miscellaneous Support routines:

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These include operating systems supports (\$\$CALLX); calling convention supports (\$\$dyncall); utilities (\$\$get_version); etc...

The following table lists all the entry points in the millicode library and summarizes their function. The next section will show the complete interfaces for all routines.

TABLE 26.

Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$get_ascii_ptr	COBOL support	Get a pointer to tables of constants for various unpacked ASCII decimal transformations (ASCII table).
\$\$tbl_ASCII	COBOL support	Export the address of the ASCII table.
\$\$cvt_id	COBOL support	Convert 32-bit binary to packed decimal.
\$\$cvt_dg_regs	COBOL support	Convert a packed decimal number in register form to an ASCII unpacked decimal in register form.
\$\$cvt_gd_regs	COBOL support	Convert an ASCII decimal in 'special register format' to a packed decimal in register form.
\$\$d_mul	COBOL support	Multiply 2 unsigned packed decimals to produce an unsigned packed decimal result.
\$\$d_mul1	COBOL support	Multiply 2 packed decimal of 4 bytes long to produce a product of double that precision.
\$\$d_mul2	COBOL support	Multiply 2 packed decimal of 8 bytes long to produce a product of double that precision.
\$\$d_mul3	COBOL support	Multiply 2 packed decimal of 12 bytes long to produce a product of double that precision.
\$\$d_mul4	COBOL support	Multiply 2 packed decimal of 16 bytes long to produce a product of double that precision.
\$\$dadd1	COBOL support	One word packed decimal add. Operands and destination are 1 word in length.
\$\$dadd2	COBOL support	Two words packed decimal add. Operands and destination are 2 words in length.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$dadd3	COBOL support	Three words packed decimal add. Operands and destination are 3 words in length.
\$\$dadd4	COBOL support	Four words packed decimal add. Operands and destination are 4 words in length.
\$\$dsub1	COBOL support	One word packed decimal subtraction routine.
\$\$dsub2	COBOL support	Two words packed decimal subtraction routine.
\$\$dsub3	COBOL support	Three words packed decimal subtraction routine.
\$\$dsub4	COBOL support	Four words packed decimal subtraction routine.
\$\$dcmp1	COBOL support	One word packed decimal comparison. Operand1 is compared to operand2 and RET1 (r29) is set to the following: $op1 == op2 \implies RET1 = 0$ $op1 > op2 \implies RET1 = 1$ $op1 < op2 \implies RET1 = -1$
\$\$dcmp2	COBOL support	Same as \$\$dcmp1, but operands are 2 words in length.
\$\$dcmp3	COBOL support	Same as \$\$dcmp1, but operands are 3 words in length.
\$\$dcmp4	COBOL support	Same as \$\$dcmp1, but operands are 4 words in length.
\$\$gcmp	COBOL support	Compare 2 unpacked ASCII decimal strings of the same length. See \$\$dmp1 for return values.
\$\$g_cmp_reg	COBOL support	Compare two decimal numbers in ASCII register format. See \$\$dmp1 for return values.
\$\$dcvtdh2	COBOL support	Convert a 15-digit packed decimal to a double precision unsigned integer and a sign bit.
\$\$dcvtdh3	COBOL support	Convert a 23-digit packed decimal to a double precision unsigned integer and a sign bit.
\$\$dcvtdi1	COBOL support	Convert a 7-digit packed decimal to a single precision unsigned integer and a sign bit.

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TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$dcvtdi2	COBOL support	Convert a 15-digit packed decimal to a single precision unsigned integer and a sign bit.
\$\$dcvthd	COBOL support	Convert an unsigned double precision integer to a 23-digit packed decimal with a specified sign.
\$\$dcvtid	COBOL support	Convert an unsigned single precision integer to a 15-digit packed decimal with a specified sign.
\$\$gcvt_d_to_g	COBOL support	Convert a packed decimal to an unpacked decimal number.
\$\$gcvt_g_to_d	COBOL support	Convert an unpacked decimal to a packed decimal number.
\$\$gcvt_g_to_i	COBOL support	Convert an unpacked decimal to a binary integer number.
\$\$gcvt_i_to_g	COBOL support	Convert a signed binary integer to an unpacked decimal number.
\$\$gcvt_i_to_g_reg	COBOL support	Convert a signed binary integer to an unpacked decimal number. The difference with \$\$gcvt_i_to_g is that this routine returns the sign of the source value in RET1 (-1 if neg., +1 if 0 or pos.).
\$\$g_equ	COBOL support	Compare 2 unpacked decimal strings for equality. RET1 returns as: 0 if unequal; +1 as equal.
\$\$g_equ_cont	COBOL support	Continue compare 2 ASCII decimal numbers. The right-most digits have been compared and are either equal or inconclusive. Return an indication of equality as in \$\$g_equ.
\$\$g_equ_reg_cont	COBOL support	Continue compare 2 ASCII decimal numbers in register format. The right-most digits have been compared and are either equal or inconclusive. Return an indication of equality as in \$\$g_equ.
\$\$g_inc_inplace	COBOL support	Specialized routine for COBOL, used to complete an increment operation when operating on the right-most byte was insufficient to complete the operation.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$g_dec_inplace	COBOL support	Specialized routine for COBOL, used to complete an decrement operation when operating on the right-most byte was insufficient to complete the operation.
\$\$g_inc_reg_inplace	COBOL support	Continue an increment operation. The right-most digit has been handled and determined to be a special case. The special cases are: '1' and has neg. sign; '0' and has neg. sign, '9' and has pos. sign.
\$\$g_dec_reg_inplace	COBOL support	Continue an decrement operation. The right-most digit has been handled and determined to be a special case. Special cases are '0' and has pos. sign; '9' and has neg. sign.
\$\$ddiv4	COBOL support	Divide two 16-byte packed decimals to produce a 16-byte packed decimal.
\$\$ddiv5	COBOL support	Divide two 20-byte packed decimals to produce a 20-byte packed decimal.
\$\$g_zero_check	COBOL support	Special routine used for COBOL compiler to check a decimal string for being zero.
\$\$g_zero_check_word	COBOL support	Special routine used for COBOL compiler to check a decimal string for being zero. The string must be word aligned and has an integral number of words.
\$\$g_add_const_reg	COBOL support	Add a constant and a variable in ASCII register format.
\$\$g_add_const	COBOL support	Add a positive constant to an ASCII unpacked decimal number.
\$\$g_add_reg	COBOL support	Add 2 strings of ASCII digits. This routine is specialized for COBOL.
\$\$g_sub_reg	COBOL support	Subtract 2 strings of ASCII digits. This routine is specialized for COBOL.
\$\$gadd	COBOL support	Add 2 unpacked ASCII decimal strings. Both operands and result are of the same length.
\$\$gsub	COBOL support	Subtract 2 unpacked ASCII decimal strings. Both operands and result are of the same length.
\$\$valg	COBOL support	COBOL unpacked ASCII decimal validation routine. All digit positions are checked for valid representation.

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TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$valg_lb	RPG support	Same as \$\$valg but allows leading blanks. This is used for RPG language.
\$\$d_val	COBOL support	General routine for packed decimal validation.
\$\$d_valf	COBOL support	Same as \$\$d_val but this routine will fix an invalid sign.
\$\$d_val2	COBOL support	Packed decimal validation for 2 nibbles, all alignments.
\$\$d_val4_e	COBOL support	Packed decimal validation for 4 nibbles, aligned 0, 2.
\$\$d_val4_1	COBOL support	Packed decimal validation for 4 nibbles, aligned 1.
\$\$d_val4_3	COBOL support	Packed decimal validation for 4 nibbles, aligned 3 or unknown.
\$\$d_val6_0	COBOL support	Packed decimal validation for 6 nibbles, aligned 0.
\$\$d_val6_1	COBOL support	Packed decimal validation for 6 nibbles, aligned 1.
\$\$d_val6_2	COBOL support	Packed decimal validation for 6 nibbles, aligned 2.
\$\$d_val6_3	COBOL support	Packed decimal validation for 6 nibbles, aligned 3.
\$\$d_val8_0	COBOL support	Packed decimal validation for 8 nibbles, aligned 0.
\$\$d_val8_1	COBOL support	Packed decimal validation for 8 nibbles, aligned 1.
\$\$d_val8_2	COBOL support	Packed decimal validation for 8 nibbles, aligned 2.
\$\$d_val8_3	COBOL support	Packed decimal validation for 8 nibbles, aligned 3.
\$\$divI, \$\$divoI	Arithmetic millicode	Single precision divide for signed binary integer. Division of -2^{31} by -1 is trapped for \$\$divoI but not for \$\$divI.
\$\$divJ	Arithmetic millicode	Division for signed 16-bit binary integer.
\$\$divU	Arithmetic millicode	Single precision divide for unsigned integer.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$divI_#, where # is any of: 2,3,4,5,6,7,8,9,10,12,14,15,16,17	Arithmetic millicode	Divide by constant for single precision binary integer. no overflow.
\$\$divU_# where # is any of: 3,5,6,7,9,10,12,14,15,17.	Arithmetic millicode	Divide by constant for single precision binary integer. Overflow is allowed.
\$\$divo2I, \$\$div2I, \$\$div2U	Arithmetic millicode	Divide a signed 64-bit by a signed 64-bit to produce a signed 64-bit result. The result will be truncated toward zero.
\$\$mulI	Arithmetic millicode	Multiply 2 single word integers to produce a single word integer result. No overflow trap.
\$\$muloI	Arithmetic millicode	Multiply 2 single word integers to produce a single word integer result. Overflow trap if result does not fit in 1 word.
\$\$mulU	Arithmetic millicode	Multiply 2 single word unsigned integers to produce a single word integer result. No overflow trap.
\$\$mul2U, \$\$mulo2U	Arithmetic millicode	Multiply two unsigned 64-bit arguments to produce an unsigned 64-bit product.
\$\$muloU	Arithmetic millicode	Multiply 2 single word unsigned integers to produce a single word integer result. Overflow trap if result does not fit in 1 word.
\$\$mul12U	Arithmetic millicode	Multiply two unsigned 32-bit arguments to produce an unsigned 64-bit product.
\$\$mulo2I	Arithmetic millicode	Multiply double precision signed integers to produce a precision signed integer result. Trap on overflow.
\$\$remI	Arithmetic millicode	Return the remainder of the division of 2 signed 32-bit integers. Sign of remainder is the same as the sign of dividend

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$remJ	Arithmetic millicode	Remainder for 16-bit division. Both dividend and divisor are 32-bit quantity but they are guaranteed by the caller to be in the range of 16-bit or: $-2^{15} \dots 2^{15} - 1$ The returned remainder will be a 32-bit integer but also in the 16-bit range. Sign of remainder is the same as the sign of dividend
\$\$remU	Arithmetic millicode	Return the remainder as result of a single precision divide of unsigned binary integers.
\$\$remI	Arithmetic millicode	Return a 32-bit signed remainder as result of a 32-bit signed divide. Overflow trap will be detected for: 0x80000000 / -1 and 0 / -1.
\$\$rem2I	Arithmetic millicode	Divide a signed 64 bit dividend by a signed 64 bit divisor. Produce a signed 64 bit remainder satisfying the division equality where the quotient is obtained by truncation towards zero. The sign of the remainder will be the same as the sign of the dividend. Trap on "divide by zero".
\$\$rem2U	Arithmetic millicode	Divide an unsigned 64 bit dividend by an unsigned 64 bit divisor. Produce an unsigned 64 bit remainder satisfying the division equality where the quotient is obtained by truncation towards zero.
\$\$remo2I	Arithmetic millicode	Return a 64-bit signed remainder as result of a 64-bit signed divide. Overflow trap will be detected for: 0x80000000 / -1 and 0 / -1.
\$\$scmp2_and_fill_tran	Strings comparison	Compare 2 strings for equality.
\$\$scmp2_byte_tran	Strings comparison	Compare 2 strings for equality.
\$\$scmp2_fill_tran	Strings comparison	Compare 2 strings for equality.
\$\$scmp2_pasc_tran	Strings comparison	Compare 2 strings for equality.
\$\$scmp_and_fill	Strings comparison	Compare 2 strings for equality.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$scmp_and_fill_long	Strings comparison	Compare 2 strings for equality.
\$\$scmp_and_fill_tran	Strings comparison	Compare 2 strings for equality.
\$\$scmp_byte	Strings comparison	Compare 2 strings left to right.
\$\$scmp_byte_long	Strings comparison	Compare 2 strings left to right. This is the long version.
\$\$scmp_byte_tran	Strings comparison	Compare 2 string left to right after byte by byte translation thru a caller supplied 256-byte max table in the caller address space.
\$\$scmp_fill	Strings comparison	Compare a string to a fill character.
\$\$scmp_fill_long	Strings comparison	Compare a string to a fill character. This is the long version.
\$\$scmp_fill_tran	Strings comparison	Compare a string to a fill character after byte by byte translation thru a caller supplied 256-byte max table in the caller address space.
\$\$scmp_pasc	Strings comparison	Compare 2 strings in the Pascal manner.
\$\$scmp_pasc_long	Strings comparison	Compare 2 strings in the Pascal manner. This is the long version.
\$\$scmp_pasc_tran	Strings comparison	Compare 2 strings in the Pascal manner after byte by byte translation thru a caller supplied 256-byte max table in the caller address space
\$\$wa_scmp_neq	Strings comparison	Compare 2 word-aligned strings for equality.
\$\$wa_scmp_neq_long	Strings comparison	Compare 2 word-aligned strings for equality. This is the long version.
\$\$bit_adrs_load	Back end support	Load a 1 to 64 bit item from an address given by byte address and an integer bit offset from that byte.
\$\$bit_adrs_load_long	Back end support	Same as \$\$bit_adrs_load except that a long load (load using given space register) is issued.
\$\$bit_adrs_store	Back end support	Store a 1 to 64 bit item from an address given by byte address and an integer bit offset from that byte.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$bit_adrs_store_long	Back end support	Same as \$\$bit_adrs_store except that a long store (store using given space register) is issued.
\$\$copy_byte	Back end support	Copy an unaligned byte string to an unaligned location.
\$\$copy_byte_long	Back end support	Copy an unaligned byte string to an unaligned location. Using long pointer (load/store with given space register).
\$\$copy_fill	Back end support	Move an unaligned byte string to an unaligned string.
\$\$copy_fill_long	Back end support	Move an unaligned byte string to an unaligned string. Using long pointer (load/store with given space register).
\$\$cvtl2s	Back end support	Convert long pointer to short pointer.
\$\$fill3	Back end support	Fill an unaligned byte string with a 3-byte fill value.
\$\$fill3_long	Back end support	Fill an unaligned byte string with a 3-byte fill value. Using long pointer (load/store with given space register).
\$\$fill4	Back end support	Fill an unaligned byte string with a 4-byte fill value.
\$\$fill4_long	Back end support	Fill an unaligned byte string with a 4-byte fill value. Using long pointer (load/store with given space register).
\$\$fill_byte	Back end support	Fill an unaligned memory area with a value.
\$\$fill_byte_long	Back end support	Fill an unaligned memory area with a value. Using long pointer (load/store with given space register).
\$\$move_byte	Back end support	Move an unaligned byte string to an unaligned location.
\$\$move_byte_long	Back end support	Move an unaligned byte string to an unaligned location. Using long pointer (load/store with given space register)
\$\$move_fill	Back end support	Move an unaligned byte string to an unaligned byte string. Fill out the remainder of the destination with a fill value when the destination string is longer than the source string.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$move_fill_long	Back end support	Move an unaligned byte string to an unaligned byte string. Fill out the remainder of the destination with a fill value when the destination string is longer than the source string. Long pointer version.
\$\$lr_na_unk	Back end support	General data move. Move data from one address to another. Source and target do not have the same alignment and lengths are unknown.
\$\$lr_na_## where ## = 1 to 31	Back end support	Specific data move. Entry point is 1 less than the number of initial words to be stored into.
\$\$lr_unk_unk	Back end support	Alignments and lengths are unknown at compile time.
\$\$lr_wa_unk	Back end support	Data move. Source & target are word aligned but length unknown.
\$\$lr_wa_big	Back end support	Data move. Source & target are word aligned and length > 32 words.
\$\$lr_wa_## where ## = 1 to 31	Back end support	Data move. Source & target are word aligned and lengths are known. The entry point is the number of initial full words.
\$\$lr_na_unk_long	Back end support	Long pointer version of <i>\$\$lr_na_unk</i> .
\$\$lr_na_##_long where ## = 1 to 31	Back end support	Long pointer version of <i>\$\$lr_na_##</i> .
\$\$lr_unk_unk_long	Back end support	Long pointer version of <i>\$\$lr_unk_unk</i> .
\$\$lr_wa_unk_long	Back end support	Long pointer version of <i>\$\$lr_wa_unk</i>
\$\$lr_wa_big_long	Back end support	Long pointer version of <i>\$\$lr_wa_big</i>
\$\$lr_wa_##_long where ## = 1 to 31	Back end support	Long pointer version of <i>\$\$lr_wa_##</i>
\$\$fill_unk_unk	Back end support	Fill an area with a specified character. Alignment and length are unknown at compile time.
\$\$fill_wa_unk	Back end support	Fill an area with a specified character. The address is word aligned but length is unknown.
\$\$fill_big	Back end support	Fill an area with a specified character. Fill covers more than 32 words.

Millicode Library

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$fill_xx where ## = 1 to 32	Back end support	Fill an area with a specified character. Alignment and length are own at compile time.
\$\$fill_unk_unk_long	Back end support	Fill an area with a specified character. Alignment and length are unknown at compile time. Used long pointer.
\$\$fill_wa_unk_long	Back end support	Fill an area with a specified character. The address is word aligned but length is unknown. Used long pointer.
\$\$fill_big_long	Back end support	Fill an area with a specified character. Fill covers more than 32 words. Used long pointer.
\$\$fill_xx_long where ## = 1 to 32	Back end support	Fill an area with a specified character. Alignment and length are own at compile time. Used long pointer.
\$\$mv_lr_na_unk	Back end support	Move data from one address to another. Source & target are not aligned to the same byte and length is unknown.
\$\$mv_lr_na_## where ## = 1 to 31	Back end support	Move data from one address to another. Source & target are not aligned to the same byte. Entry point is 1 less than the number of initial words to be stored into.
\$\$mv_lr_unk_unk	Back end support	Move data from one address to another. Source & target are not aligned to the same byte and length is unknown.
\$\$mv_lr_wa_unk	Back end support	Move data from one address to another. Source & target are word aligned and length is unknown.
\$\$mv_lr_wa_big	Back end support	Move data from one address to another. Source & target are word aligned and length is more than 32 word.
\$\$mv_lr_wa_## where ## = 1 to 32	Back end support	Move data from one address to another. Source & target are word aligned. Entry point is number of initial full words.
\$\$mv_lr_na_unk_long	Back end support	Move data from one address to another. Source & target are not aligned to the same byte and length is unknown. Long pointer version.

TABLE 26. Content of the millicode library

Routine / Entry Name	Type	Purpose
\$\$mv_lr_na_##_long where ## = 1 to 31	Back end support	Move data from one address to another. Source & target are not aligned to the same byte. Entry point is 1 less than the number of initial words to be stored into. Long pointer version.
\$\$mv_lr_unk_unk_long	Back end support	Move data from one address to another. Source & target are not aligned to the same byte and length is unknown. Long pointer version.
\$\$mv_lr_wa_unk_long	Back end support	Move data from one address to another. Source & target are word aligned and length is unknown. Long pointer version.
\$\$mv_lr_wa_big_long	Back end support	Move data from one address to another. Source & target are word aligned and length is more than 32 word. Long pointer version.
\$\$mv_lr_wa_##_long where ## = 1 to 32	Back end support	Move data from one address to another. Source & target are word aligned. Entry point is number of initial full words. Long pointer version.
\$\$ripple	Back end support	Move unaligned byte string to an unaligned location. Ripple occurs as if a left to right byte at a time move were done.
\$\$ripple_long	Back end support	This is the long pointer version of <i>\$\$ripple</i> .
\$\$cerror	Misc.	Standard system call error routine.
\$\$CALLX	Misc.	External call mechanism for MPE/iX. Normal case (xleast=3, exec_level=3)
\$\$CALL32	Misc.	External call mechanism for MPE/iX. Special case (xleast=3, exec_level=2)
\$\$CALLX31	Misc.	External call mechanism for MPE/iX. Special case (xleast=3, exec_level=1)
\$\$CALLX30	Misc.	External call mechanism for MPE/iX. Special case (xleast=3, exec_level=0)

Millicode Library

TABLE 26. **Content of the millicode library**

Routine / Entry Name	Type	Purpose
\$\$CALLX21	Misc.	External call mechanism for MPE/iX. Special case (xleast=2, exec_level=1)
\$\$CALLX10	Misc.	External call mechanism for MPE/iX. Special case (xleast=1, exec_level=0)
\$\$dyncall	Misc.	Procedure label call mechanism.
\$\$get_version	Misc.	Return a pointer to a string holding the version number of the millicode library.
\$\$get_libc_version	Misc.	Return a pointer to a string holding the version number of the milli code library used in libc.a.
\$\$get_libcl_version	Misc.	Return a pointer to a string holding the version number of the milli code library used in libcl.a (HP-UX).
\$\$get_milli_version	Misc.	Return a pointer to a string holding the version number of the milli code library used in libcl.a (MPE/iX).
\$\$slide_frame	Ada support	Stack frame expansion routine. Stack overflow trap will be checked.
\$\$NC_slide_frame	Ada support	Stack frame expansion routine. Stack overflow trap will <i>NOT</i> be checked,
\$\$sh_func_adrs	Back end support	Used for function pointers comparison.

NOTE: *The space register SR0 is a return space register reserved for external millicode. External millicode, if supported must be re-assemble.*

All millicode routines that execute load/store may trap on null pointers or on stack overflow.

10.2 Library Routines Interfaces

This section describes individual millicode routines and their external interfaces.

ROUTINE: \$\$get_ascii_ptr

DESCRIPTION:

Returns a pointer to tables of constants for various transformations involving unpacked ASCII decimal numbers and of one word constants useful in calculations.

INPUT REGISTERS:

r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

ret1 = short pointer to table

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$bit_adrs_load

DESCRIPTION:

Will load a 1 to 64 bit item from an address given by a byte address and an integer bit offset from that byte. This routine, however, does assume (in some cases) that things are truly nonaligned.

ARGUMENTS

arg0 address to first byte desired
arg1 positive bit offset from arg0 to 1st significant bit, must be 0..7

arg2 length: number of bits of interest

RETURN VALUE:

1..32 bits: ret0

33..64 bits: hi order in ret0, low order in ret1

REGISTERS DESTROYED

r1, arg0, arg1, arg2, arg3, r22

INPUT REGISTERS:

arg0 == address of first byte to load

arg1 == positive bit offset to 1st significant bit.

arg2 == length in bits to load

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = Len <= 32 Bits: bits loaded, right justified.

Len > 32 Bits: High Order Bits, right justified.

ret1 = Len <= 32 Bits: undefined

Len > 32 Bits: Low Order Bits , right justified.

OTHER REGISTERS AFFECTED:

r1 = undefined

arg3 = undefined

r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: `$$bit_adrs_load_long`

DESCRIPTION:

Will load a 1 to 64 bit item from an address given by a byte address and an integer bit offset from that byte. This routine, however, does assume (in some cases) that things are truly nonaligned.

ARGUMENTS

arg0 address to first byte desired

arg1 positive bit offset from arg0 to 1st significant bit, must be 0..7

arg2 length: number of bits of interest

RETURN VALUE:

1..32 bits: ret0

33..64 bits: hi order in ret0, lo order in ret1

REGISTERS DESTROYED

r1, arg0, arg1, arg2, arg3, r22

INPUT REGISTERS:

arg0 == address of first byte to load

arg1 == positive bit offset to 1st significant bit.

arg2 == length in bits to load

r31 == return pc

sr0 == return space when called externally

sr1 == sid

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = Len <= 32 Bits: bits loaded, right justified.

Len > 32 Bits : High Order Bits, right justified.

ret1 = Len <= 32 Bits: undefined

Len > 32 Bits: Low Order Bits , right justified.

OTHER REGISTERS AFFECTED:

r1 = undefined

arg3 = undefined

r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: `$$bit_adrs_store`

DESCRIPTION:

arg0 (1..32 bits) Item to store, right justified. (33..64 bits) hi order bits of item to store.

arg1 (33..64 bits) low 32 bits of item to store.

arg2 address to 1st byte to store into.

arg3 positive bit offset from arg0 to 1st significant bit, must be 0..7

arg4(?) length (could put this in arg1 iff 1..32 bits)

REGISTERS NOT PRESERVED

arg0, arg1, arg3, r22, ret0, ret1

The address parameter (arg2) is preserved.

INPUT REGISTERS:

arg0 == Item to store, 32 bits, or high order, 64 bits, right justified.

arg1 == Low order, 64 bits, of item to store.

arg2 == Address of first byte to store into.

arg3 == Positive bit offset from arg0 to 1st bit, range 0..7.

arg4 == undefined.

ret0 == Length in Bits.

ret1 == undefined.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = address of 1st target byte preserved.
arg3 = undefined
ret0 = undefined
ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$bit_adrs_store_long

DESCRIPTION:

arg0 (1..32 bits) Item to store, right justified. (33..64 bits) hi order bits of item to store.

arg1 (33..64 bits) low 32 bits of item to store.

arg2 address to 1st byte to store into.

arg3 positive bit offset from arg0 to 1st significant bit, must be 0..7

arg4(?) length (could put this in arg1 iff 1..32 bits)

REGISTERS NOT PRESERVED

arg0, arg1, arg3, r22, ret0, ret1

The address parameter (arg2) is preserved.

INPUT REGISTERS:

arg0 == Item to store, 32 bits, or high order, 64 bits, right justified.

arg1 == Low order, 64 bits, of item to store.

arg2 == Address of first byte to store into.

arg3 == Positive bit offset from arg0 to 1st bit, range 0..7.

arg4 == undefined.

ret0 == Length in Bits.

ret1 == undefined.

r31 == return pc

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sr0 == return space when called externally
sr1 == space register for long pointer store address.

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = address of 1st target byte preserved.
arg3 = undefined
ret0 = undefined
ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$cerror

DESCRIPTION:

Standard system call error routine.

INPUT REGISTERS:

ret0 == standard error value.

OUTPUT REGISTERS:

ret0 == Always -1.

OTHER REGISTERS AFFECTED: r1

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places:errno

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

Types of arguments: integers

Type of the return value: Always returns -1.

Setup conditions to be performed by the caller: Place the error values in **ret0** and **ret1**.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

ROUTINE: \$\$copy_byte

Copies an unaligned byte string to an unaligned location. Performs as if all data were first moved from source to temp storage and then to the target. Must not ripple when overlap occurs.

INPUT REGISTERS:

arg0 == pointer to source byte string

arg1 == pointer to destination byte string

arg2 == number of bytes to copy (signed number)

copies zero when less than zero

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes located by arg1

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Branches to other millicode routines: \$\$move_byte

Comparison of pointers must be done with unsigned completers!

FUTURE POSSIBLE ENHANCEMENTS:

- update target pointer
- find something faster than byte at a time move

ROUTINE: `$$copy_fill`

Moves an unaligned byte string to an unaligned string. Fills out the target string with a provided value when the target length is greater than the source length.

Must copy source as if first completely moved to temporary space.

This is a complete replacement of the previous version which had the following problems:

- Copied all of source to the target regardless of source length.
- After copying source, advanced a number of bytes equal to the source length before filling.
- Was not unwindable.
- Did not handle negative or zero lengths.

INPUT REGISTERS:

arg0 == pointer to source string

arg1 == byte length of source string

NOP when negative.

arg2 == pointer to target string

arg3 == byte length of target string

NOP when negative.

ret1 == value for fill byte when target longer than source This is a four byte value with all bytes equal.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg3 bytes at location given by arg2

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers and return pointers.

DISCUSSION:

Calls other millicode routines using r31:

 \$\$copy_byte

 \$\$fill_byte

Calls other millicode routines: NONE

ROUTINE: \$\$copy_byte_long

Long pointers!

Copies an unaligned byte string to an unaligned location. Performs as if all data were first moved from source to temp storage and then to the target. Must not ripple when overlap occurs.

INPUT REGISTERS:

arg0 == pointer to source byte string

arg1 == pointer to destination byte string

arg2 == number of bytes to copy (signed number) copies zero when less than zero

r31 == return pc

sr0 == return space when called externally

sr1 == space pointer for source string

sr2 == space pointer for target string

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes located by arg1

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Branches to other millicode routines:

 \$\$move_byte_long

ROUTINE: \$\$copy_fill_long

Long pointers!

Moves an unaligned byte string to an unaligned string. Fills out the target string with a provided value when the target length is greater than the source length.

Must copy source as if first completely moved to temporary space.

This is a complete replacement of the previous version which had the following problems

- Copied all of source to the target regardless of source length.
- After copying source, advanced a number of bytes equal to the source length before filling.
- Was not unwindable.
- Did not handle negative or zero lengths.

INPUT REGISTERS:

arg0 == inner space pointer to source string

arg1 == byte length of source string

NOP when negative.

arg2 == inner space pointer to target string

arg3 == byte length of target string

NOP when negative.

ret1 == value for fill byte when target longer than source. This is a four byte value with all bytes equal.

r31 == return pc

sr0 == return space when called externally

sr1 == space pointer for source string

sr2 == space pointer for target string

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret1 = undefined

sr1 = unchanged

sr2 = unchanged

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg3 bytes at location given by sr2:arg2

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.
Makes a stack frame for saving registers and return pointers.

DISCUSSION:

Calls other millicode routines using r31:

 \$\$copy_byte

 \$\$fill_byte

Calls other millicode routines: NONE

ROUTINE: \$\$cvt_id

DESCRIPTION:

Convert a 32-bit binary number to packed decimal.

Packed decimal register format is a string of words with each digit consuming a nibble.
The last nibble holds the sign indicated by one of the values:

 0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 == pointer to msd of left (msw) destination word.

arg1 == 32 bit signed value to be converted.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$cvt_dg_regs

Converts a packed decimal number in register form to an ASCII unpacked decimal number in register form. The length is the number of words of digits to produce. Signs are preserved including designation as unsigned.

ASCII decimal register format is a string of words where the first word has the sign indicated by -1, 0, or +1. Succeeding words each hold 4 ASCII decimal digits. A blank on an input operand is equivalent to an ASCII zero. A minus zero value is not acceptable.

A sign value of 0 implies an unsigned value.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 ==short pointer to rightmost word of packed number
arg1 ==short pointer to leftmost word (sign word) of target area for the unpacked number
arg2 ==number of words containing digits to produce does not include the sign word
arg3 ==short pointer to millicode ascii table for constants
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =undefined
ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2+1 words at location given in arg1

PERMISSIBLE CONTEXT:

Special purpose routine for COBOL

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$cvt_gd_regs

Converts an ASCII decimal number in special “register” format to a packed decimal number in its “register” format.

ASCII decimal register format is a string of words where the first word has the sign indicated by -1, 0, or +1. Succeeding words each hold 4 ASCII decimal digits. A blank on an input operand is equivalent to an ASCII zero. A minus zero value is not acceptable.

A sign value of 0 implies an unsigned value.

Packed decimal format is a string of characters with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Output of routine is in multiples of 4 characters (whole words).

Input size	Output size (bytes)
4	4
8	8
12	8
16	12

When the unpacked number is unsigned, the packed number will be marked as unsigned.

The leftmost word of the result is filled with zeros to the left.

INPUT REGISTERS:

arg0 ==short pointer to leftmost word of ASCII decimal string in register format (the sign word)

arg1 ==short pointer to rightmost word of target area for packed decimal string in register format

arg2 ==number of words of source operand excluding sign word

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 =undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Memory located by arg1 is modified for length specified above.

PERMISSIBLE CONTEXT:

Special routine for COBOL.

Unwindable

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes special millicode register convention.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$scvtl2s

DESCRIPTION:

Convert long pointer to short pointer. Traps when long pointer cannot be represented by short pointer.

Implements UCODE operation CVT F <- a.

INPUT REGISTERS:

arg0 == offset part of long pointer

arg1 == space id of long pointer

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = sid returned from sr.

arg1 = undefined

ret1 = short pointer (just a copy of arg0)

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Quadrant of the offset part does not allow representation for short pointer or space id does not agree.

Trap instruction is ADDITO,TR -20,r0,r0.

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$d_mul

Multiply two unsigned packed decimal numbers producing an unsigned packed decimal result. The multiplicand is no more than 7 digits. The multiplier should be smaller than the multiplicand, but may be 8 digits.

This routine is intended to be called by multiple precision packed decimal routines which take sign into consideration and properly align operands. It may not be suitable for calls from compilers since it uses call save registers in a way not currently compatible with optimizer conventions.

INPUT REGISTERS:

arg0 == multiplicand == 7 digit unsigned packed decimal number

arg1 == multiplier == unsigned packed decimal number

arg2 == constant 0x11111111

arg3 == constant 0x66666666

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = unchanged

arg3 = unchanged

ret0 = biased high word of product (excess 0x66666666)

ret1 = biased low word of product

OTHER REGISTERS AFFECTED:

r1 = undefined

r22 = undefined

r21 = undefined

r20 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

A multiply is done for each digit of the multiplier.

After each multiply, the product is shifted right by a digit.

To do a multiply by a digit, a case statement on the digit value selects a multiply by a constant.

Initially the multiplier is complemented and placed in the lower word of the product. As the product is shifted right the digit just used is shifted out. The complement of the digit is used to be able to reverse the order of table entries. This allows many cases to deliberately fall into the next one. The original multiplier is retained and shifted for each digit to determine when remaining digits are zero. The result is a saving of 2 instructions in the inner loop.

ROUTINE: `$$dadd1`

DESCRIPTION:

`$$dadd1` is a one word packed decimal add millicode routine. Operands and destination are one word in length, seven (7) digits and a right sign digit. The sum of the two one word operands is placed in the one word destination. Short, word aligned pointers to the one word are passed as arguments. Arg0 contains a short pointer to the one word of the one word destination area in memory. Arg1 and arg2 contain short pointers to the one word of the one word operands, op1 and op2. **Ret1** is to contain a one (1) on overflow, else zero (0). Input registers remain untouched. Illegal data goes unreported. Input operands and output target are assumed to not overlap.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst is a short word-aligned pointer to one-word result.

arg1 == op1 is a short word-aligned pointer to one-word operand 1.

arg2 == op2 is a short word-aligned pointer to one-word operand 2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged

arg3 = undefined
ret0 = undefined
ret1 = overflow = 1, else 0

OTHER REGISTERS AFFECTED:

#ifdef REGISTER_SAVE_KLUDGE

#else

 r21 = undefined

#endif

r1 = undefined

r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: dst - a one word area in memory.

PERMISSIBLE CONTEXT:

#ifdef REGISTER_SAVE_KLUDGE

 Unwindable

 Makes a frame stack for saving registers

#else

 Unwindable.

 Does not create a stack frame.

#endif

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$dadd2

DESCRIPTION:

\$\$dadd2 is a two word packed decimal add millicode routine. Operands and destination are two word in length, fifteen (15) digits and a right sign digit. The sum of the two operands is placed in the two word destination area. Short, word aligned pointers to the beginning of the left word are passed as arguments. Arg0 contains a short pointer to the left word of the two word destination area in memory. Arg1 and arg2 contain short pointers to the left word of the two word operands, op1 and op2. Input registers remain untouched. Illegal data goes unreported. Input operands and output target are assumed to not overlap. **Ret1** returns 1 if overflow, else 0.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

 0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to two word destination.
arg1 == op1 a word-aligned short pointer to two word operand 1.
arg2 == op2 a word-aligned short pointer to two word operand 2.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged
arg1 = unchanged
arg2 = unchanged
arg3 = undefined
ret0 = undefined
ret1 = overflow = 1 , else 0

OTHER REGISTERS AFFECTED:

```
#ifdef REGISTER_SAVE_KLUDGE
#else
    r21 = undefined
    r20 = undefined
#endif
r22 = undefined
r1 = undefined
```

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: dst a two word destination area for sum.

PERMISSIBLE CONTEXT:

```
#ifdef REGISTER_SAVE_KLUDGE
    Unwindable.
    Creates a stack frame for saving callsave register(s).
#else
    Unwindable.
    Does not create a stack frame.
#endif
Suitable for internal or external millicode.
Assumes the special millicode register convention.
```

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$dadd3

DESCRIPTION:

\$\$dadd3 is a three word packed decimal add millicode routine. Operands and destination are three word in length, twenty-three (23) digits and a right sign digit. The sum of the two operands is placed in the three word destination area. Short, word aligned pointers to the beginning of the left word are passed as arguments. Arg0 contains a short pointer to the left word of the three word destination area in memory. Arg1 and arg2 contain short pointers to the left word of the three word operands, op1 and op2. Input registers remain untouched. Illegal data goes unreported. Input operands and output target are assumed to not overlap. **Ret1** returns overflow = 1, else ret1 = 0.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to three word destination.

arg1 == op1 a word-aligned short pointer to three word operand 1.

arg2 == op2 a word-aligned short pointer to three word operand 2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged

arg3 = undefined

ret0 = undefined

ret1 = overflow = 1, else 0.

OTHER REGISTERS AFFECTED:

```
#ifdef REGISTER_SAVE_KLUDGE
```

```
#else
```

```
    r21 = undefined
```

```
    r20 = undefined
```

```
#endif
```

```
r22 = undefined
```

```
r1 = undefined
```

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: dst - a three word destination area.

PERMISSIBLE CONTEXT:

```
#ifdef REGISTER_SAVE_KLUDGE
```

Unwindable.

Creates a stack frame for saving callsave register(s).

```
#else
```

Unwindable.

Does not create a stack frame for saving callsave registers.

```
#endif
```

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$dadd4

DESCRIPTION:

\$\$dadd4 is a four word packed decimal add millicode routine. Operands and destination are four words in length, thirty-one (31) digits and a right sign digit. The sum of the two operands is placed in the four word destination. Short, word aligned pointers to the beginning of the left word are passed as arguments. Arg0 contains a short pointer to the left word of the four word destination area in memory. Arg1 and arg2 contain short pointers to the left word of the four word operands, op1 and op2. Input registers remain untouched. Illegal data goes unreported. **Ret1** is to contain a one (1) on overflow, else zero (0). Input operands and output target are assumed to not overlap.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to four word destination.

arg1 == op1 a word-aligned short pointer to four word operand 1.

arg2 == op2 a word-aligned short pointer to four word operand2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged

arg3 = undefined

ret0 =undefined

ret1 = overflow = 1, else 0 .

OTHER REGISTERS AFFECTED:

```
#ifdef REGISTER_SAVE_KLUDGE
```

```
#else
```

```
    r21 = undefined
```

```
    r20 = undefined
```

```
#endif
```

```
r22 = undefined
```

```
r1 = undefined
```

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: dst - a four word location in memory.

PERMISSIBLE CONTEXT:

```
#ifdef REGISTER_SAVE_KLUDGE
```

```
    Unwindable.
```

```
    Makes a stack frame for saving registers.
```

```
#else
```

```
    Unwindable
```

```
    Does not create a stack frame
```

```
#endif
```

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$dcmp1**DESCRIPTION:**

\$\$dcmp1 is a packed decimal one word comparison millicode routine. It is passed word-aligned short pointers in arg0 and arg1 to two, one word packed decimal numbers, seven (7) digits plus right sign digit. The two words are compared and **ret1** returns the following:

```
    op1 == op2 -> ret1 = 0;
```

```
    op1 > op2 -> ret1 = 1;
```

```
    op1 < op2 -> ret1 = -1.
```

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

```
    0xc == positive, 0xd == negative, 0xf == unsigned.
```

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == op1 word-aligned short pointer to one word operand 1.
arg1 == op2 word-aligned short pointer to one word operand 2.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged
arg1 = unchanged
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = result of compare, as above.

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: **\$\$dcmp2**

DESCRIPTION:

\$\$dcmp2 is a packed decimal two word comparison millicode routine. It is passed left word-aligned short pointers in arg0 and arg1 to two, two word packed decimal numbers, fifteen (15) digits plus right sign digit. The two word operands are compared and **ret1** returns the following:

op1 == op2 -> ret1 = 0;
op1 > op2 -> ret1 = 1;
op1 < op2 -> ret1 = -1.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == op1 left word-aligned short pointer to operand 1.
arg1 == op2 left word-aligned short pointer to operand 2.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged
arg1 = unchanged
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = result of compare as above.

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: `$$dcmp3`

DESCRIPTION:

`$$dcmp3` is a packed decimal three word comparison millicode routine. It is passed left word-aligned short pointers in arg0 and arg1 to two, three word packed decimal numbers, twenty-three (23) digits plus the right sign digit. The two operands are compared and `ret1` returns the following:

op1 == op2 -> ret1 = 0;

op1 > op2 -> ret1 = 1;

op1 < op2 -> ret1 = -1.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == op1 left word-aligned short pointer to three word operand 1.
arg1 == op2 left word-aligned short pointer to three word operand 2.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged
arg1 = unchanged
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = result of compare as above.

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: **\$\$dcmp4**

DESCRIPTION:

\$\$dcmp4 is a packed decimal four word comparison millicode routine. It is passed left word-aligned short pointers in arg0 and arg1 to two, four word packed decimal numbers, thirty-one (31) digits plus right sign digit. The two operands are compared and **ret1** returns the following:

op1 == op2 -> ret1 = 0;
op1 > op2 -> ret1 = 1;
op1 < op2 -> ret1 = -1.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == op1 left word-aligned short pointer to four word operand 1.
arg1 == op2 left word-aligned short pointer to four word operand 2.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged
arg1 = unchanged
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = result of compare, as above.

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$dcvtdh2

Converts a 15-digit packed decimal to a double precision unsigned integer and sign. Packed decimal format is a string of words with each digit consuming a nibble. The rightmost nibble holds the sign indicated by one of the values:
0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 == pointer to 15-digit packed decimal
arg1 == pointer to where to place the double precision unsigned integer
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

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arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =undefined
ret1 = 0 if positive or unsigned; 1 if negative

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Two words located by arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Modified to be unwindable by using the standard millicode call save registers instead of pushing entry save registers onto the stack.

ROUTINE: \$\$dcvtdh3

Converts a 23-digit packed decimal to a double precision unsigned integer and sign. Only looks at 19 digits. Other 4 digits are ignored with no trap or error indication. Packed decimal format is a string of words with each digit consuming a nibble. The rightmost nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 ==pointer to 23-digit packed decimal

arg1 ==pointer to where to place the double precision unsigned integer

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 =undefined

ret1 = 0 if positive or unsigned; 1 if negative

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Two words located by arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Modified to be unwindable by using the standard millicode call save registers instead of pushing entry save registers onto the stack.

ROUTINE: \$\$dcvtdi1

Converts a 7-digit packed decimal to a single precision unsigned integer and sign.

Packed decimal format is a string of words with each digit consuming a nibble. The rightmost nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 == pointer to 7-digit packed decimal

arg1 == pointer to where to place the single precision unsigned integer

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret1 = sign of packed decimal number reduced by 12

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: One word located by arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Modified to be unwindable by using the standard millicode call save registers instead of pushing entry save registers onto the stack.

ROUTINE: `$$dcvtdi2`

Converts a 15-digit packed decimal to a single precision unsigned integer and sign. Only looks for 10 digits. Does not cause exception when ignored digits are nonzero.

Packed decimal format is a string of words with each digit consuming a nibble. The rightmost nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 == pointer to 15-digit packed decimal

arg1 == pointer to where to place the single precision unsigned integer

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret1 = 1 when sign digit is 13, 0 otherwise

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: One word located by arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Modified to be unwindable by using the standard millicode call save registers instead of pushing entry save registers onto the stack.

ROUTINE: \$\$dcvthd

Converts an unsigned double precision integer to 23-digit packed decimal with a specified sign. Packed decimal format is a string of words with each digit consuming a nibble. The rightmost nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 == pointer to double precision unsigned binary integer

arg1 == pointer to where 23-digit pd number is to be placed

arg2 ==value (valid values are 0,1,3) to be added to 12 for sign nibble

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 =undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r22 =undefined

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Three words at the location provided by arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Modified to be unwindable by using the standard millicode call save registers instead of pushing entry save registers onto the stack.

ROUTINE: \$\$dcvtid

Converts a single precision unsigned integer to 15-digit packed decimal with a specified sign. Packed decimal format is a string of words with each digit consuming a nibble. The right most nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 == pointer to unsigned binary integer

arg1 == pointer to where 15 digit pd number is to be placed

arg2 ==value (valid values are 0,1,3) to be added to 12 for sign nibble

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 =undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r22 =undefined

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

Two words at the location provided by arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Modified to be unwindable by using the standard millicode call save registers instead of pushing entry save registers onto the stack.

ROUTINE: \$\$ddiv4

DESCRIPTION:

\$\$ddiv4 divides two 16-byte packed decimal strings to produce a 16-byte result.

INPUT REGISTERS:

arg0 == q - pointer to leftmost byte of Result area

arg1 == n - pointer to leftmost byte of dividend (numerator)

arg2 == d - pointer to leftmost byte of divisor (denominator)

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r19 = undefined(Not anymore. Use r18 instead.)

r20 = undefined

r21 = undefined

r22 = undefined

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:divisor is zero

Changes memory at the following places:q for 16 bytes

PERMISSIBLE CONTEXT:

Unwindable

Creates a stack frame to save registers.

Is usable for internal or external microcode

Uses special millicode register conventions

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

CHANGES:

Removed r19 from being used as a caller save, since r19 is now being used as a PIC/SHLIB register. Changed to routine to use r18 instead.

Changed trap code. Have to trap w/o a stack frame.

ROUTINE: \$\$ddiv5

DESCRIPTION:

\$\$ddiv5 divides two 20-byte packed decimal strings to produce a 20-byte result.

INPUT REGISTERS:

arg0 == q - pointer to leftmost byte of Result area

arg1 == n - pointer to leftmost byte of dividend (numerator)

arg2 == d - pointer to leftmost byte of divisor (denominator)

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r19 = Saved/restored for PIC.

r20 = undefined

r21 = undefined

r22 = undefined

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:divisor is zero

Changes memory at the following places: q for 20 bytes

PERMISSIBLE CONTEXT:

Unwindable

Creates a stack frame to save registers.

Is usable for internal or external microcode

Uses special millicode register conventions

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

CHANGES:

Changed the routine to create a frame marker on the stack. It stores r19 at sp -32 before using r19. This is necessary for unwind purposes with the PIC/SHLIB release. This had to be done because this routine uses every callee save reg, so there is no way to replace r19 with some other register.

Modified to trap w/o a stack frame. Also changed the location where r19 was getting stored away.

ROUTINE: \$\$div2I

Divide a signed 64 bit dividend by a signed 64 bit divisor. Produce a signed 64 bit quotient with truncation towards zero. Traps are caused by: "divide by zero".

INPUT REGISTERS:

arg0 == low word of dividend

arg1 == high word of dividend

arg2 == low word of divisor

arg3 == high word of divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 to arg3 = undefined

ret0 = high word of quotient

ret1 = low word of quotient

OTHER REGISTERS AFFECTED:

r1 = undefined

r20 =undefined

r21 =undefined

r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Divide by zero via "ADDIT,= 0,R0,R0"

Changes memory at the following places:

NONE

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This version uses the long division algorithm taught in most advanced elementary schools before the invention of calculators.

In binary, the guess for the next digit becomes trivial.

The inner loop takes 8 instructions for each quotient bit produced.

The algorithm terminates when the proper number of quotient bits are produced.

Changes to this routine will probably coincide with changes to other 64 bit division-related routines: \$\$divo2I, \$\$div2U, \$\$remo2I, \$\$rem2I, \$\$rem2U

See \$\$divo2I (including its revision log) for further discussion.

CHANGES FROM \$\$divo2I:

Removed check for division of 80000000,00000000 by -1,-1

Removed ICA__START, ICA__END labels

ROUTINE: \$\$div2U

Divide an unsigned 64 bit dividend by an unsigned 64 bit divisor. Produce an unsigned 64 bit quotient with truncation towards zero. Traps are caused by: "divide by zero".

INPUT REGISTERS:

arg0 == low word of dividend

arg1 == high word of dividend

arg2 == low word of divisor

arg3 == high word of divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = high word of quotient

ret1 = low word of quotient

OTHER REGISTERS AFFECTED:

r1 = undefined
r20 =undefined
r21 =undefined
r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Divide by zero via “ADDIT,= 0,R0,R0”

Changes memory at the following places:

NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Unwindable.

Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This version uses the long division algorithm taught in most advanced elementary schools before the invention of calculators. In binary, the guess for the next digit becomes trivial. The inner loop takes 8 or 9 instructions for each quotient bit produced in the usual case, or 10 or 11 instructions under certain circumstances when an alternate inner loop must be used instead. The algorithm terminates when the proper number of quotient bits are produced. Changes to this routine will probably coincide with changes to other 64 bit division-related routines: `$$divo2I`, `$$div2I`, `$$remo2I`, `$$rem2I`, `$$rem2U`

See `$$divo2I` (including its revision log) for further discussion.

CHANGES FROM `$$divo2I`:

Removed sign-computations; this permitted the elimination of a register that had been used to store the sign of the quotient;

this register, a callee-save, is now used for `LoopCtr` instead of a register that was callee-save; and so no stack frame is needed.

Added code to handle dividend greater than or equal to 80000000,00000000; this code needs a callee-save register, and so it creates a stack frame.

Removed special-case alignment behavior when dividend is 80000000,00000000

Removed check for division of 80000000,00000000 by -1,-1

Removed `ICA__START`, `ICA__END` labels

ROUTINE: \$\$divI, \$\$divoI

Single precision divide for signed binary integers. The quotient is truncated towards zero.

The sign of the quotient is the XOR of the signs of the dividend and divisor. Divide by zero is trapped. Divide of $-2^{*}31$ by -1 is trapped for \$\$divoI but not for \$\$divI.

INPUT REGISTERS:

arg0 ==dividend

arg1 ==divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = quotient

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

divisor is zero (traps with ADDIT,= 0,25,0)

dividend== $-2^{*}31$ and divisor== -1 and routine is \$\$divoI

(traps with ADDO 26,25,0)

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Branches to other millicode routines using BE

\$\$div_# for # being 2,3,4,5,6,7,8,9,10,12,14,15

For selected divisors, calls a divide by constant routine. Eligible divisors are 1..15 excluding 11 and 13.

The only overflow case is $-2^{*}31$ divided by -1 .

Both routines return $-2^{*}31$ but only \$\$divoI traps.

ROUTINE: \$\$divJ

Division for signed 16-bit binary integers. Dividend and divisor are 32-bit binary integers but are guaranteed by the caller to be in the range $(-2^{*}15)..(2^{*}15-1)$.

The quotient will be a 32-bit binary integer in the range $(-2^{15})..(2^{15})$. The quotient is truncated towards zero. The sign of the quotient is the XOR of the signs of the dividend and divisor.

Divide by zero is trapped. Divide of -2^{15} by -1 is not trapped; the result is $+2^{15}$.

INPUT REGISTERS:

arg0 ==dividend

arg1 ==divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = quotient

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

divisor is zero (traps with ADDITO,= 0,25,0)

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Branches to other millicode routines using BE

\$\$div_# for # being 2,3,4,5,6,7,8,9,10,12,14,15

For selected divisors, calls a divide by constant routine.

Eligible divisors are 1..15 excluding 11 and 13.

ROUTINE: \$\$divU

Single precision divide for unsigned integers. Quotient is truncated towards zero. Traps on divide by zero.

INPUT REGISTERS:

arg0 ==dividend

arg1 ==divisor

r31 == return pc

Millicode Library

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = quotient

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: divisor is zero

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Branches to other millicode routines using BE:

\$\$divU_# for 3,5,6,7,9,10,12,14,15

For selected small divisors calls the special divide by constant routines. These are:
3,5,6,7,9,10,12,14,15.

ROUTINE:

\$\$divI_2
\$\$divI_3, \$\$divU_3
\$\$divI_4
\$\$divI_5, \$\$divU_5
\$\$divI_6, \$\$divU_6
\$\$divI_7, \$\$divU_7
\$\$divI_8
\$\$divI_9, \$\$divU_9
\$\$divI_10, \$\$divU_10
\$\$divI_12, \$\$divU_12
\$\$divI_14, \$\$divU_14
\$\$divI_15, \$\$divU_15
\$\$divI_16
\$\$divI_17, \$\$divU_17

Divide by selected constants for single precision binary integers.

INPUT REGISTERS:

arg0 ==dividend
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
ret1 = quotient

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$divo2I

Divide a signed 64 bit dividend by a signed 64 bit divisor. Produce a signed 64 bit quotient with truncation towards zero. Traps are caused by: “divide by zero” and “overflow”.

INPUT REGISTERS:

arg0 == low word of dividend
arg1 == high word of dividend
arg2 ==low word of divisor
arg3 ==high word of divisor
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined

arg3 = undefined
ret0 =high word of quotient
ret1 = low word of quotient

OTHER REGISTERS AFFECTED:

r1 = undefined
r20 =undefined
r21 =undefined
r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Divide by zero via“ADDIT,= 0,R0,R0”

Overflow via“ADDO ARG1,ARG1,R0”

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Unwindable.

Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This version uses the long division algorithm taught in most advanced elementary schools before the invention of calculators. In binary, the guess for the next digit becomes trivial.

The inner loop takes 8 instructions for each quotient bit produced.

The algorithm terminates when the proper number of quotient bits are produced.

Changes to this routine will probably coincide with changes to the 64 bit signed remainder routine.

Attempts at using the divide step instruction have not been successful. Propagation of PSW(V) being the problem. The best case obtained used about 12 instructions in the inner loop.

Making a special case when both upper words are zero has also been unsuccessful. The algorithm failed with large numbers where bit 0 was on.

CHANGES:

Changed routine to use r3 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 is replaced with r3.

ROUTINE: \$\$ddmul2, \$\$dmul3, \$\$dmul4

Multiply two packed decimal numbers (8, 12, 16 bytes long) to produce a product of double that precision. Packed decimal format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

INPUT REGISTERS:

arg0 ==short pointer to rightmost word of multiplicand
arg1 ==short pointer to rightmost word of multiplier
arg2 ==short pointer to rightmost word of target area for the product
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =undefined
ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined
r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

- 4 words located by \$arg2 for \$\$dmul2
- 6 words located by \$arg2 for \$\$dmul3
- 8 words located by \$arg2 for \$\$dmul4

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Assumes the special millicode register conventions.
Makes a stack frame for saving registers.

]

DISCUSSION:

Calls other millicode routines using r31: \$\$d_mul

CHANGES:

Changed routine to use r11 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable r19 has been replaced with r11.

ROUTINE: \$\$dmul1

Multiply two 7-digit (4 byte) packed decimal to produce a 15-digit (8 byte) packed decimal product. The parameters are two short pointers to the operands and a short pointer to the target area. There is no problem with the target area overlapping the source operands, however it is discouraged since it will cause a problem with multi-precision versions.

Packed decimal format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

The product produced by this routine will not be unsigned. There is no indication for erroneous sign in an operand.

BEWARE: Previous versions of packed decimal multiply produced a result that was ten times too great!

INPUT REGISTERS:

arg0 == short pointer to multiplicand

arg1 == short pointer to multiplier

arg2 == short pointer to where product is to be placed

points to least significant of two words

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: 2 words at location provided by arg2

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Assumes the special millicode register conventions.
Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: `$$d_mul`

CHANGES:

Changed routine to use r4 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r4.

ROUTINE: `$$dsub1`

DESCRIPTION:

`$$dsub1` is a one word packed decimal subtract millicode routine. The operands and destination are one word in length, seven (7) digits and a right sign digit. The difference of the two operands is put into the destination area in memory. Short, word aligned pointers to the beginning of the one word are passed as arguments. Arg0 contains a short pointer to the one word of the one word destination area in memory. Arg1 and arg2 contain short pointers to the one word of the one word operands, op1 and op2. Input registers remain not touched.

Ret1 = 1 when overflow, else 0. Illegal data goes unreported. Input operands and output target are assumed to not overlap.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to the one word destination.

arg1 == op1 a word-aligned short pointer to the one word operand 1.

arg2 == op2 a word-aligned short pointer to the one word operand 2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged

arg3 = undefined

ret0 = undefined

ret1 = overflow = 1, else 0

OTHER REGISTERS AFFECTED:

```
#ifdef REGISTER_SAVE_KLUDGE
#else
r21 = undefined
#endif
r1 = undefined
r22 = undefined
```

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: dst a one word destination area for the difference.

PERMISSIBLE CONTEXT:

```
#ifdef REGISTER_SAVE_KLUDGE
Unwindable.
Creates a stack frame to save callsave registers
#else
Unwindable.
Does not create a stack frame.
#endif
Suitable for internal or external millicode.
Assumes the special millicode register conventions.
```

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$dsub2

DESCRIPTION:

\$\$dsub1 is a two word packed decimal subtract millicode routine. The operands and destination are two words in length, fifteen (15) digits and a right sign digit. The difference of the two operands is put into the destination area in memory. Short, word aligned pointers to the beginning of the left word are passed as arguments. Arg0 contains a short pointer to the left word of the two word destination area in memory. Arg1 and arg2 contain short pointers to the left word of the two word operands, op1 and op2. Input registers remain not touched.

Ret1 = 1 for overflow, else 0. Illegal data goes unreported. Input operands and output target are assumed to not overlap.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to the two word destination.

arg1 == op1 a word-aligned short pointer to the two word operand 1.

arg2 == op2 a word aligned short pointer to the two word operand 2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged

arg3 = undefined

ret0 = undefined

ret1 = overflow = 1, else 0

OTHER REGISTERS AFFECTED:

```
#ifdef REGISTER_SAVE_KLUDGE
```

```
#else
```

```
r21 = undefined
```

```
r20 = undefined
```

```
#endif
```

```
r22 = undefined
```

```
r1 = undefined
```

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: dst the two word destination area.

PERMISSIBLE CONTEXT:

```
#ifdef REGISTER_SAVE_KLUDGE
```

```
Unwindable.
```

```
Creates a stack frame for saving call register(s).
```

```
#else
```

```
Unwindable.
```

```
Does not create a stack frame.
```

```
#endif
```

```
Suitable for internal or external millicode.
```

```
Assumes the special millicode register conventions.
```

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$dsub3

DESCRIPTION:

\$\$dsub3 is a three word packed decimal subtract millicode routine. The operands and destination are three word in length, twenty-three (23) digits and a right sign digit. The difference of the two operands is in the destination area in memory. Short, word aligned pointers to the beginning of the left word are passed as arguments. Arg0 contains a short pointer to the left word of the three word destination area in memory. Arg1 and arg2 contain short pointers to the left word of the three word operands, op1 and op2. Input registers remain not touched.

Ret1 = 1 for overflow, else = 0. Illegal data goes unreported.

Input operands and output target are assumed to not overlap.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to three word destination.

arg1 == op1 a word-aligned short pointer to three word operand 1.

arg2 == op2 a word-aligned short pointer to three word operand 2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged

arg3 = undefined

ret0 = undefined

ret1 = overflow = 1, else 0

OTHER REGISTERS AFFECTED:

```
#ifdef REGISTER_SAVE_KLUDGE
```

```
#else
```

```
r21 = undefined
```

```
r20 = undefined
```

```
#endif
```

```
r22 = undefined
```

```
r1 = undefined
```

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: dst - the three word destination area.

PERMISSIBLE CONTEXT:

`#ifdef REGISTER_SAVE_KLUDGE`

Unwindable.

Creates a stack frame for saving callsave register(s).

`#else`

Unwindable.

Does not create a stack frame.

`#endif`

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: `$$dsub4`**DESCRIPTION:**

`$$dsub4` is a four word packed decimal subtract millicode routine. The operands and destination are four words in length, thirty-one (31) digits and right sign digit. The difference of the two operands is in the destination area in memory. Short, word aligned pointers to the beginning of the left word are passed as arguments. Arg0 contains a short pointer to the left word of the four word destination area in memory. Arg1 and arg2 contain short pointers to the left word of the four word operands, op1 and op2. Input registers remain not touched.

Illegal data goes unreported. Ret1 is to return overflow, 1 = overflow, else 0.

Input operands and output target are assumed to not overlap.

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

Any value other than 0xd is to be considered positive.

INPUT REGISTERS:

arg0 == dst a word-aligned short pointer to the four word destination.

arg1 == op1 a word-aligned short pointer to the four word operand 1.

arg2 == op2 a word-aligned short pointer to the four word operand 2.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = unchanged

arg2 = unchanged
arg3 = undefined
ret0 = undefined
ret1 = overflow = 1, else = 0.

OTHER REGISTERS AFFECTED:
#ifdef REGISTER_SAVE_KLUDGE
#else
r21 = undefined
r20 = undefined
#endif
r22 = undefined
r1 = undefined
SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: dst the four word destination area.

PERMISSIBLE CONTEXT:
#ifdef REGISTER_SAVE_KLUDGE
Unwindable.
Makes a stack frame for saving registers.
#else
Unwindable.
Does not create a stack frame.
#endif
Suitable for internal or external millicode.
Assumes the special millicode register conventions.

DISCUSSION:
Calls other millicode routines using r31:NONE
Calls other millicode routines: NONE
Dynamic Procedure Call ALGORITHM
IF X bit in procedure label = 0
THEN
Branch Vectored using procedure label
ELSE
BEGIN
Clear X bit.
Save DP.
Load address of CALLX.
Save RP'.
Move SR4 to old DP register.
Branch to CALLEE.

END.

ROUTINE: \$\$fill3

Fill an unaligned byte string with a 3 byte fill value. The individual bytes are not assumed to be equal. The value is cyclicly repeated for the byte count.

INPUT REGISTERS:

arg0 ==Fill value. Three bytes left justified.

arg1 ==Pointer to location to be filled.

arg2 ==Number of bytes to be stored (signed number); NOP when <0.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = updated to next byte

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes at location given by arg1

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

\$\$ripple branches to this routine.

ROUTINE: \$\$fill3_long

Long Pointers! Fill an unaligned byte string with a 3 byte fill value. The bytes are not assumed to be equal.

INPUT REGISTERS:

arg0 ==Fill value. Three bytes left justified.

arg1 ==Pointer to location to be filled.

arg2 ==Number of bytes to be stored (signed number); NOP when <=0

r31 == return pc
sr0 == return space when called externally
sr2 == space pointer for target

OUTPUT REGISTERS:

arg0 = undefined
arg1 = updated to next target byte
arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes at location given by sr2:arg1

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

\$\$ripple branches to this routine.

ROUTINE: \$\$fill4

Fill an unaligned byte string with a four byte value. The individual bytes are not assumed to be equal. The value is cyclically repeated for the byte count.

INPUT REGISTERS:

arg0 ==four byte value with which to fill the string
arg1 ==pointer to the target byte string
arg2 ==number of bytes to be stored (signed number); NOP when <=0
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = updated to next byte
arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes located by arg1

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

\$\$ripple branches to this routine.

ROUTINE: \$\$fill4_long

Long pointers! Fill an unaligned byte string with a four byte value. The individual bytes are not assumed to be equal. The value is cyclically repeated for the byte count.

INPUT REGISTERS:

arg0 ==four byte value with which to fill the string

arg1 ==pointer to the target byte string

arg2 ==number of bytes to be stored (signed number); NOP when <=0

r31 == return pc

sr0 == return space when called externally

sr2 == space pointer to target

OUTPUT REGISTERS:

arg0 = undefined

arg1 = updated to next byte

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes located by arg1

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Makes a stack frame for saving registers.

DISCUSSION:
Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE
\$\$ripple branches to this routine.

ROUTINE: \$\$fill_byte

Fills an unaligned memory area with a value.

INPUT REGISTERS:
arg0 ==value with which to fill destination This must be 4 bytes of the same byte value.
arg1 ==pointer to byte aligned memory area
arg2 ==number of bytes to fill (signed number) No effect when negative.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:
arg0 = unchanged
!arg1 = undefined
!arg2 = undefined

OTHER REGISTERS AFFECTED:
r1 = undefined

SIDE EFFECTS:
Causes a trap under the following conditions: NONE
Changes memory at the following places: arg2 bytes at location given by arg1.

PERMISSIBLE CONTEXT:
Unwindable.
Makes a stack frame for saving registers.
Suitable for internal or external millicode.
Uses a restrictive set of registers.

DISCUSSION:
Calls other millicode routines using r31: NONE
Calls other millicode routines: NON
This routine is called by \$\$copy_fill.
\$\$move_fill and \$\$ripple branch to this routine.

ROUTINE: \$\$fill_byte_long

Long pointers! Fills an unaligned memory area with a value.

INPUT REGISTERS:

arg0 ==value with which to fill destination This must be 4 bytes of the same byte value.

arg1 ==pointer to byte aligned memory area

arg2 ==number of bytes to fill (signed number)

No effect when negative.

r31 == return pc

sr0 == return space when called externally

sr2 == space pointer to target

OUTPUT REGISTERS:

arg0 = unchanged

arg1 = undefined

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg2 bytes at location given by sr2:arg1.

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This routine is called by \$\$copy_fill_long.

\$\$move_fill_long and \$\$ripple_long branch to this routine.

ROUTINE: \$\$g_zero_check

A specialized routine for COBOL that checks a decimal string for being zero.

INPUT REGISTERS:

arg0 == short pointer to ASCII string

arg1 == length of string (positive signed integer)

ret1 == a value to be incremented by 2 or 0

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 += 2 if see a character that is not an ASCII zero

0 otherwise

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS: NONE

PERMISSIBLE CONTEXT:

Unwindability is no problem.

Routine is suitable for internal or external millicode.

Unwind descriptors are created for external millicode.

DISCUSSION:

An ASCII zero is either 0x20 or 0x30 but we only look at the low nibble. The count is decremented down to 1 since it is assumed to be positive. In the loop the count is examined before memory access to avoid accessing memory off the end of the string where a read violation could occur.

ROUTINE: \$\$g_zero_check_word

A specialized routine for COBOL that checks a decimal string for being zero when string is word aligned and has an integral number of words.

INPUT REGISTERS:

arg0 == short pointer to ASCII word aligned string

arg1 == length of string in words (positive signed integer)

arg2 == mask for digits (0x0f0f0f0f)

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = unchanged

ret1 = -1 if see a character that is not an ASCII zero +1 otherwise

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS: NONE

PERMISSIBLE CONTEXT:

Unwindability is no problem.

Routine is suitable for internal or external millicode.

Unwind descriptors are created for external millicode.

DISCUSSION:

An ASCII zero is either 0x20 or 0x30 but we only look at the low nibble. The count is decremented down to 1 since it is assumed to be positive. In the loop the count is examined before memory access to avoid accessing memory off the end of the string where a read violation could occur.

ROUTINE: `$$g_add_const_reg`

Add a constant and a variable in ASCII register format. The constant has been pre-biased by adding 0x96 to each byte. The constant did not have blanks, that is, no byte is 0xb0. The constant is assumed to be positive. The variable may contain blanks for zeros. The operands and the result are all word aligned. The result will always be signed. The result will not retain any blanks that may have been in the variable.

ASCII decimal register format is a string of words where the first word has the sign indicated by -1, 0, or +1. Succeeding words each hold 4 ASCII decimal digits. A blank on an input operand is equivalent to an ASCII zero. A minus zero value is not acceptable. A sign value of 0 implies an unsigned value.

INPUT REGISTERS:

arg0 ==short pointer to the rightmost word of the constant (NOT the leftmost! There is no sign word)

arg1 ==short pointer to the sign word (leftmost) of the variable

arg2 ==short pointer to sign word (leftmost) of the result area

arg3 ==word length of the digit part of the operands and the result

arg4 ==short pointer to millicode ASCII table

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

arg4 =undefined (==r22)

r20 =undefined

r19 =undefined(Not anymore. Used r3 instead.)

ret0 =undefined
ret1 = 1 if overflow, else 0

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: arg3+1 words starting at location in arg2

PERMISSIBLE CONTEXT:

`#ifdef REGISTER_SAVE_KLUDGE`

Not unwindable.

Creates a nonstandard stack frame.

Awaiting SLLIC and UCODE modifications to permit use of r20 + r19.

`#else`

Assumes SLLIC and UCODE modification permitting use of r20 + r19.

Unwindable.

Does not create a stack frame.

`#endif`

Suitable for internal or external millicode.

Assumes special millicode conventions regarding register use.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

The instruction “**sh2add** NumWords,ZPtr,ZPtr” will reset carry when the operation leaves ZPtr in the same quadrant and space.

The case where the variable is positive is expected to be more common than when it is negative.

CHANGES:

Changed routine to use r3 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r3.

ROUTINE: `$$g_add_const`

Add a positive constant to an ASCII unpacked decimal number. Since the compiler known that a constant is being added, the constant has been pre-biased. The result will be unsigned only when the variable is unsigned. Each byte of the constant has been pre-biased by adding 0x96 to it. Thus 9110 would look like 0xcfc7c7c6.

The data format for ASCII decimal has the following conventions for the sign on the right digit:

char	hex	value
{	7B	+0
}	7D	-0
A	41	+1
...		
...		
I	49	+9
J	4A	-1
...		
...		
R	52	-9

INPUT REGISTERS:

arg0 ==short pointer to rightmost byte of the constant
pre-biased positive unpacked decimal

arg1 ==short pointer to rightmost byte of the variable
unpacked ASCII decimal number

arg2 ==short pointer to rightmost byte of target variable

arg3 ==byte length of the operands and the result

arg4 == short pointer to millicode ASCII tables

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

arg4 =undefined

ret0 =undefined

ret1 = 1 if overflow, 0 otherwise

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

The ASCII tables with a decimal digit index return a byte describing the digit in the form *ss1nnnn* where:

ss is the sign: 00=unsigned, 01=positive, 11-negative

nnnn is the digit part

The ASCII tables are also used to produce the proper signed digit for the rightmost digit of the result.

ROUTINE: `$$g_add_reg` and `$$g_sub_reg`

Specialized for COBOL to add/sub two strings of ASCII digits. Each operand string and the result string is a string of words. The first word has the sign in binary:

-1 == negative,

0 == unsigned (indistinguishable from positive)

+1 == positive

Successive words each hold exactly four ASCII digits. A blank may also occur in place of a zero. The operands and result are the same length in words (this is called ASCII register format).

A result of minus zero is not permitted. A minus zero operand is unexpected.

INPUT REGISTERS:

arg0 short pointer to leftmost word of result string

arg1 short pointer to leftmost word of left operand string

arg2 short pointer to leftmost word of right operand string

arg3 number of words in the digit part of the strings

arg4 (r22) short pointer to millicode ascii table

r31 return pc

sr0 return space when called externally

OUTPUT REGISTERS:

ret1 = 0 when no overflow

1 when overflow

OTHER REGISTERS AFFECTED:

`#ifdef REGISTER_SAVE_KLUDGE`

All temporary registers are preserved.

The following registers are left undefined:

arg0 = undefined

arg1 = undefined

arg2 = undefined

```
arg3 = undefined
arg4 = undefined
ret0 = undefined
r1 = undefined
#else
```

All call-save (caller-saves) registers except for ret1 are destroyed.

```
arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
arg4 = undefined
ret0 = undefined
r1 = undefined
r19 = undefined(Not anymore. r3 is used instead.)
r20 = undefined
r21 = undefined
#endif
```

SIDE EFFECTS:

No traps occur.

Only memory located by result pointer is modified.

PERMISSIBLE CONTEXT:

```
#ifdef REGISTER_SAVE_KLUDGE
```

Stack space is acquired and registers saved in an unconventional manner.

```
#else
```

Unwindability is no problem.

```
#endif
```

Routine is suitable for internal or external millicode.

Unwind descriptors are created for external millicode.

Assumes special millicode register conventions.

DISCUSSION:

arg4 is a pointer to a table of constants defined within millicode. Subtraction (add with different signs) first proceeds left to right until a non-zero result is obtained. The resulting sign is then determined and the operand pointers swapped if it changes. Then, subtraction proceeds right to left. This avoids a complementation pass on the result when a final borrow would otherwise occur on a right to left subtraction.

The subtraction loop is duplicated to avoid the extra instructions it would take to adjust the pointers for a common loop.

CHANGES:

Changed routine to use r3 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r3.

ROUTINE: \$\$gadd, \$\$gsub

DESCRIPTION:

\$\$gadd adds two unpacked ASCII decimal strings. \$\$gsub subtracts two unpacked ASCII decimal strings. Both strings are the same length, which is the same as the result. The last digit of the operand strings also encodes the sign. Blanks are equivalent to zeros. Negative zero is a valid operand, but will not be produced as a result.

INPUT REGISTERS:

arg0 == ResP - pointer to leftmost byte of Result area
arg1 == Len - length of operands and result in bytes
arg2 == Op1P - pointer to leftmost byte of Operand 1
arg3 == Op2P - pointer to leftmost byte of Operand 2
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = overflow = 1, else 0

OTHER REGISTERS AFFECTED:

r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: ResP for Len bytes

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$gcmp

DESCRIPTION:

\$\$gcmp compares two unpacked ASCII decimal strings. Both strings are the same length. The last digit of the operand strings also encodes the sign. Blanks are equivalent to zeros. Negative zero is a valid operand.

INPUT REGISTERS:

arg0 == Op1P - pointer to leftmost byte of Operand 1
arg1 == Op2P - pointer to leftmost byte of Operand 2
arg2 == Len - length of operands and result in bytes MINUS ONE
r22 == Table - pointer to ASCII table
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = return value: -1, 0, or +1

OTHER REGISTERS AFFECTED:

r22 = undefined
r20 = undefined
r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$g_cmp_reg

Compare two decimal numbers in ASCII register format. Return indication of less, equal, or greater. ASCII decimal register format is a string of words where the first word has the sign indicated by -1, 0, or +1. Succeeding words each hold 4 ASCII decimal digits. A blank on an input operand is equivalent to an ASCII zero. A minus zero value is not acceptable. A sign value of 0 implies an unsigned value.

INPUT REGISTERS:

arg0 ==short pointer to leftmost word of left operand
arg1 ==short pointer to leftmost word of right operand
arg2 ==number of words in the digit part of the numbers
arg3 ==short pointer to the millicode table of ASCII constants
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =undefined
ret1 = -1 when left < right
 0 when =
 +1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Special routine for COBOL.
Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE
The time/space trade off is decided in favor of time.
The comparison loop is duplicated to save cycles.

ROUTINE: `$$gcvt_d_to_g`**DESCRIPTION:**

Convert a packed decimal number to an unpacked decimal number. Word aligned src,dest required, else address error. Result's specified length constrains conversion and is correct. Sign is preserved and all undefined values for the packed sign result in an positive resultant sign.

DEFINITIONS:

Packed decimal register format is a string of words with each digit consuming a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

The data format is ASCII decimal, and is the same as `$$g_add_const_reg`.

INPUT REGISTERS:

arg0 ==short pointer to result, word aligned.
arg1 ==short pointer to source, word aligned.
arg2 ==length of result unpacked in bytes.
arg3 == length of source packed in bytes.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret1 = undefined

OTHER REGISTERS AFFECTED:

r20 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: ResP- arg0 pointer to result area.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Uses \$\$tbl_ASCII to determine sign digit.

ROUTINE: \$\$gcvt_g_to_d

DESCRIPTION:

Convert an unpacked decimal number to a packed decimal number. Preserves sign (+/-/ u) from source to destination.

DEFINITIONS:

Packed decimal register format is a string of words with each digit consumes a nibble. The last nibble holds the sign indicated by one of the values:

0xc == positive, 0xd == negative, 0xf == unsigned.

The data format is ASCII decimal, and is the same as \$\$g_add_const_reg.

INPUT REGISTERS:

arg0 ==short pointer to result, word aligned.

arg1 ==short pointer to source, word aligned.

arg2 ==length in bytes of source.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: ResP - arg0 pointer to result area.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$gcvt_g_to_i

DESCRIPTION:

Convert and unpacked decimal number to an binary integer. Does not handle one digit unsigned unpacked decimal numbers.

DEFINITIONS:

The data format is ASCII decimal, and is the same as \$\$g_add_const_reg.

INPUT REGISTERS:

arg0 == pointer to source, word aligned.
arg1 == length - 1 in bytes of source.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
ret1 = result.

OTHER REGISTERS AFFECTED:

r20 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:
NONE in module NA
Calls other millicode routines:
NONE in module NA

ROUTINE: \$\$gcvt_i_to_g

DESCRIPTION:

Convert a signed binary integer to unpacked decimal. If result overflows length specified, will not trap but will truncate high-order digits.

DEFINITION:

The data format is ASCII decimal, and is the same as \$\$g_add_const_reg.

INPUT REGISTERS:

arg0 == pointer to result.
arg1 == source to be converted.
arg2 == length in bytes - 1, must be less than 10!
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
r22 = undefined.
ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

NONE

Changes memory at the following places:

ResP - result area from arg0 pointer for arg2+1 bytes

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: \$\$remU

Calls other millicode routines: NONE

Uses \$\$tbl_IG.

This routine is similar to \$\$gcvt_i_to_g_reg. Any changes needed here are likely to be needed there also.

ROUTINE: \$\$gcvt_i_to_g_reg

DESCRIPTION:

Convert a signed binary integer to unpacked decimal. If result overflows length specified, will not trap but will truncate high-order digits.

DEFINITIONS:

The data format is ASCII decimal, There is no sign on the right digit.

INPUT REGISTERS:

arg0 == pointer to result.
arg1 == source value to be converted.
arg2 == length in bytes - 1.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
r22 = undefined
ret1 = sign of source value
 -1 if negative
 +1 if zero or positive

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

ResP - result area from arg0 pointer for arg2+1 bytes

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: \$\$remU

Calls other millicode routines: NONE

Uses \$\$tbl_IG

This routine is similar to \$\$gcvt_i_to_g. Changes made here may have to made there also.

ROUTINE: \$\$g_equ

DESCRIPTION:

\$\$gequ compares two unpacked ASCII decimal strings for equality. Both strings are the same length. The last digit of the operand strings also encodes the sign. Blanks are equivalent to zeros. Negative zero is a valid operand.

INPUT REGISTERS:

arg0 == Op1P - pointer to leftmost byte of Operand 1
arg1 == Op2P - pointer to leftmost byte of Operand 2
arg2 == Len - length of operands and result in bytes MINUS ONE
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = return value: 0 if unequal, or +1 if equal

OTHER REGISTERS AFFECTED:

r1 = undefined
r20 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE

ROUTINE: `$$g_equ_cont`

Continue the comparison of two ASCII decimal numbers. The rightmost digits have been compared and determined to be either equal or inconclusive. Returns an indication of equal or unequal. Makes no assumption about memory alignment of operands. Permits a negative zero as a legal argument.

The data format is ASCII decimal with the following conventions for the sign on the right digit:

char	hex	value
0	30	+0
space	20	+0
{	7B	+0

}	7D	-0
A	41	+1
...		
I	49	+9
J	4A	-1
...		
R	52	-9

INPUT REGISTERS:

arg0 ==short pointer to rightmost byte of left operand
arg1 ==short pointer to rightmost byte of right operand
arg2 == byte length of operands excluding rightmost byte
ret0 ==original rightmost digit of left operand
ret1 == original rightmost digit of right operand
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret1 = 1 if equal, 0 if unequal

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable
Does not creates a stack frame.
Suitable for internal or external millicode.
Assumes special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

This routine is called when the rightmost digits are equal or both are a form of zero. Of special concern is the case where one operand has a sign digit of minus zero while the other has a sign digit of one of the plus zero values.

ROUTINE: `$$g_inc_inplace` and `$$g_dec_inplace`

These specialized routines for COBOL are called to complete an increment or decrement operation when operating on the right most byte was insufficient to complete the operation. Thus these routines are called about twenty percent of the time. The right-most byte has been destroyed by the calling code.

The cases for the rightmost digit are:

- (1) increment +9 to +0: Overflow is possible.
Examples: +09 to +10, +19 to +20, +099 to +100, +109 to +110
- (2) increment -0 to -9: Must handle -0 to +1 as a special case. Overflow is not possible.
Examples: -00 to +01, -10 to -09, -100 to -099, -110 to -109
- (3) increment -1 to -0: -1 to +0 must be distinguished from other cases. Overflow is not possible.
Examples: -01 to +00, -11 to -10, -21 to -20, -101 to -100
- (4) decrement +0 to +9: Decrementing zero is a special case since a sign change occurs. Overflow is not possible.
Examples: +00 to -01, +10 to +09, +100 to +99, +110 to +109
- (5) decrement -9 to -0: Overflow is possible.
Examples: -09 to -10, -19 to -20, -099 to -100

INPUT REGISTERS:

arg0 == short pointer to right byte of operand
arg1 == byte length of operand (including right byte)
arg2 == previous value of right byte of operand (digit+overpunch)
The old value in memory has been destroyed.
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
ret1 = 1 if overflow
0 no overflow

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

The string operand has been changed.

PERMISSIBLE CONTEXT:

Unwindability is no problem.

Routine is suitable for internal or external millicode.

Unwind descriptors are created for external millicode.

Assumes special millicode register conventions.

DISCUSSION:

The data format is ASCII decimal with the following conventions for the sign on the rigid is the same as `$$g_add_const_reg`. Since this routine is only called on twenty percent of the cases, a second pass through the loop will occur only one percent. Thus, efficiency for other than the first pass is not very rewarding.

The special case of decrementing zero to obtain plus or minus one, is treated by deferring the write back of data until the exact case is determined. Ordinarily, a special case like this should not receive this amount of attention. However, this case could easily be in someone benchmark. Although minus zero is an invalid number, this routine handles it properly. Apparently there are many data bases around that have that particular value in them.

ROUTINE: `$$g_inc_reg_inplace`, `$$g_dec_reg_inplace`

Continues an increment or decrement operation from code generated by the COBOL compiler. Increment|decrement an ASCII decimal number (unpacked) in special register format. The rightmost digit has already been handled and known to cause a special case which is to be handled here. The number will be adjusted in memory. The high order bytes will be unchanged unless a carry|borrow propagation extends into them. This will be on a per word basis except for the case of incrementing a negative number whose rightmost digit is a one.

The values in the rightmost digit that cause special case handling when doing an increment (`$$g_inc_reg_inplace`):

- (1) '1' when have negative sign
- (2) '0' when have negative sign (could be 0x20)
- (3) '9' when have positive sign

The values in the rightmost digit that cause special case handling when doing an decrement (`$$g_dec_reg_inplace`):

- (1) '0' when have positive sign (could be 0x20) May produce a minus one!
- (2) '9' when have negative sign ASCII decimal register format is a string of words where the first word has the sign indicated by -1, 0, or +1. Succeeding words each hold 4 ASCII decimal digits. A blank on an input operand is equivalent to an ASCII zero. A minus zero value is not acceptable. A sign value of 0 implies an unsigned value.

INPUT REGISTERS:

`arg0` ==short pointer to rightmost word of operand

`arg1` ==word length of digit part of operand

`arg2` ==rightmost digit of operand before increment|decrement was attempted. The previous value has been destroyed.

arg3 == pointer to millicode table of constants (i.e. \$\$tbl_ASCII)

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 =undefined

ret1 = returns 1 when overflow occurs, otherwise 0

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

arg0 for up to arg1-1 preceding words.

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes special millicode register convention.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Assumes that:

(1) the RightByte determines the proper case.

(2) there will be at least one word (otherwise there cannot be a right byte!) When decreasing, a left to right search for non-zero will be made before attempting the right to left decrementation. A complementation step for producing -1 is then not necessary. The rightmost word is always decreased immediately.

ROUTINE: \$\$g_equ_reg_cont

Continue a compare for equality of two decimal numbers in ASCII register format. The rightmost words are known to match. The signs have not been compared. ASCII decimal register format is a string of words where the first word has the sign indicated by -1, 0, or +1. Succeeding words each hold 4 ASCII decimal digits. A blank on an input operand is equivalent to an ASCII zero. A minus zero value is not acceptable. A sign value of 0 implies an unsigned value.

INPUT REGISTERS:

arg0 ==short pointer to rightmost word of left operand
arg1 ==short pointer to rightmost word of right operand
arg2 ==number of words less one of the digit parts
actual number of words to compare
arg3 ==short pointer to millicode tables of ASCII constants
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =undefined
ret1 = 1 if equal, 0 if unequal

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.
Assumes special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE
It is expected that a difference will show first between the magnitudes of the numbers before the signs. That is, comparisons of numbers with the same sign is expected to be more common.

ROUTINE: `$$get_libc_version`

Returns a pointer to a string holding the version of millicode. The first word of the string is its length in bytes including the word holding the length. The string is terminated with a null character. The main purpose for this routine is to hold a secondary version identification string, to identify the version of Millicode contained in libc on HP-UX.

Millicode Library

INPUT REGISTERS:

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

ret0 =short pointer to the version string

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

ROUTINE: \$\$get_libcl_version

Returns a pointer to a string holding the version of millicode. The first word of the string is its length in bytes including the word holding the length. The string is terminated with a null character. The main purpose for this routine is to hold a secondary version identification string, to identify the version of Millicode contained in libcl on HP-UX.

INPUT REGISTERS:

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

ret0 =short pointer to the version string

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

ROUTINE: \$\$get_milli_version

Returns a pointer to a string holding the version of millicode. The first word of the string is its length in bytes including the word holding the length. The string is terminated with a null character. The main purpose for this routine is to hold a product_level version identification string, to identify the version of Millicode contained in MILLI.LIB.SYS on **MPE/iX**.

INPUT REGISTERS:

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

ret0 =short pointer to the version string

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

ROUTINE: \$\$move_byte

Moves an unaligned byte string to an unaligned location. Leaves the destination pointer pointing to the next byte position. Ripples data when target address exceeds source address by at least four (4). Ripple occurs as if a left to right byte at a time move were done. Thus when Target=Source+delta, delta bytes will be repeated.

INPUT REGISTERS:

arg0 ==pointer to source byte string

arg1 ==pointer to destination byte string

arg2 ==number of bytes to move

(signed number considered zero when negative)

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = incremented by input value of arg2

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

arg2 bytes at location given by arg1

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

\$\$ripple, \$\$copy_byte, \$\$move_fill branch to this routine.

\$\$move_fill calls this routine

ROUTINE: \$\$move_fill

Move an unaligned byte string to an unaligned byte string.

Fill out the remainder of the destination with a fill value when the destination string is longer than the source string. There is no special behavior expected when the source and target areas overlap. This is a complete replacement of the previous version which had the following problems:

- () Was not unwindable.
- () Did not handle negative or zero lengths.

INPUT REGISTERS:

arg0 == pointer to source byte string

arg1 == number of bytes in source string

arg2 == pointer to destination byte string

arg3 == number of bytes in destination string

ret1 == fill value (4 bytes, all equal)

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

arg3 bytes at location given by arg2

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers and calling other routines.

DISCUSSION:

Calls other millicode routines using r31:

\$\$move_byte

\$\$fill_byte

Calls other millicode routines: NONE

ROUTINE: \$\$lr_na_unk

\$\$lr_na_##, where ## = 1 to 31

\$\$lr_unk_unk

\$\$lr_wa_unk

\$\$lr_wa_big

\$\$lr_wa_##, where ## = 1 to 31

DESCRIPTION:

Move data from one address to another address.

\$\$lr_na_unk--source and target not aligned to same byte and length unknown

\$\$lr_na_##--source and target not aligned to same byte entry point is one less than the number of initial words to be stored into

\$\$lr_unk_unk--alignment and length unknown at compile

\$\$lr_wa_unk--word aligned but length unknown

\$\$lr_wa_big--word aligned with length more than 32 words

\$\$lr_wa_##--word aligned and length known at compile entry point is number of initial full words

INPUT REGISTERS:

For all routines:

r31 == return pc

sr0 == return space when called externally

For all routines except `$$mv_lr_na_##` and `$$mv_lr_wa_##`:

arg0 == Src => Source pointer
arg1 == Dst => Destination pointer
arg2 == Len => Length of move (in bytes)

For `$$mv_lr_na_##`:

arg0 == Src => Adjusted source pointer
arg1 == Dst => Adjusted target pointer
arg2 == see discussion below
arg3 == see discussion below
ret1 == see discussion below
cr11 == shift amount for aligning data

For `$$mv_lr_wa_##`:

arg0 == Src => Source pointer -- word after last full word
arg1 == Dst => Target pointer -- word after last full word
arg2 == Even => First word to be moved; if word length is even
arg3 == Odd => First word to be moved; if word length is odd
ret1 == Temp2=> Length mod 4; if zero set to -1 (this is the residual number of bytes to be moved)

OUTPUT REGISTERS:

arg0 = updated to next word aligned byte, when `wa_big` | `wa_##` | `na_##` undefined, otherwise
arg1 = updated to point to next byte
arg2 = undefined
arg3 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined
ret1 = undefined
cr11 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: Dst for Len bytes

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE

This group of move routines have the following in common:

- 1- When target is less than source, data copy is correct even though overlap may occur.
- 2- When target exceeds source by at least 8 bytes a ripple effect will occur within the overlapped area. There is no guaranteed effect when overlap occurs and the difference is less than 8.
- 3- The target pointer is always updated to point to where the next byte would be stored.
- 4- Data outside of the source area will not be accessed. Thus an unexpected segmentation violation will not occur when moving data stored near a page edge.
- 5- The only general registers used are r1, arg0, arg1, arg2, and arg3.

CALLING SEQUENCE FOR `$$lr_na_##`

Using C notation, the following static computations would be performed to select the proper code to emit by a compiler or macro assembler.

Given:

Length == the number of bytes to move.

Source == the pointer to the source area.

Target == the pointer to the target area.

Compute word relative byte positions:

`SrcAlign=Source%4;`

`TrgAlign=Target%4;`

Compute index of routine to call (number of initial words to be stored at target minus one):

`XX=(Length+TrgAlign)/4-1;`

Adjust source pointer to word boundary:

`Source -= SrcAlign;`

Set shift amount register:

`emit("ldi (TrgAlign-SrcAlign)*8,r1")`

`emit("mrsar r1");`

Emit instructions according to whether XX is odd and according to relative alignments of the pointers:

`if(XX+1 & 1)`

```
{
  if(SrcAlign>TrgAlign)
    { emit(" LDW Source(dp),arg2"); Source+=4; }
  emit(" LDW Source(dp),arg3"); Source+=4;
  emit(" VSHD arg2,arg3,r1");
  emit(" LDW Source(dp),arg2"); Source+=4;
}
```

else

```
{
  if(SrcAlign>TrgAlign)
    { emit(" LDW Source(dp),arg3"); Source+=4; }
  emit(" LDW Source(dp),arg2"); Source+=4;
}
```

```
emit(" VSHD arg3,arg2,r1");
emit(" LDW Source(dp),arg3"); Source+=4;
}
emit(" STBYS,B r1,Target(dp)")
Adjust the target pointer
Target = Target - TrgAlign + 4*(XX+1);
Emit the call and set ret1 to the number of residual bytes:
emit(" BLE $$lr_na_XX(sr4,r0)")
emit(" LDI (Length+TrgAlign)%4,ret1")
```

In the event that both pointers have the same word relative byte position, the compiler should handle the first partial word by a LDW followed by a STBYS and then call a word aligned routine, e.g. `$$lr_wa_XX`. These routines will fail to copy correctly when relative byte positions are equal.

ROUTINE: `$$lr_na_unk_long`

`$$lr_na_##_long` where ## = 1 to 31
`$$lr_unk_unk_long`
`$$lr_wa_unk_long`
`$$lr_wa_big_long`
`$$lr_wa_##_long` where ## = 1 to 31

DESCRIPTION:

Move data from one address to another address in different spaces.

`$$lr_na_unk_long` source and target not aligned to same byte and length unknown

`$$lr_na_##_long` source and target not aligned to same byteentry point is one less than the number of initial words to be stored into

`$$lr_unk_unk_long` alignment and length unknown at compile

`$$lr_wa_unk_long` word aligned but length unknown

`$$lr_wa_big_long` word aligned with length more than 32 words

`$$lr_wa_##_long` word aligned and length known at compile entry point is number of initial full words

INPUT REGISTERS:

For all routines:

r31 == return pc

sr0 == return space when called externally

sr1 ==source space register

sr2 == target space register

For all routines except `$$lr_na_##_long` and `$$lr_wa_##_long`:

arg0 == Src => Source pointer

arg1 == Dst => Destination pointer

arg2 == Len => Length of move (in bytes)

For \$\$lr_na_##_long:

arg0 == Src => Adjusted source pointer
arg1 == Dst => Adjusted destination pointer
arg2 == see discussion below
arg3 == see discussion below
ret1 == see discussion below
cr11 == shift amount for aligning data

For \$\$lr_wa_##_long:

arg0 == Src => Source pointer -- word after last full word
arg1 == Dst => Target pointer -- word after last full word
arg2 == Even => First word to be moved; if word length is even
arg3 == Odd => First word to be moved; if word length is odd
ret1 == Temp2=> Length mod 4; if zero set to -1 (this is the residual number of bytes to be moved)

OUTPUT REGISTERS:

arg0 = updated to next word aligned byte, when wa_big | wa_## | na_##
undefined, otherwise
arg1 = updated to point to next byte
arg2 = undefined
arg3 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined
ret1 = undefined
cr11 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: Dst for Len bytes

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE
This group of move routines have the following in common:
1- When target is less than source, data copy is correct even though overlap may occur.

- 2- When target exceeds source by at least 8 bytes a ripple effect will occur within the overlapped area. There is no guaranteed effect when overlap occurs and the difference is less than 8.
- 3- The target pointer is always updated to point to where the next byte would be stored.
- 4- Data outside of the source area will not be accessed. Thus an unexpected segmentation violation will not occur when moving data stored near a page edge.
- 5- The only general registers used are r1, arg0, arg1, arg2, and arg3.

CALLING SEQUENCE FOR \$\$lr_na_##

Using C notation, the following static computations would be performed to select the proper code to emit by a compiler or macro assembler.

Given:

Length == the number of bytes to move.

Source == the pointer to the source area.

Target == the pointer to the target area.

Compute word relative byte positions:

SrcAlign=Source%4;

TrgAlign=Target%4;

Compute index of routine to call (number of initial words to be stored at target minus one):

XX=(Length+TrgAlign)/4-1;

Adjust source pointer to word boundary:

Source -= SrcAlign;

Set shift amount register:

```
emit("ldi (TrgAlign-SrcAlign)*8,r1")
```

```
emit("mtsar r1");
```

Emit instructions according to whether XX is odd and according to relative alignments of the pointers:

```
if(XX+1 & 1)
{
  if(SrcAlign>TrgAlign)
  { emit(" LDW Source(dp),arg2"); Source+=4; }
  emit(" LDW Source(dp),arg3"); Source+=4;
  emit(" VSHD arg2,arg3,r1");
  emit(" LDW Source(dp),arg2"); Source+=4;
}
else
{
  if(SrcAlign>TrgAlign)
  { emit(" LDW Source(dp),arg3"); Source+=4; }
  emit(" LDW Source(dp),arg2"); Source+=4;
  emit(" VSHD arg3,arg2,r1");
}
```

```
    emit(" LDW Source(dp),arg3"); Source+=4;
}
emit(" STBYS,B r1,Target(dp)")
Adjust target pointer
Target = Target - TrgAlign+4*(XX+1);
Emit the call and set ret1 to the number of residual bytes:
emit(" BLE $$lr_na_XX(sr4,r0)")
emit(" LDI (Length+TrgAlign)%4,ret1")
```

In the event that both pointers have the same word relative byte position, the compiler should handle the first partial word by a LDW followed by a STBYS and then call a word aligned routine, e.g. \$\$lr_wa_XX_long. These routines will fail to copy correctly when relative byte positions are equal.

ROUTINE: \$\$mul12U

Multiply two unsigned 32-bit arguments to produce an unsigned 64-bit product.

INPUT REGISTERS:

arg0 == multiplicand
arg1 == multiplier
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =high word of product
ret1 = low word of product

OTHER REGISTERS AFFECTED:

r1 = undefined
r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.
Assumes the special millicode register conventions.
Unwindable.
Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

CHANGES FROM impyu:

Changed register usage to conform to millicode conventions.

Modified detection of zero multiplicand.

ROUTINE: `$$mul2U`

Multiply two unsigned 64-bit arguments to produce an unsigned 64-bit product. This works equally well for signed 64-bit integers.

INPUT REGISTERS:

arg0 == low word of first operand

arg1 == high word of first operand

arg2 == low word of second operand

arg3 == high word of second operand

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = high word of product

ret1 = low word of product

OTHER REGISTERS AFFECTED:

r1 = undefined

r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Unwindable.

Makes a stack frame for saving registers and return pointers.

DISCUSSION:

Calls other millicode routines using r31: \$\$mul12U, \$\$mulU

Changes to this routine should track changes to \$\$mulo2U

ROUTINE: \$\$mulI

DESCRIPTION:

\$\$mulI multiplies two single word integers, giving a single word result.

INPUT REGISTERS:

arg0 = Operand 1

arg1 = Operand 2

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = result

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$mulU

DESCRIPTION:

\$\$mulU multiplies two single word unsigned integers, giving a single word result.

INPUT REGISTERS:

arg0 = Operand 1

arg1 = Operand 2

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
ret1 = result

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$mulo2I

Multiply double precision signed integers to produce a double precision signed integer result. Trap on overflow of product.

INPUT REGISTERS:

arg0 ==low word of first operand
arg1 ==high word of first operand
arg2 ==low word of second operand
arg3 ==high word of second operand
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =high word of product
ret1 = low word of product

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Overflow -- product requires more than 64 bits.

Changes memory at the following places:

NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This flavor of multiply switches on nibbles of the multiplier to perform a constant multiply. Initial setup requires from 12 to 18 instructions. The main body takes min=10, avg=18, max=24 instructions per nibble. A straight line bit at a time algorithm would take 28 instructions per nibble. The algorithm terminates when the multiplier becomes zero.

ROUTINE: \$\$mulo2U

Multiply two unsigned 64-bit arguments to produce an unsigned 64-bit product. Trap on overflow of product.

INPUT REGISTERS:

arg0 == low word of first operand

arg1 == high word of first operand

arg2 == low word of second operand

arg3 == high word of second operand

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = high word of product

ret1 = low word of product

OTHER REGISTERS AFFECTED:

r1 = undefined

r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Overflow -- product requires more than 64 bits

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Unwindable.

Makes a stack frame for saving registers and return pointers.

DISCUSSION:

Calls other millicode routines using r31: \$\$mul12U, \$\$muloU

Changes to this routine should track changes to \$\$mul2U

ROUTINE: \$\$muloI

DESCRIPTION:

\$\$muloI multiplies two single word integers, giving a single word result. Overflow is indicated if the result is larger than one word.

INPUT REGISTERS:

arg0 = Operand 1

arg1 = Operand 2

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = result

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: OVERFLOW

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$muloU

DESCRIPTION:

\$\$muloU multiplies two single word unsigned integers, giving a single word result. A trap is generated if the value will not fit in a single word.

INPUT REGISTERS:

arg0 = Operand 1

arg1 = Operand 2

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = result

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: OVERFLOW

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$move_byte_long

Long pointers!

Moves an unaligned byte string to an unaligned location. Leaves the destination pointer pointing to the next byte position.

Ripples data when target address exceeds source address by at least four (4).

Ripple occurs as if a left to right byte at a time move were done. Thus when
Target=Source+delta, delta bytes will be repeated.

INPUT REGISTERS:

arg0 ==pointer to source byte string
arg1 ==pointer to destination byte string
arg2 ==number of bytes to move
(signed number considered zero when negative)
r31 == return pc
sr0 == return space when called externally
sr1 == space pointer to source
sr2 ==space pointer to target

OUTPUT REGISTERS:

arg0 = undefined
arg1 = incremented by input value of arg2
arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places:
arg2 bytes at location given by sr2:arg1

PERMISSIBLE CONTEXT:

Unwindable.
Suitable for internal or external millicode.
Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE
\$\$ripple, \$\$copy_byte, \$\$move_fill branch to this routine.
\$\$move_fill calls this routine

ROUTINE: \$\$move_fill_long

Long pointers!

Move an unaligned byte string to an unaligned byte string. Fill out the remainder of the destination with a fill value when the destination string is longer than the source string. There is no special behavior expected when the source and target areas overlap. This is a complete replacement of the previous version which had the following problems:

- () Was not unwindable.
- () Did not handle negative or zero lengths.

INPUT REGISTERS:

arg0 ==inner space pointer to source byte string
arg1 ==number of bytes in source string
arg2 ==inner space pointer to destination byte string
arg3 ==number of bytes in destination string
ret1 ==fill value (4 bytes, all equal)
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
sr1 =unchanged
sr2 =unchanged

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

arg3 bytes at location given by arg2

PERMISSIBLE CONTEXT:

Unwindable.

Suitable for internal or external millicode.

Makes a stack frame for saving registers and calling other routines.

DISCUSSION:

Calls other millicode routines using r31:

\$\$move_byte_long

\$\$fill_byte_long

Calls other millicode routines: NONE

ROUTINE: \$\$fill_unk_unk

\$\$fill_big

\$\$fill_wa_unk

\$\$fill_xx where xx = 1 to 32

Millicode Library

DESCRIPTION:

Fill an area with a specified character.

Special case routines:

\$\$fill_unk_unk -- alignment and length unknown at compile

\$\$fill_wa_unk -- word aligned fill but length unknown

\$\$fill_big-- fill covers more than 32 words

\$\$fill_xx-- alignment and length both known at compile

INPUT REGISTERS:

For all routines

arg0 == Fill => Fill character, expanded to full word

arg1 == Dst => Destination pointer

For \$\$fill_unk_unk, \$\$fill_wa_unk:

arg2 == Len => Length of fill (in bytes)

For \$\$fill_big:

arg2 == Len => Byte length of fill + (Destination pointer mod 4)

OUTPUT REGISTERS:

arg0 = NOT changed

arg1 = updated to next byte

arg2 = undefined(\$\$fill_unk_unk, \$\$fill_wa_unk, \$\$fill_big)

OTHER REGISTERS AFFECTED:

r1 = undefined (\$\$fill_unk_unk, \$\$fill_wa_unk, \$\$fill_big)

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Dst for Len bytes

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$fill_unk_unk_long

\$\$fill_big_long

\$\$fill_wa_unk_long

\$\$fill_xx_long where xx = 1 to 32

DESCRIPTION:

Fill an area in an arbitrary data space with a specified character.

Special case routines:

\$\$fill_unk_unk_long -- alignment and length unknown at compile

\$\$fill_wa_unk_long -- word aligned fill but length unknown

\$\$fill_big_long -- fill covers more than 32 words

\$\$fill_xx_long -- alignment & length known at compile

INPUT REGISTERS:

For all routines

arg0 == Fill => Fill character, expanded to full word

arg1 == Dst => Destination pointer

sr2 == DstSr=> Destination space register

For \$\$fill_unk_unk, \$\$fill_wa_unk:

arg2 == Len => Length of fill (in bytes)

For \$\$fill_big:

arg2 == Len => Byte length of fill + (Destination pointer mod 4)

OUTPUT REGISTERS:

arg0 = NOT changed

arg1 = updated to next byte

arg2 = undefined(\$\$fill_unk_unk, \$\$fill_wa_unk, \$\$fill_big)

OTHER REGISTERS AFFECTED:

r1 = undefined (\$\$fill_unk_unk, \$\$fill_wa_unk, \$\$fill_big)

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Dst for Len bytes

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$mv_lr_na_unk

\$\$mv_lr_na_##where ## = 1 to 32

\$\$mv_lr_unk_unk

\$\$mv_lr_wa_unk

\$\$mv_lr_wa_big

\$\$mv_lr_wa_##where ## = 1 to 32

DESCRIPTION:

Move data from one address to another address.

\$\$mv_lr_na_unk--source and target not aligned to same byte and length unknown

\$\$mv_lr_na_##--source and target not aligned to same byte entry point is one less than the number of initial words to be stored into

\$\$mv_lr_unk_unk--alignment and length unknown at compile

\$\$mv_lr_wa_unk--word aligned but length unknown

\$\$mv_lr_wa_big--word aligned with length more than 32 words

\$\$mv_lr_wa_##--word aligned and length known at compile entry point is number of initial full words

INPUT REGISTERS:

For all routines:

r31 == return pc

sr0 == return space when called externally

For all routines except **\$\$mv_lr_na_##** and **\$\$mv_lr_wa_##**:

arg0 == Src => Source pointer

arg1 == Dst => Destination pointer

arg2 == Len => Length of move (in bytes)

For **\$\$mv_lr_na_##**:

arg0 == Src => Adjusted source pointer

arg1 == Dst => Destination pointer

arg2 == see discussion below

arg3 == see discussion below

ret1 == see discussion below

cr11 == shift amount for aligning data

For **\$\$mv_lr_wa_##**:

arg0 == Src => Adjusted source pointer

arg1 == Dst => Destination pointer

arg2 == Even => First word to be moved; if word length is even

arg3 == Odd => First word to be moved; if word length is odd

ret1 == Temp2=> Length mod 4; if zero set to -1 (this is the residual number of bytes to be moved)

OUTPUT REGISTERS:

arg0 = updated to next word aligned byte, when wa_big | wa_## | na_## undefined, otherwise

arg1 = updated to point to next byte

arg2 = undefined

arg3 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

ret1 = undefined

cr11 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Dst for Len bytes

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

This group of move routines have the following in common:

- 1- When target is less than source, data copy is correct even though overlap may occur.
- 2- When target exceeds source by at least 8 bytes a ripple effect will occur within the overlapped area. There is no guaranteed effect when overlap occurs and the difference is less than 8.
- 3- The target pointer is always updated to point to where the next byte would be stored.
- 4- Data outside of the source area will not be accessed. Thus an unexpected segmentation violation will not occur when moving data stored near a page edge.

CALLING SEQUENCE FOR \$\$mv_lr_na_##

The compiler (or assembly language programmer) known the Length and alignments of the source and target. Computing these at run time is a mistake which is corrected by calling \$\$mv_lr_unk_unk.

Using C notation, the following static computations would be performed to select the proper code to emit by a compiler or macro assembler.

Given:

Length == the number of bytes to move.

Source == the pointer to the source area.

Target == the pointer to the target area.

Compute word relative byte positions:

SrcAlign=Source%4;

Trgalign=Target%4;

Compute index of routine to call (number of initial words to be stored at target minus one):

XX=(Length+TrgAlign)/4-1;

Adjust source pointer to word boundary:

```
Source -= SrcAlign;
```

Set shift amount register:

```
emit("ldi (TrgAlign-Srcalign)*8,r1")
```

```
emit("mtsar r1");
```

Emit instructions according to whether XX is odd and according to relative alignments of the pointers:

```
if(XX+1 & 1)
{
  if(SrcAlign>TrgAlign)
    { emit(" LDW Source(dp),arg2"); Source+=4; }
  emit(" LDW Source(dp),arg3"); Source+=4;
  emit(" VSHD arg2,arg3,r1");
  emit(" LDW Source(dp),arg2"); Source+=4;
}
else
{
  if(Srcalign>TrgAlign)
    { emit(" LDW Source(dp),arg3"); Source+=4; }
  emit(" LDW Source(dp),arg2"); Source+=4;
  emit(" VSHD arg3,arg2,r1");
  emit(" LDW Source(dp),arg3"); Source+=4;
}
emit(" STBYS,B r1,Target(dp)");
```

Adjust the target pointer

```
Target = Target - TrgAlign + 4;
```

Emit the call and set ret1 to the number of residual bytes:

```
emit(" BLE $lr_na_XX(sr4,r0)");
```

```
emit(" LDI (Length+TrgAlign)%4,ret1");
```

In the event that both pointers have the same word relative byte, the compiler should handle the first partial word by a LDW followed by a STBYS and then call a word aligned routine, e.g. \$lr_wa_XX. These routines will fail to copy correctly when relative byte positions are equal.

ROUTINE: **\$\$mv_lr_na_unk_long**
\$\$mv_lr_na_##_longwhere ## = 1 to 32
\$\$mv_lr_unk_unk_long
\$\$mv_lr_wa_unk_long
\$\$mv_lr_wa_big_long
\$\$mv_lr_wa_##_longwhere ## = 1 to 32

DESCRIPTION:

Move data from one address to another address in different spaces.

\$\$mv_lr_na_unk_long: source and target not aligned to same byte and length unknown

\$\$mv_lr_na_##_long: source and target not aligned to same byte entry point is one less than the number of initial words to be stored into

\$\$mv_lr_unk_unk_long: alignment and length unknown at compile

\$\$mv_lr_wa_unk_long: word aligned but length unknown

\$\$mv_lr_wa_big_long: word aligned with length more than 32 words

\$\$mv_lr_wa_##_long: word aligned and length known at compile entry point is number of initial full words

INPUT REGISTERS:

For all routines:

r31 == return pc

sr0 == return space when called externally

sr1 == SrcSr =>space register for Source

sr2 == DstSr =>space register for Destination

For all routines except \$\$mv_lr_na_##_long and \$\$mv_lr_wa_##_long:

arg0 == Src => Source pointer

arg1 == Dst => Destination pointer

arg2 == Len => Length of move (in bytes)

For \$\$mv_lr_na_##_long:

arg0 == Src => Adjusted source pointer

arg1 == Dst => Destination pointer

arg2 == see discussion below

arg3 == see discussion below

ret1 == see discussion below

cr11 ==shift amount for aligning data

For \$\$mv_lr_wa_##_long:

arg0 == Src => Adjusted source pointer

arg1 == Dst => Destination pointer

arg2 == Even => First word to be moved; if word length is even

arg3 == Odd => First word to be moved; if word length is odd

ret1 == Temp2=> Length mod 4; if zero set to -1 (this is the residual number of bytes to be moved)

OUTPUT REGISTERS:

arg0 =updated to next word aligned byte, when wa_big | wa_##_ | na_##_ undefined, otherwise

arg1 = updated to point to next byte

arg2 = undefined

arg3 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

ret1 = undefined

cr11 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: Dst for Len bytes

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

This group of move routines have the following in common:

- 1- When target is less than source, data copy is correct even though overlap may occur.
- 2- When target exceeds source by at least 8 bytes a ripple effect will occur within the overlapped area. There is no guaranteed effect when overlap occurs and the difference is less than 8.
- 3- The target pointer is always updated to point to where the next byte would be stored.
- 4- Data outside of the source area will not be accessed. Thus an unexpected segmentation violation will not occur when moving data stored near a page edge.

CALLING SEQUENCE FOR \$\$mv_lr_na_##_long

The compiler (or assembly language programmer) known the Length and alignments of the source and target. Computing these at run time is a mistake which is corrected by calling \$\$mv_lr_unk_unk_long.

Using C notation, the following static computations would be performed to select the proper code to emit by a compiler or macro assembler.

Given:

Length == the number of bytes to move.

Source == the pointer to the source area.

Target == the pointer to the target area.

Compute word relative byte positions:

SrcAlign=Source%4;

Trgalign=Target%4;

Compute index of routine to call (number of initial words to be stored at target minus one):

```
XX=(Length+TrgAlign)/4-1;
Adjust source pointer to word boundary:
Source -= SrcAlign;
Set shift amount register:
emit("ldi (Trgalign-SrcAlign)*8,r1")
emit("mtsar r1");
Emit instructions according to whether XX is odd and according to relative alignments
of the pointers:
if(XX+1 & 1)
{
  if(SrcAlign>TrgAlign)
    { emit(" LDW Source(dp),arg2"); Source+=4; }
  emit(" LDW Source(dp),arg3"); Source+=4;
  emit(" VSHD arg2,arg3,r1");
  emit(" LDW Source(dp),arg2"); Source+=4;
}
else
{
  if(Srcalign>TrgAlign)
    { emit(" LDW Source(dp),arg3"); Source+=4; }
  emit(" LDW Source(dp),arg2"); Source+=4;
  emit(" VSHD arg3,arg2,r1");
  emit(" LDW Source(dp),arg3"); Source+=4;
}
emit(" STBYS,B r1,Target(dp)")
Adjust the target pointer
Target = Target - TrgAlign + 4;
Emit the call and set ret1 to the number of residual bytes:
emit(" BLE $$lr_na_XX_long(sr4,r0)")
emit(" LDI (Length+TrgAlign)%4,ret1")
In the event that both pointers have the same word relative byte, the compiler should
handle the first partial word by a LDW followed by a STBYS and then call a word
aligned routine, e.g. $$lr_wa_XX_long. These routines will fail to copy correctly when
relative byte positions are equal.
ENTRIES:$$ripw_tab0, $$ripw_tab1, $$ripw_tab2, $$ripw_tab3, $$ripw_tab4
$$ripw_tab0 is used for move while alphabetic.
$$ripw_tab1 is used for move while numeric.
$$ripw_tab2 is used for move while alphanumeric.
$$ripw_tab3 is used for move while alphabetic, upshifting.
$$ripw_tab4 is used for move while alphanumeric, upshifting.
```

INPUT REGISTERS: NONE

OUTPUT REGISTERS: NONE

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS: NONE

PERMISSIBLE CONTEXT:

These tables are NOT presently used by Millicode. They are being packaged with Millicode so that multiple copies of the tables won't have to be dumped into generated code. They are used by the UCODE operator Ripple While.

ROUTINE: \$\$slide_frame

INPUT REGISTERS:

arg0= New stack pointer.

OUTPUT REGISTERS:

None.

OTHER REGISTERS AFFECTED:

arg0=Undefined

arg1=Undefined

r1=Undefined

sp=Reduced.

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

arg0 - 16

arg0 - 4

PERMISSIBLE CONTEXT:

Unwindable. (uses Ada aux unwind scheme).

Does not create stack frame.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: None.

DESCRIPTION:

The routine will reduce the stack to the value specified in ARG0. The values of the static link and previous sp will be copied back to the new stack area.

Note: This routine should be used in conjunction with \$\$slide_frame.

ROUTINE: \$\$rem2I

Divide a signed 64 bit dividend by a signed 64 bit divisor.
Produce a signed 64 bit remainder satisfying the division equality
where the quotient is obtained by truncation towards zero.
The sign of the remainder will be the same as the sign of the
dividend.

Trap on “divide by zero”.

INPUT REGISTERS:

arg0 == low word of dividend
arg1 == high word of dividend
arg2 ==low word of divisor
arg3 ==high word of divisor
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 =high word of remainder
ret1 = low word of remainder

OTHER REGISTERS AFFECTED:

r1 = undefined
r21 =undefined
r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions: Divisor is zero.
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.
Assumes the special millicode register conventions.
Unwindable.
Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines:NONE

This version uses the long division algorithm taught in most advanced elementary schools before the invention of calculators. In binary, the guess for the next digit becomes trivial. The inner loop takes 6 or 7 instructions for each quotient bit produced. The algorithm terminates when the proper number of quotient bits are produced. Changes to this routine will probably coincide with changes to other other 64 bit division-related routines: `$$divo2I`, `$$div2I`, `$$div2U`, `$$remo2I`, `$$rem2U`. See `$$remo2I` (including its revision log) for further discussion.

CHANGES FROM `$$remo2I`:

Removed check for division of [80000000,0] by [-1,-1]
`dvdl` isn't needed after being copied to `r1`; this frees up a register which can be used in place of `r3`, and so nothing needs to be saved on the stack. This could be done in `$$remo2I`, too.

ROUTINE: `$$rem2U`

Divide an unsigned 64 bit dividend by an unsigned 64 bit divisor.
Produce an unsigned 64 bit remainder satisfying the division equality where the quotient is obtained by truncation towards zero.

Trap on "divide by zero".

INPUT REGISTERS:

`arg0` == low word of dividend
`arg1` == high word of dividend
`arg2` == low word of divisor
`arg3` == high word of divisor
`r31` == return pc
`sr0` == return space when called externally

OUTPUT REGISTERS:

`arg0` = undefined
`arg1` = undefined
`arg2` = undefined
`arg3` = undefined
`ret0` = high word of remainder
`ret1` = low word of remainder

OTHER REGISTERS AFFECTED:

`r1` = undefined
`r21` = undefined
`r22` = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: Divisor is zero.

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Unwindable.

Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This version uses the long division algorithm taught in most advanced elementary schools before the invention of calculators.

In binary, the guess for the next digit becomes trivial.

The inner loop takes 6 or 7 instructions for each quotient bit produced in the usual case, or 8 or 9 instructions under certain circumstances when an alternate inner loop must be used instead.

The algorithm terminates when the proper number of quotient bits are produced.

Changes to this routine will probably coincide with changes to other other 64 bit division-related routines: `$$divo2I`, `$$div2I`, `$$div2U`, `$$remo2I`, `$$rem2I`

See `$$remo2I` (including its revision log) for further discussion.

CHANGES FROM `$$remo2I`:

Removed check for division of `[80000000,0]` by `[-1,-1]`

Removed sign computations; this freed up the register previously used for `dvdu` (which had been preserved to keep track of the sign).

Removed special-case alignment behavior when dividend is `[80000000,0]`; added code to handle dividend greater than or equal to `[80000000,0]`, which uses the register previously used for `dvdu`.

ROUTINE: `$$remI`**DESCRIPTION:**

`$$remI` returns the remainder of the division of two signed 32-bit integers. The sign of the remainder is the same as the sign of the dividend.

INPUT REGISTERS:

arg0 == dividend
arg1 == divisor
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = destroyed
arg1 = destroyed
ret1 = remainder

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: DIVIDE BY ZERO
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable
Does not create a stack frame
Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$remJ

DESCRIPTION:

Remainder for signed 16-bit binary integers. \$\$remJ returns the remainder of the division of two signed integers. Dividend and divisor are 32-bit quantities but are guaranteed by the caller to be in the range $(-2^{*15})..(2^{*15}-1)$. The remainder will be a 32-bit binary integer in the range $(-2^{*15}+1)..(2^{*15}-1)$. The sign of the remainder will be the same as the sign of the dividend.

INPUT REGISTERS:

arg0 == dividend
arg1 == divisor
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = destroyed
arg1 = destroyed
ret1 = remainder

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

DIVIDE BY ZERO (traps with ADDITO,= 0,25,0)

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$remU

Single precision divide for remainder with unsigned binary integers. The remainder must be $\text{dividend} - (\text{dividend}/\text{divisor}) * \text{divisor}$. Divide by zero is trapped.

INPUT REGISTERS:

arg0 == dividend

arg1 == divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

ret1 = remainder

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: DIVIDE BY ZERO

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$remo2I

Divide a signed 64 bit dividend by a signed 64 bit divisor. Produce a signed 64 bit remainder satisfying the division equality where the quotient is obtained by truncation towards zero. The sign of the remainder will be the same as the sign of the dividend. The traps are “divide by zero” and “overflow”

INPUT REGISTERS:

arg0 == low word of dividend

arg1 == high word of dividend

arg2 ==low word of divisor

arg3 ==high word of divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 =high word of remainder

ret1 = low word of remainder

OTHER REGISTERS AFFECTED:

r1 = undefined

r21 =undefined

r22 =undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

Divisor is zero.

Overflow when $dvnd = 0x80000000,0$ and $dvsr = -1,-1$.

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Suitable for internal or external millicode.

Assumes the special millicode register conventions.

Unwindable.

Does not create a stack frame.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

This version uses the long division algorithm taught in most advanced elementary schools before the invention of calculators.

In binary, the guess for the next digit becomes trivial.

The inner loop takes 6 or 7 instructions for each quotient bit produced.

The algorithm terminates when the proper number of quotient bits are produced.

Changes to this routine will probably coincide with changes to the 64 bit signed divide routine.

CHANGES:

Changed routine to use r3 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r3.

dvdl and LoopCtr have disjoint lifetimes; b allowing them to share the same register, the need for r3 to be saved and restored is eliminated.

ROUTINE: \$\$remol**DESCRIPTION:**

\$\$remol returns the remainder of the division of two signed 32-bit integers. The sign of the remainder is the same as the sign of the dividend. A trap is generated on overflow.

INPUT REGISTERS:

arg0 == dividend

arg1 == divisor

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = destroyed

arg1 = destroyed

ret1 = remainder

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: OVERFLOW

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable

Does not create a stack frame

Is usable for internal or external microcode

DISCUSSION:

Calls other millicode routines via r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$ripple

Move unaligned byte string to unaligned location.

Ripple occurs as if a left to right byte at a time move were done. Thus when Target=Source+delta, delta bytes will be repeated.

INPUT REGISTERS:

arg0 ==pointer to source byte string

arg1 ==pointer to destination location (unaligned)

arg2 ==number of bytes to move

NOP when negative.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:

arg2 bytes at location given by arg1

PERMISSIBLE CONTEXT:

Unwindable. (well close anyway)

Suitable for internal or external millicode.

Makes a stack frame for saving registers.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

Branches to other millicode routines:

 \$\$move_byte

 \$\$fill_byte

 \$\$fill3

 \$\$fill4

Several proc's are declared to gain multiple unwind descriptors.

This is the best we can do right now without region specification in the unwind descriptors.

ROUTINE: \$\$ripple_long

Long pointers version.

Move unaligned byte string to unaligned location.

Ripple occurs as if a left to right byte at a time move were done. Thus when Target=Source+delta, delta bytes will be repeated.

This version has been corrected to compare space register values before deciding to ripple.

INPUT REGISTERS:

arg0 ==pointer to source byte string

arg1 ==pointer to destination location (unaligned)

arg2 ==number of bytes to move

NOP when negative.

r31 == return pc

sr0 == return space when called externally

sr1 ==space register part of source pointer

sr2 ==space register part of target pointer

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

sr1 =unchanged

sr2 =unchanged

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places:
arg2 bytes at location given by sr2:arg1

PERMISSIBLE CONTEXT:
Unwindable. (well close anyway)
Suitable for internal or external millicode.
Makes a stack frame for saving registers.

DISCUSSION:
Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE
Branches to other millicode routines:
 \$\$move_byte_long
 \$\$fill_byte_long
 \$\$fill3_long
 \$\$fill4_long
This routine really requires multiple unwind descriptors.
Due to a SLLIC incapacity, there is but one.

ROUTINE: \$\$scmp2_and_fill_tran

Compare two strings. The goal(s) is/are to determine the equality of the two strings for their total extent, or failing that determine if the shorter is equal to the after 'filling' the shorter to alignment before the compare.

If string lengths are equal an initial 'non-stack frame' procedure branches (no return) to scmp_byte(_tran) with strings compared to each other, its ret1 == -1/0/+1 for left string </=> right string respectively.

If the string lengths are unequal, a branch and link (return) to scmp_byte(_tran) with the two strings and the length set to the shortest length is performed by a second 'stack frame' procedure with ret1 returned from scmp_byte(_tran) as above.

If the strings are unequal in value, exit with ret1 = +1/-1 , as above from scmp_byte(_tran). Further string comparison is not productive.

Else, a branch with no return is made to scmp_fill(_tran) with the longer length pointer incremented by the shorter length becoming the string to be compared to the shorter string as the 'fill value' to be compared against for a length equal to short.

This comparison determines if the trailing bytes of the long string are 'fill characters', or in this case, the same as the short strings 'leading' bytes. The return from scmp_fill(_tran), ret1, will then be -1/0/+1, depending on the longer string's trailer bytes being </=> than the 'fill characters', the shortstring.

The 'tran', translation variant of the above will simply use a supplied table to translate the strings before any compare is performed. Table is a user supplied 256-byte table.

INPUT REGISTERS:

arg0 ==pointer to left string
arg1 ==length in bytes of left string
zero assumed when negative
arg2 ==pointer to right string
arg3 ==length in bytes of right string
zero assumed when negative
r22 == pointer to table in callers space.
r21 ==fill value (same character repeated)
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 =undefined
ret1 =-1 when left string < right string
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Builds a stack frame for saving r31,sr0, four temp values.
Utilizes special millicode register conventions.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

 \$\$scmp2_byte_tran

 \$\$scmp2_fill_tran

Branches to other millicode routines:

 \$\$scmp2_byte_tran

 \$\$scmp2_fill_tran

Calls other millicode routines: NONE

ROUTINE: \$\$scmp2_byte_tran

Compare two strings (left to right), after byte-by_byte translation thru caller-supplied 256-byte max. table in caller address space.

INPUT REGISTERS:

arg0 ==pointer to left string
arg1 ==pointer to right string
arg2 == pointer to table in user literal space.
arg3 ==length in bytes of both strings
NOP when <=0
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 =-1 when left<right
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined
r19 = undefined(Not anymore. Used r5 instead.)
r20 = undefined
r21 = undefined
r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Creates a stack frame for saving r3,r4.
Utilizes special millicode register convention.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

CHANGES:

Changed routine to use r5 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r5.

ROUTINE: `$$scmp2_fill_tran`

Compares a string to a fill character, after string byte-by-byte translated thru table. Table is caller-supplied 256-byte max. table in caller address space. Returns in ret1 result of compare. New named (*2*) version to use callsave regs . Stack frame used for r3.

INPUT REGISTERS:

arg0 == pointer to string
arg1 == fill value (same character repeated)
arg2 == pointer to table in caller address space.
arg3 == length in bytes of the string
NOP when negative
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = -1 when string < replicated fill char
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined
r22 = undefined
r21 = undefined
r20 = undefined
r19 = undefined
r3 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

Millicode Library

PERMISSIBLE CONTEXT:

Unwindable.

Creates a stack frame for saving r3.

Utilizes the special millicode register convention.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

CHANGES:

Changed routine to use r3 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r3.

ROUTINE: `$$scmp2_pasc_tran`

Compare two strings in the pascal manner, after a byte-by-byte translation thru caller-supplied 256-byte max table in caller address space. If both are equal for the length of the shorter, the longer is greater. New named (*2*) version for direct use of callsave regs. Stack frame used for r31,sr0 in millicode call and return.

INPUT REGISTERS:

arg0 ==pointer to left string

arg1 ==length in bytes of left string

zero assumed when negative

arg2 ==pointer to right string

arg3 ==length in bytes of right string

zero assumed when negative

arg4 == pointer to table in caller space.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 =undefined

ret1 =-1 when left<right

0 when =

+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined
r22 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Creates a stack frame for saving r31, sr0.
Utilizes special millicode register convention.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:
 \$\$scmp2_byte_tran
Calls other millicode routines:
 \$\$scmp2_byte_tran

ROUTINE: \$\$scmp_and_fill

Compare two strings. The goal(s) is/are to determine the equality of the two strings for their total extent, or failing that determine if the shorter is equal to the after 'filling' the shorter to alignment before the compare.

If string lengths are equal an initial 'non-stack frame' procedure branches (no return) to scmp_byte(_tran) with strings compared to each other, its ret1 == -1/0/+1 for left string </=> right string respectively.

If the string lengths are unequal, a branch and link (return) to scmp_byte(_tran) with the two strings and the length set to the shortest length is performed by a second 'stack frame' procedure with ret1 returned from scmp_byte(_tran) as above.

If the strings are unequal in value, exit with ret1 = +1/-1, as above from scmp_byte(_tran). Further string comparison is not productive.

Else, a branch with no return is made to scmp_fill(_tran) with the longer length pointer incremented by the shorter length becoming the string to be compared to the shorter string as the 'fill value' to be compared against for a length equal to short.

This comparison determines if the trailing bytes of the long string are 'fill characters', or in this case, the same as the short strings 'leading' bytes. The return from scmp_fill(_tran), ret1, will then be -1/0/+1, depending on the longer string's trailer bytes being </=> than the 'fill characters', the short string.

The 'tran', translation variant of the above will simply use a supplied table to translate the strings before any compare is performed.

INPUT REGISTERS:

arg0 ==pointer to left string
arg1 ==length in bytes of left string
zero assumed when negative
arg2 ==pointer to right string
arg3 ==length in bytes of right string
zero assumed when negative
ret1 ==fill value (same character repeated)
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 =undefined
ret1 =-1 when left string < right string
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Makes a stack frame for saving registers.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

 \$\$scmp_byte

 \$\$scmp_fill

Branches to other millicode routines:

 \$\$scmp_byte

 \$\$scmp_fill

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_and_fill_long

Compare two strings. The goal(s) is/are to determine the equality of the two strings for their total extent, or failing that determine if the shorter is equal to the after ‘filling’ the shorter to alignment before the compare.

If string lengths are equal an initial ‘non-stack frame’ procedure branches (no return) to `scmp_byte(_tran)` with strings compared to each other, its `ret1 == -1/0/+1` for left string `</=>` right string respectively.

If the string lengths are unequal, a branch and link (return) to `scmp_byte(_tran)` with the two strings and the length set to the shortest length is performed by a second ‘stack frame’ procedure with `ret1` returned from `scmp_byte(_tran)` as above.

If the strings are unequal in value, exit with `ret1 = +1/-1`, as above from `scmp_byte(_tran)`. Further string comparison is not productive.

Else, a branch with no return is made to `scmp_fill(_tran)` with the longer length pointer incremented by the shorter length becoming the string to be compared to the shorter string as the ‘fill value’ to be compared against for a length equal to short. This comparison determines if the trailing bytes of the long string are ‘fill characters’, or in this case, the same as the short strings ‘leading’ bytes. The return from `scmp_fill(_tran)`, `ret1`, will then be `-1/0/+1`, depending on the longer string’s trailer bytes being `</=>` than the ‘fill characters’, the shortstring.

The ‘tran’, translation variant of the above will simply use a supplied table to translate the strings before any compare is performed.

This is the long pointer version, using `sr1` and `sr2`.

INPUT REGISTERS:

`arg0 ==` pointer to left string
`arg1 ==` length in bytes of left string
zero assumed when negative
`arg2 ==` pointer to right string
`arg3 ==` length in bytes of right string
zero assumed when negative
`ret1 ==` fill value (same character repeated)
`r31 ==` return pc
`sr0 ==` return space when called externally
`sr1 ==` space register for left string
`sr2 ==` space register for right string

OUTPUT REGISTERS:

`arg0 =` undefined
`arg1 =` undefined
`arg2 =` undefined
`arg3 =` undefined
`ret1 = -1` when left string < right string

0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Makes a stack frame for saving registers.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

\$\$scmp_byte_long

\$\$scmp_fill_long

Branches to other millicode routines:

\$\$scmp_byte_long

\$\$scmp_fill_long

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_and_fill_tran

Compare two strings. The goal(s) is/are to determine the equality of the two strings for their total extent, or failing that determine if the shorter is equal to the after 'filling' the shorter to alignment before the compare.

If string lengths are equal an initial 'non-stack frame' procedure branches (no return) to scmp_byte(_tran) with strings compared to each other, its ret1 == -1/0/+1 for left string </=> right string respectively.

If the string lengths are unequal, a branch and link (return) to scmp_byte(_tran) with the two strings and the length set to the shortest length is performed by a second 'stack frame' procedure with ret1 returned from scmp_byte(_tran) as above.

If the strings are unequal in value, exit with ret1 = +1/-1, as above from scmp_byte(_tran). Further string comparison is not productive. Else, a branch with no return is made to scmp_fill(_tran) with the longer length pointer incremented by the shorter length becoming the string to be compared to the shorter string as the 'fill value' to be compared against for a length equal to short.

This comparison determines if the trailing bytes of the long string are 'fill characters', or in this case, the same as the short strings 'leading' bytes. The return from

scmp_fill(_tran), ret1, will then be -1/0/+1, depending on the longer string's trailer bytes being </=> than the 'fill characters', the short string.

The 'tran', translation variant of the above will simply use a supplied table to translate the strings before any compare is performed. Table is a user supplied 256-byte table.

INPUT REGISTERS:

arg0 ==pointer to left string
arg1 ==length in bytes of left string
zero assumed when negative
arg2 ==pointer to right string
arg3 ==length in bytes of right string
zero assumed when negative
r22 == pointer to table in callers space.
r21 ==fill value (same character repeated)
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 =undefined
ret1 =-1 when left string < right string
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Builds a stack frame for saving r22,r21,r31,sr0, three temp values.

Utilizes special millicode register conventions.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

 \$\$scmp_byte_tran

\$\$scmp_fill_tran

Branches to other millicode routines:

\$\$scmp_byte_tran

\$\$scmp_fill_tran

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_byte

Compare two strings (left to right).

INPUT REGISTERS:

arg0 ==pointer to left string

arg1 ==pointer to right string

arg2 ==length in bytes of both strings

NOP when <=0

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

ret1 =-1 when left<right

0 when =

+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Makes a stack frame for saving registers.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_byte_long

Compare two strings (left to right). This is long version.

INPUT REGISTERS:

arg0 ==pointer to left string
arg1 ==pointer to right string
arg2 ==length in bytes of both strings
NOP when <=0
r31 == return pc
sr0 == return space when called externally
sr1 == space register for left string pointer
sr2 == space register for right string pointer

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
ret1 =-1 when left<right
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Makes a stack frame for saving registers.
Suitable for internal or external millicode

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$scmp_byte_tran

Compare two strings (left to right), after byte-by_byte translation thru caller-supplied 256-byte max. table in caller address space.

INPUT REGISTERS:

arg0 ==pointer to left string
arg1 ==pointer to right string
arg2 == pointer to table in user literal space.
arg3 ==length in bytes of both strings

NOP when ≤ 0
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
arg3 = undefined
ret0 = undefined
ret1 = -1 when left < right
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Creates a stack frame for saving r22,r21,r20,r19,r3,r4.
Utilizes special millicode register convention.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

CHANGES:

Changed routine to use r5 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable, r19 has been replaced with r5.

ROUTINE: \$\$scmp_fill

Compares a string to a fill character.

INPUT REGISTERS:

arg0 == pointer to string
arg1 == fill value (same character repeated)
arg2 == length in bytes of the string

NOP when negative
r31 == return pc
sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined
arg2 = undefined
ret1 = -1 when string < replicated fill char
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Makes a stack frame for saving registers.
Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$scmp_fill_long

Compares a string to a fill character. This is the long version.

INPUT REGISTERS:

arg0 == pointer to string
arg1 == fill value (same character repeated)
arg2 == length in bytes of the string
NOP when negative
r31 == return pc
sr0 == return space when called externally
sr1 == space register for long pointer to string

OUTPUT REGISTERS:

arg0 = undefined
arg1 = undefined

arg2 = undefined
ret1 = -1 when string < replicated fill char
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Makes a stack frame for saving registers.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_fill_tran

Compares a string to a fill character, after string byte-by-byte translated thru table. Table is caller-supplied 256-byte max. table in caller address space. Returns in ret1 result of compare.

INPUT REGISTERS:

arg0 == pointer to string

arg1 == fill value (same character repeated)

arg2 == pointer to table in caller address space.

arg3 == length in bytes of the string

NOP when negative

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 = undefined

ret0 = undefined

ret1 = -1 when string < replicated fill char

0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Creates a stack frame for saving r22,r21,r20,r19,r3.

Utilizes the special millicode register convention.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

CHANGES:

Changed routine to use r3 instead of r19. r19 cannot be used freely like a caller save, because it is now a PIC/SHLIB register. To make this routine unwindable,r19 has been replaced with r3.

ROUTINE: \$\$scmp_pasc

Compare two strings in the *pascal* manner. If both are equal for the length of the shorter, the longer is greater.

INPUT REGISTERS:

arg0 ==pointer to left string

arg1 ==length in bytes of left string

zero assumed when negative

arg2 ==pointer to right string

arg3 ==length in bytes of right string

zero assumed when negative

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 =undefined
ret1 =-1 when left<right
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Makes a stack frame for saving registers.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

\$\$scmp_byte

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_pasc_long

Compare two strings in the *pascal* manner. If both are equal for the length of the shorter, the longer is greater. This is the long version.

INPUT REGISTERS:

arg0 ==pointer to left string

arg1 ==length in bytes of left string

zero assumed when negative

arg2 ==pointer to right string

arg3 ==length in bytes of right string

zero assumed when negative

r31 == return pc

sr0 == return space when called externally

sr1 == space register for left string long pointer

sr2 == space register for right string long pointer

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 =undefined
ret1 =-1 when left<right
0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Makes a stack frame for saving registers.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

\$\$scmp_byte_long

Calls other millicode routines: NONE

ROUTINE: \$\$scmp_pasc_tran

Compare two strings in the pascal manner, after a byte-by-byte translation thru caller-supplied 256-byte max table in caller address space.If both are equal for the length of the shorter, the longer is greater.

INPUT REGISTERS:

arg0 ==pointer to left string

arg1 ==length in bytes of left string

zero assumed when negative

arg2 ==pointer to right string

arg3 ==length in bytes of right string

zero assumed when negative

arg4 == pointer to table in caller space.

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = undefined

arg1 = undefined

arg2 = undefined

arg3 =undefined

ret1 =-1 when left<right

0 when =
+1 when >

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Creates a stack frame for saving r31,sr0,r22 .

Utilizes special millicode register convention.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31:

\$\$scmp_byte_tran

Calls other millicode routines:

\$\$scmp_byte_tran

ROUTINE: \$\$wa_scmp_neq

Compare two word-aligned strings for equality or inequality.

INPUT REGISTERS:

arg0 ==word-aligned pointer to first byte of left string

arg1 ==word-aligned pointer to first byte of right string

arg2 ==length in bytes of both strings, assumed to be signed, >0

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = if strings are equal, pointer to the byte after the last byte compared in the left string if strings are not equal, undefined

arg1 = if strings are equal, pointer to the byte after the last byte compared in the right string if strings are not equal, undefined

arg2 = undefined

ret1 =return value:

0 when the strings are equal

1 when the strings are not equal

OTHER REGISTERS AFFECTED:

arg3 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

ROUTINE: \$\$wa_scmp_neq_long

Compare two word-aligned strings for equality or inequality.

This is the long version.

INPUT REGISTERS:

arg0 == word-aligned pointer to first byte of left string

arg1 == word-aligned pointer to first byte of right string

arg2 == length in bytes of both strings, assumed to be signed, >0

r31 == return pc

sr0 == return space when called externally

sr1 == space register for left string pointer

sr2 == space register for right string pointer

OUTPUT REGISTERS:

arg0 = if strings are equal, pointer to the byte after the last byte compared in the left string if strings are not equal, undefined

arg1 = if strings are equal, pointer to the byte after the last byte compared in the right string if strings are not equal, undefined

arg2 = undefined

ret1 = return value:

0 when the strings are equal

1 when the strings are not equal

OTHER REGISTERS AFFECTED:

arg3 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.
Does not create a stack frame.
Suitable for internal or external millicode.

DISCUSSION:
Calls other millicode routines using r31: NONE
Calls other millicode routines: NONE

ROUTINE: \$\$sh_func_adrs

INPUT REGISTERS:
arg0 ==The address of the PLT entry.
OUTPUT REGISTERS:
ret1 = The address of the function, read from the first word of the PLT entry

OTHER REGISTERS AFFECTED:
r22 = undefined

SIDE EFFECTS:
Causes a trap under the following conditions: NONE
Changes memory at the following places: NONE
This routine will try to read the page where the address points to. If it cannot do so, for any reason, then the input is word aligned and returne

PERMISSIBLE CONTEXT:
Unwindable.
Does not create a stack frame.
Assumes the special millicode register conventions.

DISCUSSION:
With the advent of shared libraries it is not possible for the linker to fixup the PLT entries without serious run time overhead. Hence the code generators will call this routine with a PLT address so that we can return the real function address from the PLT. This routine assumes that the caller has already checked the 30th bit to make sure that this is a real PLT address. (i.e not word aligned)
This routine is used currently by all ucode based compilers, and the C compiler, to perform function pointer comparisons ONLY. This routine should not be used for any other reason.
Calls other millicode routines using r31:
NONE

ROUTINE: \$\$NC_slide_frame

INPUT REGISTERS:

arg0= Size in bytes to expand frame
arg1=Size in bytes of argument area + marker

OUTPUT REGISTERS:

ret1=Pointer to the newly allocated item.

OTHER REGISTERS AFFECTED:

Throughout routine,
r1 = Maintains copy of old SP
arg0=Undefined
arg1=Undefined
arg2=Undefined
r1=Undefined
sp=Extended
ret1=Pointer to newly allocated item

SIDE EFFECTS:

Causes a trap under the following conditions: NONE.

PERMISSIBLE CONTEXT:

Not Unwindable.
Creates an unconventional stack frame.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: None.

DESCRIPTION:

The routine will bump up the stack by the specified amount. It will NOT trap if the stack crosses the specified upper bound due to the addition.

If you would a trap to be generated, then use \$\$slide_frame. The static link and the previous sp from the old frame marker area are copied into the new frame marker image.

ROUTINE: \$\$slide_frame

INPUT REGISTERS:

arg0= Size in bytes to expand frame
arg1=Stack upper bound
agr2=Size in bytes of argument area + marker

OUTPUT REGISTERS:

ret1=Pointer to the newly allocated item.

OTHER REGISTERS AFFECTED:

Throughout routine,
r1 = Maintains copy of old SP
arg0=Undefined
arg1=Undefined
arg2=Undefined
r1=Undefined
sp=Extended
ret1=Pointer to newly allocated item

SIDE EFFECTS:

Causes a trap under the following conditions: Stack overflow.
Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Not Unwindable. (uses aux unwind scheme)
Creates an unconventional stack frame.
Assumes the special millicode register conventions.

DISCUSSION:

Calls other millicode routines using r31: None.

DESCRIPTION:

The routine will bump up the stack by the specified amount. It will trap if the stack crosses the specified upper bound due to the addition.

The static link and the previous sp from the old frame marker area are copied into the new frame marker image.

ENTRIES:\$\$tbl_G, \$\$tbl_DG, \$\$tbl_V, \$\$tbl_V2, \$\$tbl_V3, \$\$tbl_IG

\$\$tbl_G performs transformations for unpacked digits in the sign position to and from binary.

A binary index in the range -16+0 .. -16+9 maps to the negative unpacked sign digit.

A binary index in the range 0 .. 9 maps to the positive unpacked sign digit.

A positive or unsigned unpacked sign digit maps to values "0" .. "9".

A negative unpacked sign digit maps to values "0"+128 .. "9"+128.

Invalid values are not guaranteed to map into sensible values.

\$\$tbl_V converts unpacked sign digits to values in the range 6 .. 41.

Invalid values less than 128 are guaranteed to map to zero.

Valid values map to a value suitable for comparing two unpacked numbers.

Positive or unsigned digits monotonically map to values 32 .. 41.

Negative values, -9 .. -0, monotonically map to values 6 .. 15.

\$\$tbl_V2 is used to validate the sign digit of an unpacked decimal number.

There are 256 entries. Invalid characters map to 0.

Valid characters map to non-zero. (For convenience, they map to the ASCII value of the character itself.)

\$\$tbl_V3 is the same as \$\$tbl_V2, but has blank as a legal sign.

\$\$tbl_DG is used to convert between packed decimal and unpacked decimal.

Binary values 0 .. 9 map to unpacked +0 .. +9.

Binary values 10 .. 19 map to unpacked -0 .. -9.

Unpacked sign digits map to a two nibble packed value having the digit and sign in packed format. Sign is preserved, even when unsigned.

Invalid values are not guaranteed to map to sensible values.

Warning: \$\$tbl_G and \$\$tblDG overlap!

\$\$tbl_IG is used to convert from binary to unpacked decimal.

Binary values 0-16 .. 9-16 map to unpacked -0 .. -9.

Binary values 0 .. 9 map to unpacked +0 .. +9.

The power of ten table starts at \$\$tbl_IG+12 and consists of word values.

Two tables are intermingled. The successive values are

-30, -10, -300, -100, .. -3000000000, -1000000000.

That is, the pairs $(-3*10^{**i}, -1*10^{**i})$ for $i=1,..,9$.

INPUT REGISTERS: NONE

OUTPUT REGISTERS: NONE

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS: NONE

PERMISSIBLE CONTEXT:

To be used only by millicode routines.

These tables are subject to change in order to effect changes in the millicode routines calling them.

Furthermore, tables will be removed when no longer needed by the millicode routines.

Users should only use tables at \$\$tbl_ASCII in the asciitbl module.

DISCUSSION:

Presently, the routines using the tables are --

\$\$tbl_G:\$\$gadd, \$\$gsub, \$\$gcv_t_g_to_i

\$\$tbl_V:\$\$gcmp

\$\$tbl_V2:\$\$valg

\$\$tbl_V3:\$\$valg_lb

\$\$tbl_DG:\$\$dcvt_g_to_d

\$\$tbl_IG:\$\$gcv_t_i_to_g, \$\$gcv_t_i_to_g_reg

ROUTINE: \$\$valg, \$\$valg_lb

DESCRIPTION:

\$\$valg is a COBOL unpacked ASCII Decimal validation routine.

\$\$valg_lb is an RPG unpacked ASCII Decimal validation routine.

It is passed a short pointer to a decimal string and a length. All digit positions are checked for valid representations. Embedded blanks are not permitted.

\$\$valg_lb permits leading blanks; \$\$valg does not.

The sign position is checked by using the millicode table \$\$tbl_V2 (\$\$valg) or \$\$tbl_V3 (\$\$valg_lb).

A trap occurs if a discrepancy is found. Otherwise, return occurs.

The trap handler expects the argument registers to have not been changed so that the number can be optionally fixed.

DEFINITIONS:

Unpacked ASCII Decimal: ('0' -> '9' == 0x30 -> 0x39)

The data format is ASCII decimal with the following conventions for the sign on the right digit:

char	hex	value
space	20	+0 (\$\$valg_lb only)
0	30	+0
...		
9	39	+9
A	41	+1
...		
I	49	+9
J	4A	-1
...		
R	52	-9
{	7B	+0
}	7D	-0

INPUT REGISTERS:

arg0 == short pointer to unpacked decimal string.

arg1 == length of string in bytes

r31 ==

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = will not change at any point during execution

arg1 = will not change at any point during execution

arg2 = undefined

arg3 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

An invalid digit will cause a trap using either:

UADDCMT,NBC x,y,r0

UADDCMT,SBC x,y,r0

where x and y can be any register.

\$\$valg_lb considers leading blanks to be valid digits;

\$\$valg does not.

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

The validation of the digit in the sign position is dependent upon the entries in \$\$tbl_V2 (\$\$valg) or \$\$tbl_V3 (\$\$valg_lb).

ROUTINE: \$\$get_version

Returns a pointer to a string holding the version of millicode.

The first word of the string is its length in bytes including the word holding the length.

The string is terminated with a null character.

INPUT REGISTERS:

r31 == return pc

sr0 == return space when called externally

OUTPUT REGISTERS:

ret0 =short pointer to the version string

OTHER REGISTERS AFFECTED: NONE

SIDE EFFECTS:

Causes a trap under the following conditions: NONE

Changes memory at the following places: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

ROUTINE:d_val#_#

DESCRIPTION:

Packed decimal validation.

The following routines are provided:

\$\$d_val general routine 15+3n cycles, aligned 0,2,3

len >= 10 nibbles 17+3n cycles, aligned 1

unknown len n = # words, whole or partial

len >= 6, aligned ?

\$\$d_valf same as \$\$d_val, but will fix an invalid sign

\$\$d_val2 2 nibbles, all alignments 7 cycles

\$\$d_val4_e 4 nibbles, aligned 0,2 9 cycles

\$\$d_val4_1 4 nibbles, aligned 1 9 cycles

\$\$d_val4_3 4 nibbles, aligned 3,? 11 cycles

\$\$d_val6_0 6 nibbles, aligned 0 9 cycles

\$\$d_val6_1 6 nibbles, aligned 1 9 cycles

\$\$d_val6_2 6 nibbles, aligned 2 11 cycles

\$\$d_val6_3 6 nibbles, aligned 3 11 cycles

\$\$d_val8_0 8 nibbles, aligned 0 9 cycles

\$\$d_val8_1 8 nibbles, aligned 1 11 cycles

\$\$d_val8_2 8 nibbles, aligned 2 11 cycles

\$\$d_val8_3 8 nibbles, aligned 3 11 cycles

INPUT:

SRC - pointer to most significant byte

LEN - length (in nibbles); must be even and >0

SRC and LEN must not be modified, since they are required by any trap handler.

sr0,r31 - linkage pair for external millicode

r31 - link for internal millicode

OUTPUT:

None.

REGISTERS USED:

src - current pointer position

unknown len n = # words, whole or partial

len >= 6, aligned ?

\$\$d_valf same as \$\$d_val, but will fix an invalid sign
\$\$d_val2 2 nibbles, all alignments 7 cycles
\$\$d_val4_e 4 nibbles, aligned 0,2 9 cycles
\$\$d_val4_1 4 nibbles, aligned 1 9 cycles
\$\$d_val4_3 4 nibbles, aligned 3,? 11 cycles
\$\$d_val6_0 6 nibbles, aligned 0 9 cycles
\$\$d_val6_1 6 nibbles, aligned 1 9 cycles
\$\$d_val6_2 6 nibbles, aligned 2 11 cycles
\$\$d_val6_3 6 nibbles, aligned 3 11 cycles
\$\$d_val8_0 8 nibbles, aligned 0 9 cycles
\$\$d_val8_1 8 nibbles, aligned 1 11 cycles
\$\$d_val8_2 8 nibbles, aligned 2 11 cycles
\$\$d_val8_3 8 nibbles, aligned 3 11 cycles

INPUT:

SRC - pointer to most significant byte

LEN - length (in nibbles); must be even and >0

SRC and LEN must not be modified, since they are required by any trap handler.

sr0,r31 - linkage pair for external millicode

r31 - link for internal millicode

OUTPUT:

None.

REGISTERS USED:

src - current pointer position

len - length remaining

t1 - scratch register

t2 - scratch register; never used until we are through with all uses of src, so t2 and src are equivalence.

mask - word to test valid digits

FRAME:

No frame allocated.

INPUT REGISTERS:

arg0 == short pointer to packed source.

arg1 == length of string in nibbles.

sr0 == return space when called externally

OUTPUT REGISTERS:

arg0 = will not change at any point during execution

arg1 = will not change at any point during execution

Millicode Library

arg2 = undefined

arg3 = undefined

ret1 = undefined

OTHER REGISTERS AFFECTED:

r1 = undefined

SIDE EFFECTS:

Causes a trap under the following conditions:

An invalid digit or an invalid sign will cause a trap using :

UADDCMT,SDC x,y,r0

where x and y can be any register.

Note that \$\$d_valf will trap only on an invalid digit; an invalid sign will be fixed if all digits are valid. The sign nibble will be changed if it is invalid and all digits are valid.

All others: NONE

PERMISSIBLE CONTEXT:

Unwindable.

Does not create a stack frame.

Suitable for internal or external millicode.

DISCUSSION:

Calls other millicode routines using r31: NONE

Calls other millicode routines: NONE

11.1 Overview

Dynamic linking on HP-UX is done using **dyld** (for the dynamic linker). The dynamic linker supports dynamic linking and loading of object modules from relocatable object files (“.o files”) and relocatable libraries (“.a files”). It can be called to link and load individual .o files, or to search and selectively load modules from libraries. It can also be used to unload a previously loaded module.

Dynamically-loaded modules are loaded into the calling process’ data space, and the text is not shared by any other process. The transfer of control between the code and data space requires code sequences that are not part of the standard calling convention, and the dynamic linker automatically supplies the appropriate code sequences in the form of stub routines.

11.2 External Interface

This section describes interface routines that are used by the dynamic linker. These routines are also described in the **dyld**’s man page.

int dl_init_loader();

The `dl_init_loader` routine initializes the dynamic linker. It must be called before any other routines are called. `dl_init_loader` will define the symbols which a program requires to work with `libc.a`. Attempts to re-define these symbols will have no effect. See note below on loading `/lib/milli.a` and `dl_dyncall.o`

int dl_define_symbol(char *name, long symbol_value);

The `dl_define_symbol` routine is used to make symbols known to the dynamic linker that are defined in the main program and are available for import by dynamically-loaded modules.

The following symbols should not be defined: all millicode routines (names beginning with “\$\$”), `sigsetjmp`, `_sigsetjmp`, `siglongjmp`, and `_siglongjmp`. These routines must be dynamically loaded from the C library so that they are in the same space as the code that calls them.

Beware of replacing definitions created by `define_symbol` if you load a library. If you make the initial `define_symbols` calls after you load the libraries you intend to load, you will avoid this problem.

int dl_declare_undefined_symbol(char *name);

The `dl_declare_undefined_symbol` routine adds a symbol name to the list of currently undefined symbols. Its purpose is to prime the list with one or more initial symbols prior to invoking `dl_search_library`.

int dl_declare_common_symbol(char *name, int length);

The `dl_declare_common_symbol` routine adds a symbol name to the list of currently undefined symbols. The symbol is recorded as a common request with an associated length, and storage is allocated for it if the symbol remains undefined. Common requests have the property that storage is allocated for the largest of several requests for the same symbol.

unsigned long dl_unintern_symbol(char *name);

The `dl_unintern_symbol` routine hides the definition of the named symbol and all references to it. If the symbol is later defined, these hidden references will continue to point at the old definition. This routine can be used to implement "layered" definitions of a symbol as in dld shared libraries. If successful, a non-zero symbol ID is returned. The symbol ID can be used to lookup the value of the symbol with `dl_get_unintern_symbol_value`. Upon failure, the symbol ID returned will be zero.

long dl_get_unintern_symbol_value(unsigned long symbol_id);

The `dl_get_unintern_symbol_value` is given the symbol ID of a symbol as returned by `dl_unintern_symbol` and returns the value of the symbol. Upon failure, a value of zero is returned.

int dl_set_unsat_handler(int (*handler) ());

The `dl_set_unsat_handler` routine defines a procedure to be called whenever a call is attempted to a procedure that is undefined at the time of call. The `unsat` handler may be

a routine in the main program or a dynamically-loaded procedure. When invoked, R21 will be a pointer to the symbol, i.e. (char **) pointer to the pointer to the symbol name. As with all the `_set_XX` routines, the notification can be disabled by passing a NULL pointer to the `_set_XX` routine.

int dl_set_patch_callback(int (*proc) (char *filename));

The `dl_set_patch_callback` routine is passed a pointer to a procedure to be called whenever the data references of a module are about to be fixed up. The callback procedure is passed the file name of the module.

***int dl_set_selectv_callback(int (*proc)(char *file_name,
char*symbol_name));***

The `dl_set_selectv_callback` routine is passed a pointer to a procedure to be called whenever a library module is selected for loading to satisfy an unsatisfied reference. The callback procedure is passed the file name of the module and the name of the unsatisfied symbol.

int dl_set_select_callback(int (*proc)(char *file_name));

The `dl_set_select_callback` routine is passed a pointer to a procedure to be called whenever a module from a library is about to be loaded. The callback procedure is passed the file name of the module being loaded.

int dl_set_symbol_callback(int (*proc)(char **symbol));

The `dl_set_symbol_callback` routine is passed a pointer to a procedure to be called whenever an address is assigned to a symbol. The callback procedure is passed a pointer to the symbol. If the symbol has an inbound relocation stub, the symbol pointer points to the symbol which contains the stub.

***int dl_load_file(char *filename, int load_debug, void **__head, char*
shlib_path);***

***int dl_load_module_from_memory (char *object, int load_debug,
void **__head, char *shlib_path);***

int dl_search_library(char *filename, int load_debug, void **__head);

The `dl_load_file` routine loads a module from the named object file unconditionally. If the file is a library, it loads every module unconditionally. Symbols defined in the loaded module are used to resolve currently undefined symbols, and undefined symbols in the loaded module are either resolved to previously defined symbols or added to the list of undefined symbols.

`dl_load_file`, `dl_load_module_from_memory` and `dl_search_library` all have similar calling sequences. The `load_debug` argument is a Boolean value which indicates whether debug information present in the file is to be loaded into memory. See `dl_debug_info`. NULL should be passed for `head_address` if C++ constructors are not to be searched for and called. If invocation of C++ constructors is desired, `head_address` should be the address of the C++ symbol, `__head`. `shlib_path` is a colon separated list of directories to be searched when locating the libraries upon which a shared library depends. An empty entry indicates that the recorded path is to be used.

A shared library which is loaded is treated as one module by `dynld` as opposed to an archive library which is treated as a set of modules.

When a shared library is loaded or unloaded, the shared library initializer function is not invoked.

The `dl_load_module_from_memory` routine is identical to `dl_load_file`, except that the object module to be loaded is read from memory instead of from a file. The filename of the module is set to "(mem)". See `dl_load_file` for a description of the other arguments.

The `dl_search_library` routine searches the named library and loads (individually) any modules that satisfy currently undefined symbols. As symbols are added, the list of undefined symbols may grow, and the library is iteratively searched until no more undefined symbols can be resolved. See `dl_load_file` for a description of the other arguments.

int dl_unload_file(char *filename);

The `dl_unload_file` routine unloads the module specified. All symbols defined in the module are removed. If any symbol in the module was used to resolve undefined symbols, those symbols will be added back to the list of undefined symbols. If a library symbol was used to resolve a symbol removed when the module was unloaded and there are no other references to that library symbol, the library symbol is also removed.

The module must have been loaded first before it can be unloaded. Libraries are not unloaded (the library as a whole cannot be unloaded, but individual modules can be unloaded).

int dl_unload_module(char **module);

`dl_unload_module` is like `dl_unload_file` except that it is passed a module pointer instead of a file path.

int dl_reset_all_data();

The `dl_reset_all_data` routine resets all initialized data in dynamically-loaded modules to the original state, and clears all common blocks and bss sections to zero.

char **dl_lookup_module(char *filename)

The `dl_lookup_module` routine is given the filename by which a module was loaded and returns a pointer to the module. Upon failure, a NULL pointer is returned.

char **dl_get_modules(char **module);

The `dl_get_modules` routine returns the next module in the module list. NULL should be passed in the first time to get the first module in the list. Subsequent calls should pass the previous return value.

char **dl_get_globals(char **module, char **symbol);

The `dl_get_globals` routine returns the next global symbol in the module. If NULL is passed as the module pointer, `dl_get_globals` will scan all global symbols; otherwise, it will scan only the global symbols for the given module. NULL should be passed in as the symbol pointer for the first call. Subsequent calls should pass the previous return value.

char **dl_get_undefs(char **symbol);

The `dl_get_undefs` routine returns the next undefined symbol in the list of undefined symbols. NULL should be passed in the first time to get the first undefined symbol. Subsequent calls should pass the previous return value.

long dl_get_symbol_value(char *name);

The `dl_get_symbol_value` routine returns the address of the named symbol. If the named symbol is undefined, NULL is returned.

char *dl_get_symbol_name(long address, char **module, long *rem);

The `dl_get_symbol_name` routine returns a symbol name corresponding to a given address, if the address is within any dynamically-loaded module. If the module parameter is not NULL, the location that it points to is filled in with a pointer to the name of the module that contains the address. If the `rem` parameter is not NULL, the location that it points to is filled in with the difference between actual address of the returned symbol and the original address. The difference will always be positive. If the given address is not within any module, NULL is returned and the last two parameters are not filled in.

char *dl_dloader_version();

The `dl_dloader_version` routine returns a character string containing the version number of the dynamic linker along with the operating system release and hardware series for which it was built. You should use a version of `dynld.o` which matches your system release and hardware line to be sure that it defines the symbols used in your version of `libc.a`. For example, HP-UX release 9.0 for an s700.

int dl_symbol_scope(char **symbol_ptr);

The `dl_symbol_scope` routine returns the scope of the symbol as defined in `/usr/include/syms.h`.

int dl_symbol_type(char **symbol_ptr);

The `dl_symbol_type` routine returns the type of the symbol as defined in `/usr/include/syms.h`.

int dl_debug_info(char **module, char *name, void **addr, int *length);

The `dl_debug_info` routine searches for the named subspace in the `$DEBUG$` space of the given module and returns the address of the relocated data for that subspace in the pointer pointed to by `addr` and the length in the integer pointed to by `length`. `dl_debug_info` will return an error if it is invoked for a shared library.

int dl_call_constructors();

The `dl_call_constructors` routine should be called if C++ code was loaded after unsatisfied references have been resolved. `dl_call_constructors` will invoke the constructors for static data structures which were defined in the C++ code loaded and will register the destructors to be called when the program terminates or when the file is unloaded.

It is recommended that symbols which are to be used with `dl_get_symbol_value` should be declared external "C" so that the name will not be "mangled". Otherwise, the only means of finding a symbol is to demangle all of the symbols in a module and if only one symbol demangles to the desired name, the symbol has been found.

A C++ program should use the method illustrated in `/lib/dynld/example` to export all of its symbols to `dynld`.

11.3 Internal Design and Algorithm

1- If the requested shared library has already been loaded, `_load_file` will return `DYNLD_DUPLICATE_LOAD`.

2- Starting with the initial shared library specified, `dynld` will make a list of all of the shared libraries to be loaded. For each library on the list, `dynld` will examine the shared library list. If the specified file has not already been loaded and is not already in the to-be-loaded list, it will be added to the list. As we form the "load graph" we read in all of the required information from the shared libraries involved.

3. The files in the list will be loaded in reverse order in an attempt to avoid unsats which would cause us to process the fixups of a file again. Before each file is loaded, the `select_callback` routine will be called.

4. After all the shared libraries have been loaded, `patch_data_references` will be called for “dirty” modules - modules with direct references to symbols that have been defined or re-defined.

Loading a single shared library:

0. Load up text and data from the library: Allocate space for the data area + bss. Copy the data from the data space read in during the formation of the load graph to the new area, zero-fill the bss area.

1. For each symbol in the export table, the definition of the relevant version should be placed in the `dynld` symbol table. The “relevant version” is the version with the highest version number less than or equal to the version specified in the dependency list or the latest version if this is the initially requested shared library. For each symbol being defined, call the `symbol_callback` routine.

2. Process the import list to initialize the DLT and PLT. We will ignore the `lib_index` and simply use the global definition for the named symbol. This may cause some shared libraries which require layers of definitions not to work. For each imported symbol we will create an `SS_UNSAT/SS_EXTERN` `dynld` symbol with the `direct_ref` bit set to `TRUE` so that if the symbol definition is changed we will re-process the `dreloc_records` to pick up the new value.

3. Process the `dreloc_records`. Call the `patch_callback` routine before processing the fix-ups.

4. As with the existing load process, mark modules as dirty which have direct references to symbols defined in a shared library.

5. Fill in the fields of the `shlib_unwind_info` structure. Place the address in the DLT at offset 0. There is some odd entry in the import list which may require special case handling for the entry - e.g. skip it.

6. As we process the shared libraries, create a list of the initializers. At the end of the process, call them in the order they were processed - the initial library is processed last.

7. Figure out what callbacks we should do or perhaps provide new callbacks.

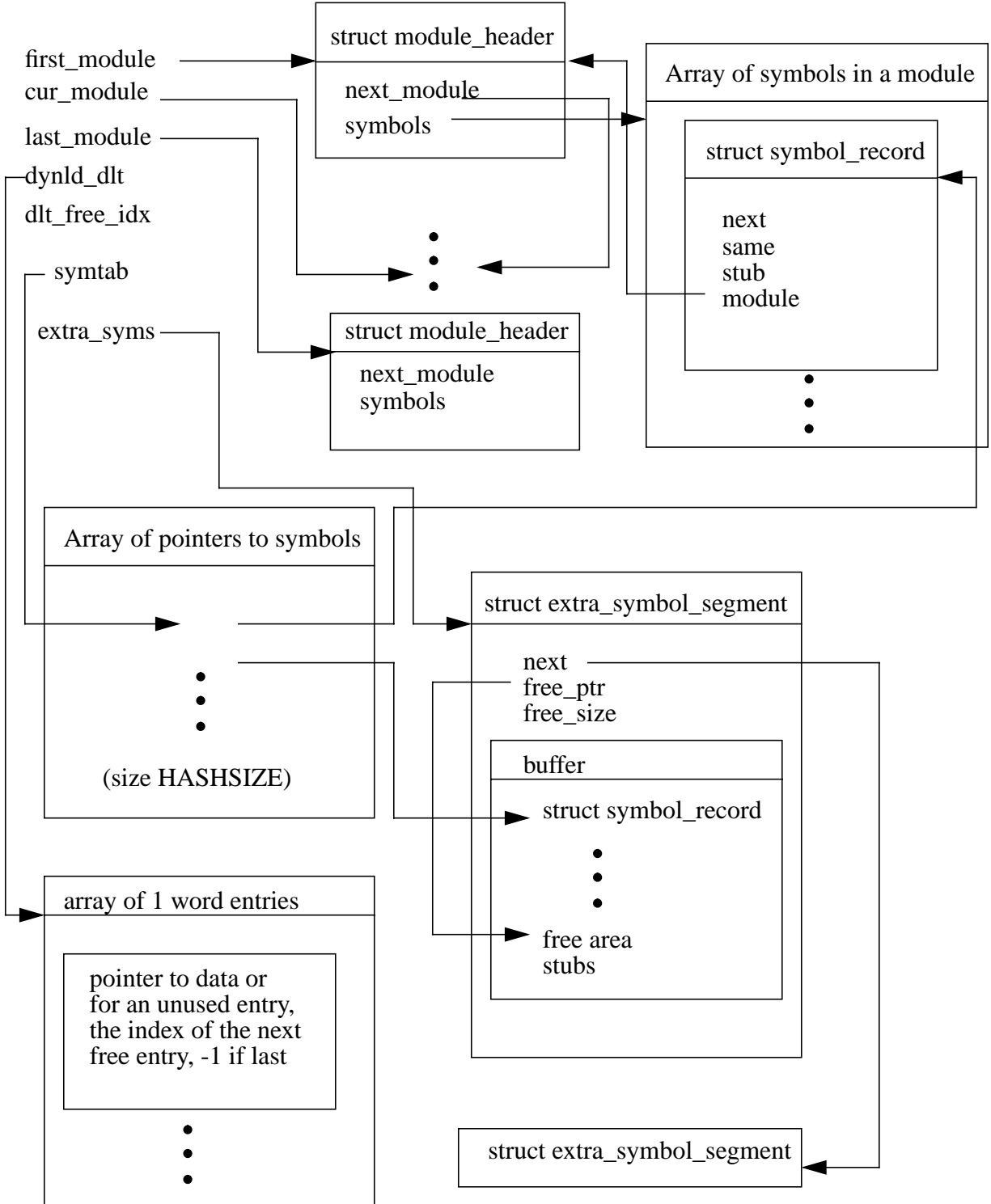
8. We allocate a table of PLT entries for the `ST_CODE` symbols which are exported by the library. The global symbol definition is a PLT symbol with `symbol->plt` pointing to the PLT entry allocated for the symbol.

The following three figures show the structure of `dynld`.

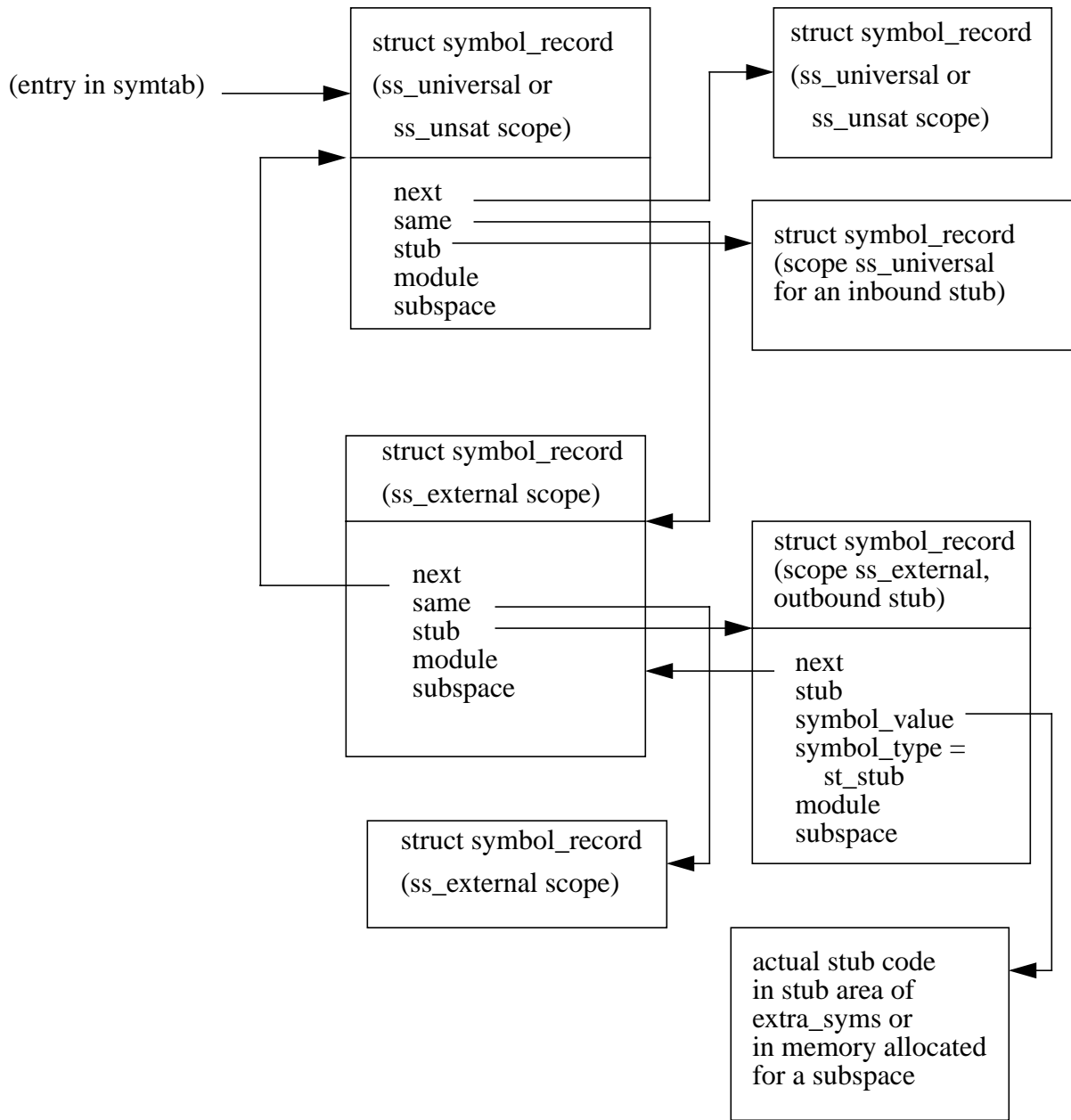
Dynamic Linking

Dynld Data Structures, Top Level

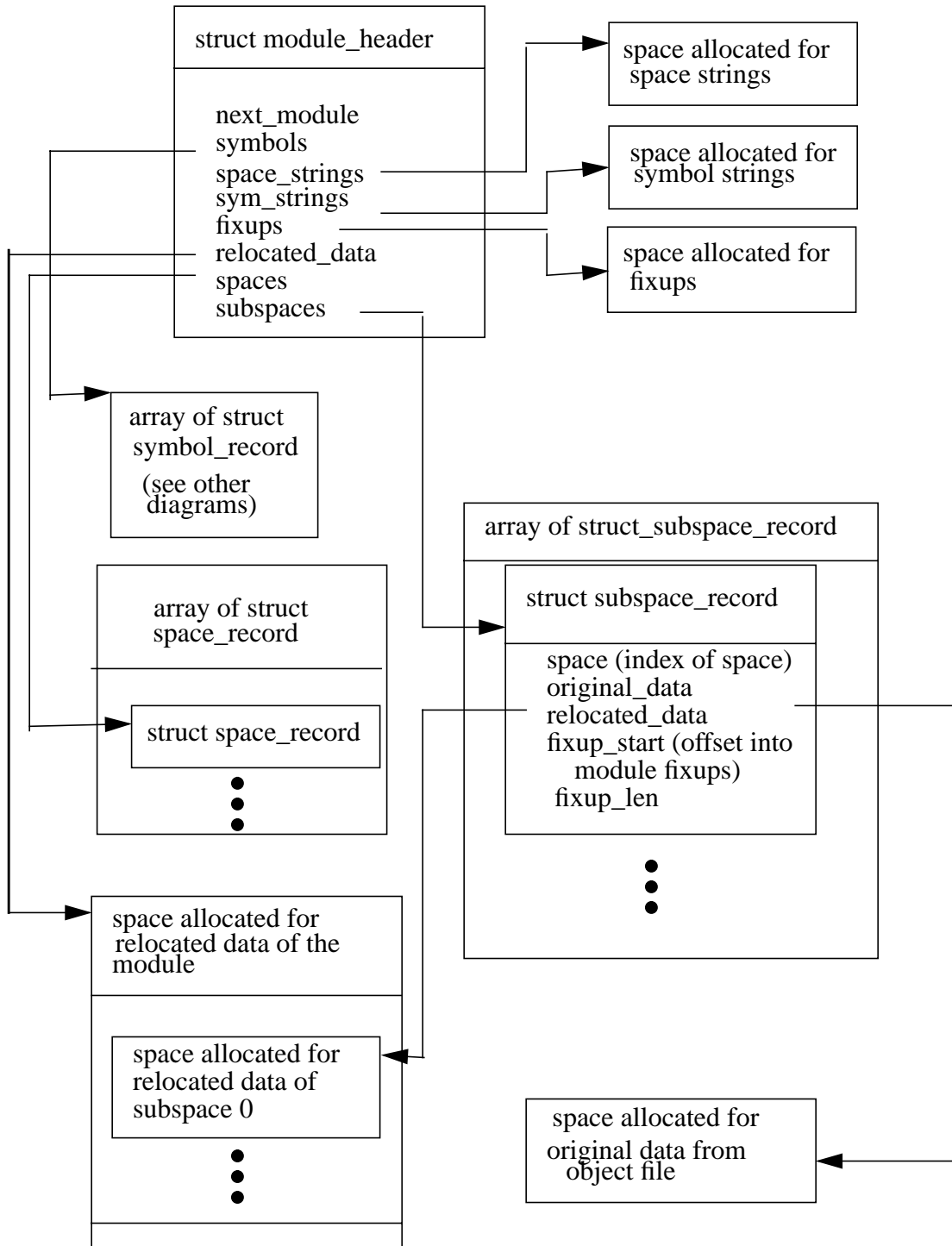
Global Variables



Dynld Data Structures - Symbol Record



Dynld Data Structures - Modules, Spaces and Subspaces



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