# Tool Interface Standard (TIS) Executable and Linking Format (ELF) Specification

## Version 1.2

TIS Committee

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## Preface

This Executable and Linking Format Specification, Version 1.2, is the result of the work of the Tool Interface Standards (TIS) Committee--an association of members of the microcomputer industry formed to work toward standardization of the software interfaces visible to development tools for 32-bit Intel Architecture operating environments. Such interfaces include object module formats, executable file formats, and debug record information and formats.

The goal of the committee is to help streamline the software development process throughout the microcomputer industry, currently concentrating on 32-bit operating environments. To that end, the committee has developed specifications--some for file formats that are portable across leading industry operating systems, and others describing formats for 32-bit Windows* operating systems. Originally distributed collectively as the TIS Portable Formats Specifications Version 1.1, these specifications are now separated and distributed individually.

TIS Committee members include representatives from Absoft, Autodesk, Borland International Corporation, IBM Corporation, Intel Corporation, Lahey, Lotus Corporation, MetaWare Corporation, Microtec Research, Microsoft Corporation, Novell Corporation, The Santa Cruz Operation, and WATCOM International Corporation. PharLap Software Incorporated and Symantec Corporation also participated in the specification definition efforts.

This specification like the others in the TIS collection of specifications is based on existing, proven formats in keeping with the TIS Committee's goal to adopt, and when necessary, extend existing standards rather than invent new ones.

### About ELF: Executable and Linking Format

The Executable and Linking Format was originally developed and published by UNIX System Laboratories (USL) as part of the Application Binary Interface (ABI). The Tool Interface Standards committee (TIS) has selected the evolving ELF standard as a portable object file format that works on 32-bit Intel Architecture environments for a variety of operating systems.

The ELF standard is intended to streamline software development by providing developers with a set of binary interface definitions that extend across multiple operating environments. This should reduce the number of different interface implementations, thereby reducing the need for recoding and recompiling code.

### About This Document

This document is intended for developers who are creating object or executable files on various 32-bit environment operating systems. In order to extend ELf into different operating systems, the current ELF version 1.2 document has been reorganized based on operating system-specific information. It is divided into the following three books:

- Book I: *Executable and Linking Format*, describes the object file format called ELF. This book also contains an appendix that describes historical references and lists processor and operating system reserved names and words.
- Book II: *Processor Specific* (*Intel Achitecture)*, conveys hardware-specific ELF information, such as Intel Architecture information.
- Book III: *Operating System Specific*, describes ELF information that is operating system dependent, such as System V Release 4 information. This book also contains an appendix that describes ELF information that is both operating system and processor dependent.

# Contents

## Preface

## Book I: Executable and Linking Format (ELF)

### 1. Object Files

### 2. Program Loading and Dynamic Linking

### A. Reserved Names

## Book II: Processor Specific (Intel Architecture)

### 1. Object Files

# Book III: Operating System Specific (UNIX System V Release 4)

## 1. Object Files

## 2. Program Loading and Dynamic Linking

## 3. Intel Architecture and System V Release 4 Dependencies

# List of Figures

## Book I: Executable and Linking Format (ELF)

## Book II: Processor Specific (Intel Architecture)

## Book III: Operating System Specific (UNIX System V Release 4)

# Book I:
# Executable and Linking Format (ELF)

# Contents

## Book I: Executable and Linking Format (ELF)

# Figures

## Introduction

This chapter describes the object file format, called ELF (Executable and Linking Format). There are three main types of object files.

- A *relocatable file* holds code and data suitable for linking with other object files to create an executable or a shared object file.
- An *executable file* holds a program suitable for execution.
- A *shared object file* holds code and data suitable for linking in two contexts. First, the link editor may process it with other relocatable and shared object files to create another object file. Second, the dynamic linker combines it with an executable file and other shared objects to create a process image.

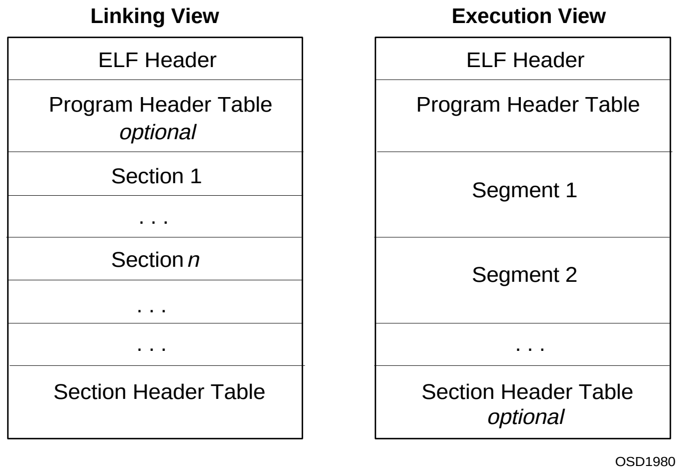
Created by the assembler and link editor, object files are binary representations of programs intended to execute directly on a processor. Programs that require other abstract machines are excluded.

After the introductory material, this chapter focuses on the file format and how it pertains to building programs. Chapter 2 also describes parts of the object file, concentrating on the information necessary to execute a program.

## File Format

Object files participate in program linking (building a program) and program execution (running a program). For convenience and efficiency, the object file format provides parallel views of a file's contents, reflecting the differing needs of these activities. Figure 1-1 shows an object file's organization.

### Figure 1-1. Object File Format



An *ELF header* resides at the beginning and holds a "road map" describing the file's organization. *Sections* hold the bulk of object file information for the linking view: instructions, data, symbol table, relocation information, and so on. Descriptions of special sections appear later in this section. Chapter 2 also describes *segments* and the program execution view of the file.

A *program header table*, if present, tells the system how to create a process image. Files used to build a process image (execute a program) must have a program header table; relocatable files do not need one. A *section header table* contains information describing the file's sections. Every section has an entry in the table; each entry gives information such as the section name, the section size, and so on. Files used during linking must have a section header table; other object files may or may not have one.

*NOTE. Although the figure shows the program header table immediately after the ELF header, and the section header table following the sections, actual files may differ. Moreover, sections and segments have no specified order. Only the ELF header has a fixed position in the file.*

## Data Representation

As described here, the object file *format* supports various processors with 8-bit bytes and 32-bit architectures. Nevertheless, it is intended to be extensible to larger (or smaller) architectures. Object files therefore represent some control data with a machine-independent format, making it possible to identify object files and interpret their contents in a common way. Remaining data in an object file use the encoding of the target processor, regardless of the machine on which the file was created.

**Figure 1-2. 32-Bit Data Types**

| Name | Size | Alignment | Purpose |
|---|---|---|---|
| `Elf32_Addr` | 4 | 4 | Unsigned program address |
| `Elf32_Half` | 2 | 2 | Unsigned medium integer |
| `Elf32_Off` | 4 | 4 | Unsigned file offset |
| `Elf32_Sword` | 4 | 4 | Signed large integer |
| `Elf32_Word` | 4 | 4 | Unsigned large integer |
| `unsigned char` | 1 | 1 | Unsigned small integer |

All data structures that the object file format defines follow the "natural" size and alignment guidelines for the relevant class. If necessary, data structures contain explicit padding to ensure 4-byte alignment for 4-byte objects, to force structure sizes to a multiple of 4, and so on. Data also have suitable alignment from the beginning of the file. Thus, for example, a structure containing an `Elf32_Addr` member will be aligned on a 4-byte boundary within the file.

For portability reasons, ELF uses no bit fields.

## Character Representations

This section describes the default ELF character representation and defines the standard character set used for external files that should be portable among systems. Several external file formats represent control information with characters. These single-byte characters use the 7-bit ASCII character set. In other words, when the ELF interface document mentions character constants, such as, ‘`/`’ or ‘`\n`’ their numerical values should follow the 7-bit ASCII guidelines. For the previous character constants, the single-byte values would be 47 and 10, respectively.

Character values outside the range of 0 to 127 may occupy one or more bytes, according to the character encoding. Applications can control their own character sets, using different character set extensions for different languages as appropriate. Although TIS-conformance does not restrict the character sets, they generally should follow some simple guidelines.

- Character values between 0 and 127 should correspond to the 7-bit ASCII code. That is, character sets with encodings above 127 should include the 7-bit ASCII code as a subset.
- Multibyte character encodings with values above 127 should contain only bytes with values outside the range of 0 to 127. That is, a character set that uses more than one byte per character should not "embed" a byte resembling a 7-bit ASCII character within a multibyte, non-ASCII character.
- Multibyte characters should be self-identifying. That allows, for example, any multibyte character to be inserted between any pair of multibyte characters, without changing the characters' interpretations.

These cautions are particularly relevant for multilingual applications.

*NOTE. There are naming conventions for ELF constants that have processor ranges specified. Names such as DT_, PT_, for processor specific extensions, incorporate the name of the processor: DT_M32_SPECIAL, for example. However, pre-existing processor extensions not using this convention will be supported.*

| <u>Pre-existing Extensions</u> |
|---|
| `DT_JMP_REL` |

## ELF Header

Some object file control structures can grow, because the ELF header contains their actual sizes. If the object file format changes, a program may encounter control structures that are larger or smaller than expected. Programs might therefore ignore "extra" information. The treatment of "missing" information depends on context and will be specified when and if extensions are defined.

### Figure 1-3.  ELF Header

```
#define EI_NIDENT        16

typedef struct {
           unsigned char  e_ident[EI_NIDENT];
           Elf32_Half     e_type;
           Elf32_Half     e_machine;
           Elf32_Word     e_version;
           Elf32_Addr     e_entry;
           Elf32_Off      e_phoff;
           Elf32_Off      e_shoff;
           Elf32_Word     e_flags;
           Elf32_Half     e_ehsize;
           Elf32_Half     e_phentsize;
           Elf32_Half     e_phnum;
           Elf32_Half     e_shentsize;
           Elf32_Half     e_shnum;
           Elf32_Half     e_shstrndx;
 } Elf32_Ehdr;
```

`e_ident` The initial bytes mark the file as an object file and provide machine-independent data with which to decode and interpret the file's contents. Complete descriptions appear below, in "ELF Identification."

`e_type` This member identifies the object file type.

| Name | Value | Meaning |
|---|---:|---|
| ET_NONE | 0 | No file type |
| ET_REL | 1 | Relocatable file |
| ET_EXEC | 2 | Executable file |
| ET_DYN | 3 | Shared object file |
| ET_CORE | 4 | Core file |
| ET_LOPROC | 0xff00 | Processor-specific |
| ET_HIPROC | 0xffff | Processor-specific |

Although the core file contents are unspecified, type `ET_CORE` is reserved to mark the file type. Values from `ET_LOPROC` through `ET_HIPROC` (inclusive) are reserved for processor-specific semantics. Other values are reserved and will be assigned to new object file types as necessary.

`e_machine` This member's value specifies the required architecture for an individual file.

| Name | Value | Meaning |
|---|---|---|
| `ET_NONE` | `0` | No machine |
| `EM_M32` | `1` | AT&T WE 32100 |
| `EM_SPARC` | `2` | SPARC |
| `EM_386` | `3` | Intel Architecture |
| `EM_68K` | `4` | Motorola 68000 |
| `EM_88K` | `5` | Motorola 88000 |
| `EM_860` | `7` | Intel 80860 |
| `EM_MIPS` | `8` | MIPS RS3000 Big-Endian |
| `EM_MIPS_RS4_BE` | `10` | MIPS RS4000 Big-Endian |
| `RESERVED` | `11-16` | Reserved for future use |

Other values are reserved and will be assigned to new machines as necessary. Processor-specific ELF names use the machine name to distinguish them. For example, the flags mentioned below use the prefix `EF_;` a flag named `WIDGET` for the `EM_XYZ` machine would be called `EF_XYZ_WIDGET`.

`e_version` This member identifies the object file version.

| Name | Value | Meaning |
|---|---|---|
| `EV_NONE` | `0` | Invalid versionn |
| `EV_CURRENT` | `1` | Current version |

The value `1` signifies the original file format; extensions will create new versions with higher numbers. The value of `EV_CURRENT`, though given as `1` above, will change as necessary to reflect the current version number.

`e_entry` This member gives the virtual address to which the system first transfers control, thus starting the process. If the file has no associated entry point, this member holds zero.

`e_phoff` This member holds the program header table's file offset in bytes. If the file has no program header table, this member holds zero.

`e_shoff` This member holds the section header table's file offset in bytes. If the file has no section header table, this member holds zero.

`e_flags` This member holds processor-specific flags associated with the file. Flag names take the form `EF_`*`machine_flag`*.

`e_ehsize` This member holds the ELF header's size in bytes.

`e_phentsize` This member holds the size in bytes of one entry in the file's program header table; all entries are the same size.

`e_phnum` This member holds the number of entries in the program header table. Thus the product of `e_phentsize` and `e_phnum` gives the table's size in bytes. If a file has no program header table, `e_phnum` holds the value zero.

`e_shentsize` This member holds a section header's size in bytes. A section header is one entry in the section header table; all entries are the same size.

`e_shnum` This member holds the number of entries in the section header table. Thus the product of `e_shentsize` and `e_shnum` gives the section header table's size in bytes. If a file has no section header table, `e_shnum` holds the value zero.

`e_shstrndx` This member holds the section header table index of the entry associated with the section name string table. If the file has no section name string table, this member holds the value `SHN_UNDEF`. See "Sections" and "String Table" below for more information.

## ELF Identification

As mentioned above, ELF provides an object file framework to support multiple processors, multiple data encodings, and multiple classes of machines. To support this object file family, the initial bytes of the file specify how to interpret the file, independent of the processor on which the inquiry is made and independent of the file's remaining contents.

The initial bytes of an ELF header (and an object file) correspond to the `e_ident` member.

**Figure 1-4.** `e_ident[]` **Identification Indexes**

| Name | Value | Purpose |
|---|---|---|
| `EI_MAG0` | 0 | File identification |
| `EI_MAG1` | 1 | File identification |
| `EI_MAG2` | 2 | File identification |
| `EI_MAG3` | 3 | File identification |
| `EI_CLASS` | 4 | File class |
| `EI_DATA` | 5 | Data encoding |
| `EI_VERSION` | 6 | File version |
| `EI_PAD` | 7 | Start of padding bytes |
| `EI_NIDENT` | 16 | Size of `e_ident[]` |

These indexes access bytes that hold the following values.

EI_MAG0 to EI_MAG3 A file's first 4 bytes hold a "magic number," identifying the file as an ELF object file.

| Name | Value | Meaning |
|---|---|---|
| ELFMAG0 | 0x7f | e_ident[EI_MAG0] |
| ELFMAG1 | ’E’ | e_ident[EI_MAG1] |
| ELFMAG2 | ’L’ | e_ident[EI_MAG2] |
| ELFMAG3 | ’F’ | e_ident[EI_MAG3] |

EI_CLASS The next byte, e_ident[EI_CLASS], identifies the file's class, or capacity.

| Name | Value | Meaning |
|---|---|---|
| ELFCLASSNONE | 0 | Invalid class |
| ELFCLASS32 | 1 | 32-bit objects |
| ELFCLASS64 | 2 | 64-bit objects |

The file format is designed to be portable among machines of various sizes, without imposing the sizes of the largest machine on the smallest. Class ELFCLASS32 supports machines with files and virtual address spaces up to 4 gigabytes; it uses the basic types defined above.

Class ELFCLASS64 is incomplete and refers to the 64-bit architectures. Its appearance here shows how the object file may change. Other classes will be defined as necessary, with different basic types and sizes for object file data.

EI_DATA Byte e_ident[EI_DATA]specifies the data encoding of the processor-specific data in the object file. The following encodings are currently defined.

| Name | Value | Meaning |
|---|---|---|
| ELFDATANONE | 0 | Invalid data encoding |
| ELFDATA2LSB | 1 | See below |
| ELFDATA2MSB | 2 | See below |

More information on these encodings appears below. Other values are reserved and will be assigned to new encodings as necessary.

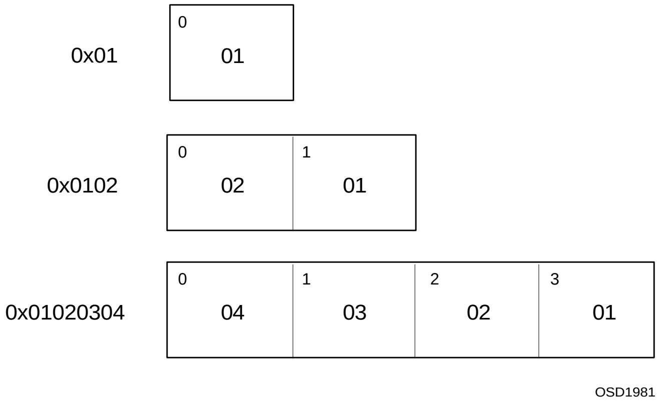
EI_VERSION Byte e_ident[EI_VERSION] specifies the ELF header version number. Currently, this value must be EV_CURRENT, as explained above for e_version.

EI_PAD This value marks the beginning of the unused bytes in e_ident. These bytes are reserved and set to zero; programs that read object files should ignore them. The value of EI_PAD will change in the future if currently unused bytes are given meanings.

A file's data encoding specifies how to interpret the basic objects in a file. As described above, class ELFCLASS32 files use objects that occupy 1, 2, and 4 bytes. Under the defined encodings, objects are represented as shown below. Byte numbers appear in the upper left corners.

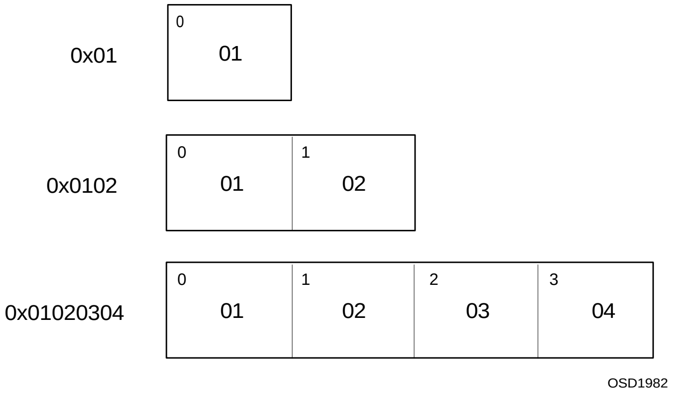
Encoding ELFDATA2LSB specifies 2's complement values, with the least significant byte occupying the lowest address.

### Figure 1-5. Data Encoding ELFDATA2LSB



Encoding ELFDATA2MSB specifies 2's complement values, with the most significant byte occupying the lowest address.

### Figure 1-6. Data Encoding ELFDATA2MSB



## Sections

An object file's section header table lets one locate all the file's sections. The section header table is an array of Elf32_Shdr structures as described below. A section header table index is a subscript into this array. The ELF header's e_shoff member gives the byte offset from the beginning of the file to the section header table; e_shnum tells how many entries the section header table contains; e_shentsize gives the size in bytes of each entry.

Some section header table indexes are reserved; an object file will not have sections for these special indexes.

### Figure 1-7. Special Section Indexes

| Name | Value |
|---|---|
| SHN_UNDEF | 0 |
| SHN_LORESERVE | 0xff00 |
| SHN_LOPROC | 0xff00 |
| SHN_HIPROC | 0xff1f |
| SHN_ABS | 0xfff1 |
| SHN_COMMON | 0xfff2 |
| SHN_HIRESERVE | 0xffff |

SHN_UNDEF — This value marks an undefined, missing, irrelevant, or otherwise meaningless section reference. For example, a symbol "defined" relative to section number SHN_UNDEF is an undefined symbol.

*NOTE. Although index 0 is reserved as the undefined value, the section header table contains an entry for index 0. That is, if the* e_shnum *member of the ELF header says a file has 6 entries in the section header table, they have the indexes 0 through 5. The contents of the initial entry are specified later in this section.*

SHN_LORESERVE — This value specifies the lower bound of the range of reserved indexes.

SHN_LOPROC through SHN_HIPROC — Values in this inclusive range are reserved for processor-specific semantics.

SHN_ABS — This value specifies absolute values for the corresponding reference. For example, symbols defined relative to section number SHN_ABS have absolute values and are not affected by relocation.

SHN_COMMON — Symbols defined relative to this section are common symbols, such as FORTRAN COMMON or unallocated C external variables.

`SHN_HIRESERVE` This value specifies the upper bound of the range of reserved indexes. The system reserves indexes between `SHN_LORESERVE` and `SHN_HIRESERVE`, inclusive; the values do not reference the section header table.That is, the section header table does *not* contain entries for the reserved indexes.

Sections contain all information in an object file, except the ELF header, the program header table, and the section header table. Moreover, object files' sections satisfy several conditions.

- Every section in an object file has exactly one section header describing it. Section headers may exist that do not have a section.
- Each section occupies one contiguous (possibly empty) sequence of bytes within a file.
- Sections in a file may not overlap. No byte in a file resides in more than one section.
- An object file may have inactive space. The various headers and the sections might not "cover" every byte in an object file. The contents of the inactive data are unspecified.

A section header has the following structure.

**Figure 1-8. Section Header**

```
typedef struct {
          Elf32_Word   sh_name;
          Elf32_Word   sh_type;
          Elf32_Word   sh_flags;
          Elf32_Addr   sh_addr;
          Elf32_Off    sh_offset;
          Elf32_Word   sh_size;
          Elf32_Word   sh_link;
          Elf32_Word   sh_info;
          Elf32_Word   sh_addralign;
          Elf32_Word   sh_entsize;
} Elf32_Shdr;
```

`sh_name` This member specifies the name of the section. Its value is an index into the section header string table section [see "String Table" below], giving the location of a null-terminated string.

`sh_type` This member categorizes the section's contents and semantics. Section types and their descriptions appear below.

`sh_flags` Sections support 1-bit flags that describe miscellaneous attributes. Flag definitions appear below.

`sh_addr` If the section will appear in the memory image of a process, this member gives the address at which the section's first byte should reside. Otherwise, the member contains 0.

sh_offset  This member's value gives the byte offset from the beginning of the file to the first byte in the section. One section type, SHT_NOBITS described below, occupies no space in the file, and its sh_offset member locates the conceptual placement in the file.

sh_size  This member gives the section's size in bytes. Unless the section type is SHT_NOBITS, the section occupies sh_size bytes in the file. A section of type SHT_NOBITS may have a non-zero size, but it occupies no space in the file.

sh_link  This member holds a section header table index link, whose interpretation depends on the section type. A table below describes the values.

sh_info  This member holds extra information, whose interpretation depends on the section type. A table below describes the values.

sh_addralign  Some sections have address alignment constraints. For example, if a section holds a doubleword, the system must ensure doubleword alignment for the entire section. That is, the value of sh_addr must be congruent to 0, modulo the value of sh_addralign. Currently, only 0 and positive integral powers of two are allowed. Values 0 and 1 mean the section has no alignment constraints.

sh_entsize  Some sections hold a table of fixed-size entries, such as a symbol table. For such a section, this member gives the size in bytes of each entry. The member contains 0 if the section does not hold a table of fixed-size entries.

A section header's sh_type member specifies the section's semantics.

**Figure 1-9. Section Types,** sh_type

| Name | Value |
|---|---|
| SHT_NULL | 0 |
| SHT_PROGBITS | 1 |
| SHT_SYMTAB | 2 |
| SHT_STRTAB | 3 |
| SHT_RELA | 4 |
| SHT_HASH | 5 |
| SHT_DYNAMIC | 6 |
| SHT_NOTE | 7 |
| SHT_NOBITS | 8 |
| SHT_REL | 9 |
| SHT_SHLIB | 10 |
| SHT_DYNSYM | 11 |
| SHT_LOPROC | 0x70000000 |
| SHT_HIPROC | 0x7fffffff |
| SHT_LOUSER | 0x80000000 |
| SHT_HIUSER | 0xffffffff |

SHT_NULL This value marks the section header as inactive; it does not have an associated section. Other members of the section header have undefined values.

SHT_PROGBITS The section holds information defined by the program, whose format and meaning are determined solely by the program.

SHT_SYMTAB and SHT_DYNSYM These sections hold a symbol table.

SHT_STRTAB The section holds a string table.

SHT_RELA The section holds relocation entries with explicit addends, such as type Elf32_Rela for the 32-bit class of object files. An object file may have multiple relocation sections. See "Relocation" below for details.

SHT_HASH The section holds a symbol hash table.

SHT_DYNAMIC The section holds information for dynamic linking.

SHT_NOTE This section holds information that marks the file in some way.

SHT_NOBITS A section of this type occupies no space in the file but otherwise resembles SHT_PROGBITS. Although this section contains no bytes, the sh_offset member contains the conceptual file offset.

SHT_REL The section holds relocation entries without explicit addends, such as type Elf32_Rel for the 32-bit class of object files. An object file may have multiple relocation sections. See "Relocation" below for details.

SHT_SHLIB This section type is reserved but has unspecified semantics.

SHT_LOPROC through SHT_HIPROC — Values in this inclusive range are reserved for processor-specific semantics.

SHT_LOUSER — This value specifies the lower bound of the range of indexes reserved for application programs.

SHT_HIUSER — This value specifies the upper bound of the range of indexes reserved for application programs. Section types between SHT_LOUSER and SHT_HIUSER may be used by the application, without conflicting with current or future system-defined section types.

Other section type values are reserved. As mentioned before, the section header for index 0 (SHN_UNDEF) exists, even though the index marks undefined section references. This entry holds the following.

**Figure 1-10. Section Header Table Entry: Index 0**

| Name | Value | Note |
|---|---|---|
| sh_name | 0 | No name |
| sh_type | SHT_NULL | Inactive |
| sh_flags | 0 | No flags |
| sh_addr | 0 | No address |
| sh_offset | 0 | No file offset |
| sh_size | 0 | No size |
| sh_link | SHN_UNDEF | No link information |
| sh_info | 0 | No auxiliary information |
| sh_addralign | 0 | No alignment |
| sh_entsize | 0 | No entries |

A section header's sh_flags member holds 1-bit flags that describe the section's attributes. Defined values appear below; other values are reserved.

**Figure 1-11. Section Attribute Flags,** sh_flags

| Name | Value |
|---|---:|
| SHF_WRITE | 0x1 |
| SHF_ALLOC | 0x2 |
| SHF_EXECINSTR | 0x4 |
| SHF_MASKPROC | 0xf0000000 |

If a flag bit is set in sh_flags, the attribute is "on" for the section. Otherwise, the attribute is "off" or does not apply. Undefined attributes are set to zero.

SHF_WRITE — The section contains data that should be writable during process execution.

`SHF_ALLOC` The section occupies memory during process execution. Some control sections do not reside in the memory image of an object file; this attribute is off for those sections.

`SHF_EXECINSTR` The section contains executable machine instructions.

`SHF_MASKPROC` All bits included in this mask are reserved for processor-specific semantics.

Two members in the section header, `sh_link` and `sh_info`, hold special information, depending on section type.

**Figure 1-12.** `sh_link` **and** `sh_info` **Interpretation**

| `sh_type` | `sh_link` | `sh_info` |
|---|---|---|
| SHT_DYNAMIC | The section header index of the string table used by entries in the section. | 0 |
| SHT_HASH | The section header index of the symbol table to which the hash table applies. | 0 |
| SHT_REL<br>SHT_RELA | The section header index of the associated symbol table. | The section header index of the section to which the relocation applies. |
| SHT_SYMTAB<br>SHT_DYNSYM | This information is operating system specific. | This information is operating system specific. |
| other | `SHN_UNDEF` | 0 |

## Special Sections

Various sections in ELF are pre-defined and hold program and control information. These Sections are used by the operating system and have different types and attributes for different operating systems.

Executable files are created from individual object files and libraries through the linking process. The linker resolves the references (including subroutines and data references) among the different object files, adjusts the absolute references in the object files, and relocates instructions. The linking and loading processes, which are described in Chapter 2, require information defined in the object files and store this information in specific sections such as `.dynamic`.

Each operating system supports a set of linking models which fall into two categories:

`Static` A set of object files, system libraries and library archives are statically bound, references are resolved, and an executable file is created that is completely self contained.

`Dynamic` A set of object files, libraries, system shared resources and other shared libraries are linked together to create the executable. When this executable is loaded, other shared resources and dynamic libraries must be made available in the system for the program to run successfully.

The general method used to resolve references at execution time for a dynamically linked executable file is described in the linkage model used by the operating system, and the actual implementation of this linkage model will contain processor-specific components.

There are also sections that support debugging, such as `.debug` and `.line`, and program control, including`.bss`, `.data`, `.data1`, `.rodata`, and `.rodata1`.

**Figure 1-13. Special Sections**

| Name | Type | Attributes |
|---|---|---|
| .bss | SHT_NOBITS | SHF_ALLOC+SHF_WRITE |
| .comment | SHT_PROGBITS | none |
| .data | SHT_PROGBITS | SHF_ALLOC + SHF_WRITE |
| .data1 | SHT_PROGBITS | SHF_ALLOC + SHF_WRITE |
| .debug | SHT_PROGBITS | none |
| .dynamic | SHT_DYNAMIC | see below |
| .hash | SHT_HASH | SHF_ALLOC |
| .line | SHT_PROGBITS | none |
| .note | SHT_NOTE | none |
| .rodata | SHT_PROGBITS | SHF_ALLOC |
| .rodata1 | SHT_PROGBITS | SHF_ALLOC |
| .shstrtab | SHT_STRTAB | none |
| .strtab | SHT_STRTAB | see below |
| .symtab | SHT_SYMTAB | see below |
| .text | SHT_PROGBITS | SHF_ALLOC + SHF_EXECINSTR |

`.bss` This section holds uninitialized data that contribute to the program's memory image. By definition, the system initializes the data with zeros when the program begins to run. The section occupies no file space, as indicated by the section type, `SHT_NOBITS`.

`.comment` This section holds version control information.

`.data` and `.data1` These sections hold initialized data that contribute to the program's memory image.

`.debug` This section holds information for symbolic debugging. The contents are unspecified. All section names with the prefix `.debug` are reserved for future use.

`.dynamic` This section holds dynamic linking information and has attributes such as `SHF_ALLOC` and `SHF_WRITE`. Whether the `SHF_WRITE` bit is set is determined by the operating system and processor.

`.hash` This section holds a symbol hash table.

`.line` This section holds line number information for symbolic debugging, which describes the correspondence between the source program and the machine code. The contents are unspecified.

`.note` This section holds information in the format that is described in the "Note Section" in Chapter 2.

`.rodata` and `.rodata1` These sections hold read-only data that typically contribute to a non-writable segment in the process image. See "Program Header" in Chapter 2 for more information.

`.shstrtab` This section holds section names.

`.strtab` This section holds strings, most commonly the strings that represent the names associated with symbol table entries. If a file has a loadable segment that includes the symbol string table, the section's attributes will include the `SHF_ALLOC` bit; otherwise, that bit will be off.

`.symtab` This section holds a symbol table, as "Symbol Table" in this chapter describes. If a file has a loadable segment that includes the symbol table, the section's attributes will include the `SHF_ALLOC` bit; otherwise, that bit will be off.

`.text` This section holds the "text," or executable instructions, of a program.

Section names with a dot (`.`) prefix are reserved for the system, although applications may use these sections if their existing meanings are satisfactory. Applications may use names without the prefix to avoid conflicts with system sections. The object file format lets one define sections not in the list above. An object file may have more than one section with the same name.

## String Table

This section describes the default string table. String table sections hold null-terminated character sequences, commonly called strings. The object file uses these strings to represent symbol and section names. One references a string as an index into the string table section. The first byte, which is index zero, is defined to hold a null character. Likewise, a string table's last byte is defined to hold a null character, ensuring null termination for all strings. A string whose index is zero specifies either no name or a null name, depending on the context. An empty string table section is permitted; its section header's `sh_size` member would contain zero. Non-zero indexes are invalid for an empty string table.

A section header's `sh_name` member holds an index into the section header string table section, as designated by the `e_shstrndx` member of the ELF header. The following figures show a string table with 25 bytes and the strings associated with various indexes.

| **Index** | **+0** | **+1** | **+2** | **+3** | **+4** | **+5** | **+6** | **+7** | **+8** | **+9** |
|---|---|---|---|---|---|---|---|---|---|---|
| **0** | \0 | n | a | m | e | . | \0 | V | a | r |
| **10** | i | a | b | l | e | \0 | a | b | l | e |
| **20** | \0 | \0 | x | x | \0 | | | | | |

**Figure 1-14. String Table Indexes**

| **Index** | **String** |
|---|---|
| 0 | *none* |
| 1 | `name.` |
| 7 | `Variable` |
| 11 | `able` |
| 16 | `able` |
| 24 | *null string* |

As the example shows, a string table index may refer to any byte in the section. A string may appear more than once; references to substrings may exist; and a single string may be referenced multiple times. Unreferenced strings also are allowed.

## Symbol Table

An object file's symbol table holds information needed to locate and relocate a program's symbolic definitions and references.  A symbol table index is a subscript into this array. Index 0 both designates the first entry in the table and serves as the undefined symbol index. The contents of the initial entry are specified later in this section.

| Name | Value |
|---|---|
| STN_UNDEF | 0 |

A symbol table entry has the following format.

### Figure 1-15.  Symbol Table Entry

```
typedef struct {
          Elf32_Word    st_name;
          Elf32_Addr    st_value;
          Elf32_Word    st_size;
          unsigned char st_info;
          unsigned char st_other;
          Elf32_Half    st_shndx;
} Elf32_Sym;
```

`st_name` This member holds an index into the object file's symbol string table, which holds the character representations of the symbol names.

`st_value` This member gives the value of the associated symbol. Depending on the context, this may be an absolute value, an address, and so on; details appear below.

`st_size` Many symbols have associated sizes. For example, a data object's size is the number of bytes contained in the object. This member holds 0 if the symbol has no size or an unknown size.

`st_info` This member specifies the symbol's type and binding attributes. A list of the values and meanings appears below. The following code shows how to manipulate the values.

```
#define ELF32_ST_BIND(i)   ((i)>>4)
#define ELF32_ST_TYPE(i)   ((i)&0xf)
#define ELF32_ST_INFO(b,t) (((b)<<4)+((t)&0xf))
```

st_other This member currently holds 0 and has no defined meaning.

st_shndx Every symbol table entry is "defined" in relation to some section; this member holds the relevant section header table index. As Figure 1-7 and the related text describe, some section indexes indicate special meanings.

A symbol's binding determines the linkage visibility and behavior.

### Figure 1-16. Symbol Binding, ELF32_ST_BIND

| Name | Value |
|---|---|
| STB_LOCAL | 0 |
| STB_GLOBAL | 1 |
| STB_WEAK | 2 |
| STB_LOPROC | 13 |
| STB_HIPROC | 15 |

STB_LOCAL Local symbols are not visible outside the object file containing their definition. Local symbols of the same name may exist in multiple files without interfering with each other.

STB_GLOBAL Global symbols are visible to all object files being combined. One file's definition of a global symbol will satisfy another file's undefined reference to the same global symbol.

STB_WEAK Weak symbols resemble global symbols, but their definitions have lower precedence.

STB_LOPROC through STB_HIPROC Values in this inclusive range are reserved for processor-specific semantics.

In each symbol table, all symbols with STB_LOCAL binding precede the weak and global symbols. A symbol's type provides a general classification for the associated entity.

**Figure 1-17. Symbol Types,** `ELF32_ST_TYPE`

| Name | Value |
|---|---|
| STT_NOTYPE | 0 |
| STT_OBJECT | 1 |
| STT_FUNC | 2 |
| STT_SECTION | 3 |
| STT_FILE | 4 |
| STT_LOPROC | 13 |
| STT_HIPROC | 15 |

`STT_NOTYPE` The symbol's type is not specified.

`STT_OBJECT` The symbol is associated with a data object, such as a variable, an array, and so on.

`STT_FUNC` The symbol is associated with a function or other executable code.

`STT_SECTION` The symbol is associated with a section. Symbol table entries of this type exist primarily for relocation and normally have `STB_LOCAL` binding.

`STT_LOPROC` through `STT_HIPROC` Values in this inclusive range are reserved for processor-specific semantics. If a symbol's value refers to a specific location within a section, its section index member, `st_shndx`, holds an index into the section header table. As the section moves during relocation, the symbol's value changes as well, and references to the symbol continue to "point" to the same location in the program. Some special section index values give other semantics.

`STT_FILE` A file symbol has `STB_LOCAL` binding, its section index is `SHN_ABS`, and it precedes the other `STB_LOCAL` symbols for the file, if it is present.

The symbols in ELF object files convey specific information to the linker and loader. See the operating system sections for a description of the actual linking model used in the system.

`SHN_ABS` The symbol has an absolute value that will not change because of relocation.

`SHN_COMMON` The symbol labels a common block that has not yet been allocated. The symbol's value gives alignment constraints, similar to a section's `sh_addralign` member. That is, the link editor will allocate the storage for the symbol at an address that is a multiple of `st_value`. The symbol's size tells how many bytes are required.

`SHN_UNDEF` This section table index means the symbol is undefined. When the link editor combines this object file with another that defines the indicated symbol, this file's references to the symbol will be linked to the actual definition.

As mentioned above, the symbol table entry for index 0 (STN_UNDEF) is reserved; it holds the following.

**Figure 1-18. Symbol Table Entry: Index 0**

| Name | Value | Note |
|---|---|---|
| st_name | 0 | No name |
| st_value | 0 | Zero value |
| st_size | 0 | No size |
| st_info | 0 | No type, local binding |
| st_other | 0 | |
| st_shndx | SHN_UNDEF | No section |

## Symbol Values

Symbol table entries for different object file types have slightly different interpretations for the st_value member.

- In relocatable files, st_value holds alignment constraints for a symbol whose section index is SHN_COMMON.
- In relocatable files, st_value holds a section offset for a defined symbol. That is, st_value is an offset from the beginning of the section that st_shndx identifies.
- In executable and shared object files, st_value holds a virtual address. To make these files' symbols more useful for the dynamic linker, the section offset (file interpretation) gives way to a virtual address (memory interpretation) for which the section number is irrelevant.

Although the symbol table values have similar meanings for different object files, the data allow efficient access by the appropriate programs.

## Relocation

Relocation is the process of connecting symbolic references with symbolic definitions. For example, when a program calls a function, the associated call instruction must transfer control to the proper destination address at execution. In other words, relocatable files must have information that describes how to modify their section contents, thus allowing executable and shared object files to hold the right information for a process's program image. *Relocation entries* are these data.

**Figure 1-19. Relocation Entries**

```
typedef struct {
        Elf32_Addr    r_offset;
        Elf32_Word    r_info;
} Elf32_Rel;

typedef struct {
        Elf32_Addr    r_offset;
        Elf32_Word    r_info;
        Elf32_Sword   r_addend;
} Elf32_Rela;
```

`r_offset` This member gives the location at which to apply the relocation action. For a relocatable file, the value is the byte offset from the beginning of the section to the storage unit affected by the relocation. For an executable file or a shared object, the value is the virtual address of the storage unit affected by the relocation.

`r_info` This member gives both the symbol table index with respect to which the relocation must be made, and the type of relocation to apply. For example, a call instruction's relocation entry would hold the symbol table index of the function being called. If the index is `STN_UNDEF`, the undefined symbol index, the relocation uses 0 as the "symbol value." Relocation types are processor-specific; descriptions of their behavior appear in the processor supplement. When the text in the processor supplement refers to a relocation entry's relocation type or symbol table index, it means the result of applying `ELF32_R_TYPE` or `ELF32_R_SYM`, respectively, to the entry's `r_info` member.

```
#define ELF32_R_SYM(i)    ((i)>>8)
#define ELF32_R_TYPE(i)   ((unsigned char)(i))
#define ELF32_R_INFO(s,t) (((s)<<8)+(unsigned char)(t))
```

`r_addend` This member specifies a constant addend used to compute the value to be stored into the relocatable field.

As shown above, only Elf32_Rela entries contain an explicit addend. Entries of type Elf32_Rel store an implicit addend in the location to be modified. Depending on the processor architecture, one form or the other might be necessary or more convenient. Consequently, an implementation for a particular machine may use one form exclusively or either form depending on context.

A relocation section references two other sections: a symbol table and a section to modify. The section header's sh_info and sh_link members, described in "Sections" above, specify these relationships. Relocation entries for different object files have slightly different interpretations for the r_offset member.

- In relocatable files, r_offset holds a section offset. That is, the relocation section itself describes how to modify another section in the file; relocation offsets designate a storage unit within the second section.
- In executable and shared object files, r_offset holds a virtual address. To make these files' relocation entries more useful for the dynamic linker, the section offset (file interpretation) gives way to a virtual address (memory interpretation).

Although the interpretation of r_offset changes for different object files to allow efficient access by the relevant programs, the relocation types' meanings stay the same.

## Introduction

This chapter describes the object file information and system actions that create running programs. Executable and shared object files statically represent programs. To execute such programs, the system uses the files to create dynamic program representations, or process images. A process image has segments that hold its text, data, stack, and so on. This section describes the program header and complements Chapter 1, by describing object file structures that relate directly to program execution. The primary data structure, a program header table, locates segment images within the file and contains other information necessary to create the memory image for the program.

Given an object file, the system must load it into memory for the program to run. After the system loads the program, it must complete the process image by resolving symbolic references among the object files that compose the process.

## Program Header

An executable or shared object file's program header table is an array of structures, each describing a segment or other information the system needs to prepare the program for execution. An object file *segment* contains one or more *sections*. Program headers are meaningful only for executable and shared object files. A file specifies its own program header size with the ELF header's `e_phentsize` and *`e_phnum`* members [see "ELF Header" in Chapter 1].

**Figure 2-1. Program Header**

```
typedef struct {
          Elf32_Word    p_type;
          Elf32_Off     p_offset;
          Elf32_Addr    p_vaddr;
          Elf32_Addr    p_paddr;
          Elf32_Word    p_filesz;
          Elf32_Word    p_memsz;
          Elf32_Word    p_flags;
          Elf32_Word    p_align;
} Elf32_Phdr;
```

`p_type` This member tells what kind of segment this array element describes or how to interpret the array element's information. Type values and their meanings appear below.

`p_offset` This member gives the offset from the beginning of the file at which the first byte of the segment resides.

`p_vaddr` This member gives the virtual address at which the first byte of the segment resides in memory.

`p_paddr` On systems for which physical addressing is relevant, this member is reserved for the segment's physical address. This member requires operating system specific information, which is described in the appendix at the end of Book III.

`p_filesz` This member gives the number of bytes in the file image of the segment; it may be zero.

`p_memsz` This member gives the number of bytes in the memory image of the segment; it may be zero.

`p_flags` This member gives flags relevant to the segment. Defined flag values appear below.

`p_align` Loadable process segments must have congruent values for `p_vaddr` and `p_offset`, modulo the page size.This member gives the value to which the segments are aligned in memory and in the file. Values 0 and 1 mean that no alignment is required. Otherwise, `p_align` should be a positive, integral power of 2, and `p_addr` should equal `p_offset`, modulo `p_align`.

Some entries describe process segments; others give supplementary information and do not contribute to the process image.

**Figure 2-2. Segment Types,** `p_type`

| Name | Value |
|---|---:|
| PT_NULL | 0 |
| PT_LOAD | 1 |
| PT_DYNAMIC | 2 |
| PT_INTERP | 3 |
| PT_NOTE | 4 |
| PT_SHLIB | 5 |
| PT_PHDR | 6 |
| PT_LOPROC | 0x70000000 |
| PT_HIPROC | 0x7fffffff |

`PT_NULL` The array element is unused; other members' values are undefined. This type lets the program header table have ignored entries.

`PT_LOAD` The array element specifies a loadable segment, described by `p_filesz` and `p_memsz`. The bytes from the file are mapped to the beginning of the memory segment. If the segment's memory size (`p_memsz`) is larger than the file size (`p_filesz`), the "extra" bytes are defined to hold the value 0 and to follow the segment's initialized area. The file size may not be larger than the memory size. Loadable segment entries in the program header table appear in ascending order, sorted on the `p_vaddr` member.

`PT_DYNAMIC` The array element specifies dynamic linking information. See Book III.

`PT_INTERP` The array element specifies the location and size of a null-terminated path name to invoke as an interpreter. See Book III.

`PT_NOTE` The array element specifies the location and size of auxiliary information.

`PT_SHLIB` This segment type is reserved but has unspecified semantics. See Book III.

`PT_PHDR` The array element, if present, specifies the location and size of the program header table itself, both in the file and in the memory image of the program. This segment type may not occur more than once in a file. Moreover, it may occur only if the program header table is part of the memory image of the program. If it is present, it must precede any loadable segment entry. See "Program Interpreter" in the appendix at the end of Book III for further information.

PT_LOPROC through PT_HIPROC — Values in this inclusive range are reserved for processor-specific semantics.

---

*NOTE. Unless specifically required elsewhere, all program header segment types are optional.That is, a file's program header table may contain only those elements relevant to its contents.*

---

## Note Section

Sometimes a vendor or system builder needs to mark an object file with special information that other programs will check for conformance, compatibility, etc. Sections of type SHT_NOTE and program header elements of type PT_NOTE can be used for this purpose. The note information in sections and program header elements holds any number of entries, each of which is an array of 4-byte words in the format of the target processor. Labels appear below to help explain note information organization, but they are not part of the specification.

### Figure 2-3. Note Information

| |
|---|
| namesz |
| descsz |
| type |
| name<br>. . . |
| desc<br>. . . |

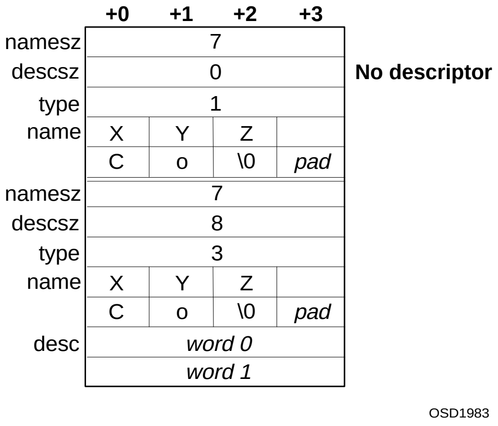
namesz and name — The first namesz bytes in name contain a null-terminated character representation of the entry's owner or originator. There is no formal mechanism for avoiding name conflicts. By convention, vendors use their own name, such as "XYZ Computer Company," as the identifier. If no name is present, namesz contains 0. Padding is present, if necessary, to ensure 4-byte alignment for the descriptor. Such padding is not included in namesz.

descsz and desc — The first descsz bytes in desc hold the note descriptor. ELF places no constraints on a descriptor's contents. If no descriptor is present, descsz contains 0. Padding is present, if necessary, to ensure 4-byte alignment for the next note entry. Such padding is not included in descsz.

type — This word gives the interpretation of the descriptor. Each originator controls its own types; multiple interpretations of a single type value may exist. Thus, a program must recognize both the name and the type to "understand" a descriptor. Types currently must be non-negative. ELF does not define what descriptors mean.

To illustrate, the following note segment holds two entries.

## Figure 2-4. Example Note Segment



NOTE. *The system reserves note information with no name (`namesz==0`) and with a zero-length name (`name[0]=='\0'`) but currently defines no types. All other names must have at least one non-null character.*

NOTE. *Note information is optional. The presence of note information does not affect a program's TIS conformance, provided the information does not affect the program's execution behavior. Otherwise, the program does not conform to the TIS ELF specification and has undefined behavior.*

## Program Loading

Program loading is the process by which the operating system creates or augments a process image. The manner in which this process is accomplished and how the page management functions for the process are handled are dictated by the operating system and processor. See the appendix at the end of Book III for more details.

## Dynamic Linking

The dynamic linking process resolves references either at process initialization time and/or at execution time. Some basic mechanisms need to be set up for a particular linkage model to work, and there are ELF sections and header elements reserved for this purpose. The actual definition of the linkage model is determined by the operating system and implementation. Therefore, the contents of these sections are both operating system and processor specific. (See the appendix at the end of Book III.)

## Introduction

This appendix lists the operating system and processor specific reserved names, as well as historical names and pre-existing naming conventions.

## Special Sections Names

Various sections hold program and control information. Sections in the list below are specified in Book I and Book III.

### Figure A-1. Special Sections

| Name |
|---|
| .bss |
| .comment |
| .data |
| .data1 |
| .debug |
| .dynamic |
| .dynstr |
| .dynsym |
| .fini |
| .got |
| .hash |
| .init |
| .interp |
| .line |
| .note |
| .plt |
| .rel*name* |
| .rela*name* |
| .rodata |
| .rodata1 |
| .shstrtab |
| .strtab |
| .symtab |
| .text |

## Dynamic Section Names

_DYNAMIC

**Figure A-2. Dynamic Array Tags, `d_tag`**

| Name |
|---|
| DT_NULL |
| DT_NEEDED |
| DT_PLTRELSZ |
| DT_PLTGOT |
| DT_HASH |
| DT_STRTAB |
| DT_SYMTAB |
| DT_RELA |
| DT_RELASZ |
| DT_RELAENT |
| DT_STRSZ |
| DT_SYMENT |
| DT_INIT |
| DT_FINI |
| DT_SONAME |
| DT_RPATH |
| DT_SYMBOLIC |
| DT_REL |
| DT_RELSZ |
| DT_RELENT |
| DT_PLTREL |
| DT_DEBUG |
| DT_TEXTREL |
| DT_JMPREL |
| DT_BIND_NOW |
| DT_LOPROC |
| DT_HIPROC |

## Pre-existing Extensions

There are naming conventions for ELF constants that have processor ranges specified. Names such as `DT_`, `PT_`, for processor specific extensions, incorporate the name of the processor: `DT_M32_SPECIAL`, for example. However, pre-existing processor extensions not using this convention will be supported.

Pre-existing Extensions

`DT_JMP_REL`

Section names reserved for a processor architecture are formed by placing an abbreviation of the architecture name ahead of the section name.  The name should be taken from the architecture names used for `e_machine`.  For instance `.FOO.psect` is the `psect` section defined by the FOO architecture. Existing extensions are called by their historical names.

Pre-existing Extensions

.

`.sdata`
`.sbss`
`.lit8`
`.gptab`
`.conflict`
`.tdesc`
`.lit4`
`.reginfo`
`.liblist`

# Book II:
# Processor Specific
# (Intel Architecture)

# Contents

# Figures

## Introduction

This section describes the Intel Architecture specific information necessary to comply with the ELF object file format. This information is independent of operating system type. Further information on Intel platforms that is both Intel Architecture and operating system dependent, is described in Book III.

# ELF Header

## Machine Information

For file identification in e_ident, the Intel architecture requires the following values.

**Figure 1-1. Intel Identification,** e_ident

| Position | Value |
|---|---|
| e_ident[EI_CLASS] | ELFCLASS32 |
| e_ident[EI_DATA] | ELFDATA2LSB |

Processor identification resides in the ELF header's e_machine member and must have the value EM_386.

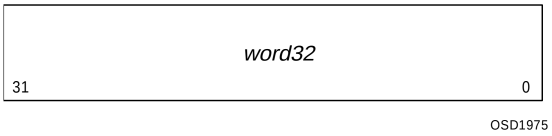
The ELF header's e_flags member holds bit flags associated with the file. The Intel architecture defines no flags; so this member contains zero.

# Relocation

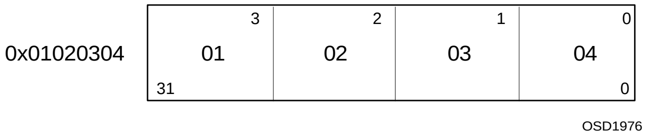
## Relocation Types

Relocation entries describe how to alter the following instruction and data fields (bit numbers appear in the lower box corners).

### Figure 1-2.  Relocatable Fields



*word32* This specifies a 32-bit field occupying 4 bytes with arbitrary byte alignment. These values use the same byte order as other word values in the Intel architecture.



Calculations below assume the actions are transforming a relocatable file into either an executable or a shared object file.  Conceptually, the link editor merges one or more relocatable files to form the output.  It first decides how to combine and locate the input files, then updates the symbol values, and finally performs the relocation.  Relocations applied to executable or shared object files are similar and accomplish the same result.  Descriptions below use the following notation.

A This means the addend used to compute the value of the relocatable field.

P This means the place (section offset or address) of the storage unit being relocated (computed using `r_offset`.

S This means the value of the symbol whose index resides in the relocation entry.

A relocation entry's `r_offset` value designates the offset or virtual address of the first byte of the affected storage unit. The relocation type specifies which bits to change and how to calculate their values. The  Intel architecture uses only `Elf32_Rel` relocation entries, the field to be relocated holds the addend.  In all cases, the addend and the computed result use the same byte order.

### Figure 1-3. Relocation Types

| Name | Value | Field | Calculation |
|---|---|---|---|
| `R_386_NONE` | 0 | none | none |
| `R_386_32` | 1 | word32 | `S+A` |
| `R_386_PC32` | 2 | word32 | `S+A-P` |

*NOTE. Relocation types 3 through 10 are reserved. (See Book III, Appendix A.)*

# Book III:
# Operating System Specific
# (UNIX System V Release 4)

# Contents

# Figures

## Figures

## Introduction

This book describes aspects of the ELF format that are specific to application programs designed to run on UNIX System V Release 4 or other operating systems that comply with the System V Interface Definition.

*NOTE. For information on references such as BA_OS, refer to the System V Interface Definition, 3rd Edition.*

## Sections

The following sections are UNIX System V Release 4 specific:

SHT_SYMTAB and SHT_DYNSYM
These sections hold a symbol table. Currently, an object file may have only one section of each type, but this restriction may be relaxed in the future. Typically, SHT_SYMTAB provides symbols for link editing, though it may also be used for dynamic linking. As a complete symbol table, it may contain many symbols unnecessary for dynamic linking. Consequently, an object file may also contain a SHT_DYNSYM section, which holds a minimal set of dynamic linking symbols, to save space. See "Symbol Table" descriptions in Book I for details.

SHT_STRTAB
An object file may have multiple string table sections. See "String Table" in Book I for details.

SHT_HASH
All objects participating in dynamic linking must contain a symbol hash table. Currently, an object file may have only one hash table, but this restriction may be relaxed in the future. See "Hash Table" in Chapter 2 for details.

SHT_DYNAMIC
Currently, an object file may have only one dynamic section, but this restriction may be relaxed in the future. See "Dynamic Section" in Chapter 2 for details.

Two members in the section header, sh_link and sh_info, hold special information, depending on section type. A symbol table section's sh_info section header member holds the symbol table index for the first non-local symbol.

.

**Figure 1-1.** sh_link **and** sh_info **Interpretation**

| sh_type | sh_link | sh_info |
|---|---|---|
| SHT_SYMTAB<br>SHT_DYNSYM | The section header index of the associated string table. | One greater than the symbol table index of the last local symbol (binding STB_LOCAL). |

### Special Sections

The following sections hold program and control information used in UNIX System V Release 4. The sections in the list below are used by the system and have the indicated types and attributes. Most of these sections are required for the linking process. The information for dynamic linking is provided in the .dynsym, .dynstr, .interp, .hash, .dynamic, .rel, .rela, .got and .plt sections. The actual contents of some of these sections (.plt and .got, for example) are processor specific, but they all support the same linkage model.

The .init and .fini sections contribute to the process initialization and termination code.

**Figure 1-2. Special Sections**

| Name | Type | Attributes |
|---|---|---|
| .dynstr | SHT_STRTAB | SHF_ALLOC |
| .dynsym | SHT_DYNSYM | SHF_ALLOC |
| .fini | SHT_PROGBITS | SHF_ALLOC + SHF_EXECINSTR |
| .init | SHT_PROGBITS | SHF_ALLOC + SHF_EXECINSTR |
| .interp | SHT_PROGBITS | see below |
| .rel*name* | SHT_REL | see below |
| .rela*name* | SHT_RELA | see below |

.dynstr — This section holds strings needed for dynamic linking, most commonly the strings that represent the names associated with symbol table entries. See Chapter 2 for more information.

.dynsym — This section holds the dynamic linking symbol table, as "Symbol Table" describes. See Chapter 2 for more information.

.fini — This section holds executable instructions that contribute to the process termination code. When a program exits normally, the system executes the code in this section.

.init — This section holds executable instructions that contribute to the process initialization code. When a program starts to run, the system executes the code in this section before calling the main program entry point (called main for C programs).

.interp — This section holds the path name of a program interpreter. If the file has a loadable segment that includes the section, the section's attributes will include the SHF_ALLOC bit; otherwise, that bit will be off. See Chapter 2 for more information.

`.rel`*`name`* and `.rela`*`name`*

These sections hold relocation information, as "Relocation" below describes. If the file has a loadable segment that includes relocation, the sections' attributes will include the `SHF_ALLOC` bit; otherwise, that bit will be off. Conventionally, *`name`* is supplied by the section to which the relocations apply. Thus a relocation section for `.text` normally would have the name `.rel.text` or `.rela.text`.

st_name If the value is non-zero, it represents a string table index that gives the symbol name. Otherwise, the symbol table entry has no name.

*NOTE. External C symbols have the same names in C and object files' symbol tables.*

Function symbols (those with type STT_FUNC) in shared object files have special significance. When another object file references a function from a shared object, the link editor automatically creates a procedure linkage table entry for the referenced symbol. Shared object symbols with types other than STT_FUNC will not be referenced automatically through the procedure linkage table. See "Symbol Table" descriptions in Book I and "Function Addresses" in the appendix at the end of this book for details.

Global and weak symbols differ in two major ways.

- When the link editor combines several relocatable object files, it does not allow multiple definitions of STB_GLOBAL symbols with the same name. On the other hand, if a defined global symbol exists, the appearance of a weak symbol with the same name will not cause an error. The link editor honors the global definition and ignores the weak ones. Similarly, if a common symbol exists (that is, a symbol whose st_shndx field holds SHN_COMMON), the appearance of a weak symbol with the same name will not cause an error. The link editor honors the common definition and ignores the weak ones.
- When the link editor searches archive libraries, it extracts archive members that contain definitions of undefined global symbols. The member's definition may be either a global or a weak symbol. The link editor does *not* extract archive members to resolve undefined weak symbols. Unresolved weak symbols have a zero value.

## Introduction

This section describes the operating system specific information, including the object file information and system actions used to create running programs on systems running the UNIX System V Release 4 operating system.

## Program Header

The following program header information is specific to UNIX System V Release 4.

`p_paddr` On systems for which physical addressing is relevant, this member is reserved for the segment's physical address. Because System V ignores physical addressing for application programs, this member has unspecified contents for executable files and shared objects.

`p_align` Loadable process segments must have congruent values for `p_vaddr` and `p_offset`, modulo the page size.

Some entries describe process segments; others give supplementary information and do not contribute to the process image. Segment entries may appear in any order, except as explicitly noted below. Defined type values follow; other values are reserved for future use.

**Figure 2-1. Segment Types,** `p_type`

| Name | Value |
|---|---:|
| PT_NULL | 0 |
| PT_LOAD | 1 |
| PT_DYNAMIC | 2 |
| PT_INTERP | 3 |
| PT_NOTE | 4 |
| PT_SHLIB | 5 |
| PT_PHDR | 6 |
| PT_LOPROC | 0x70000000 |
| PT_HIPROC | 0x7fffffff |

`PT_LOAD` The array element specifies a loadable segment, described by `p_filesz` and `p_memsz`.

`PT_DYNAMIC` The array element specifies dynamic linking information. See "Dynamic Section" below for more information.

`PT_INTERP` The array element specifies the location and size of a null-terminated path name to invoke as an interpreter. This segment type is meaningful only for executable files (though it may occur for shared objects); it may not occur more than once in a file. If it is present, it must precede any loadable segment entry. See "Program Interpreter" below for further information.

`PT_SHLIB` This segment type is reserved but has unspecified semantics. Programs that contain an array element of this type do not conform to the ELF specification for UNIX System V.

PT_PHDR The array element, if present, specifies the location and size of the program header table itself, both in the file and in the memory image of the program.

## Base Address

The virtual addresses in the program headers might not represent the actual virtual addresses of the program's memory image. Executable files typically contain absolute code. To let the process execute correctly, the segments must reside at the virtual addresses used to build the executable file. On the other hand, shared object segments typically contain position-independent code. This lets a segment's virtual address change from one process to another, without invalidating execution behavior. Though the system chooses virtual addresses for individual processes, it maintains the segments' *relative positions*. Because position-independent code uses relative addressing between segments, the difference between virtual addresses in memory must match the difference between virtual addresses in the file. The difference between the virtual address of any segment in memory and the corresponding virtual address in the file is thus a single constant value for any one executable or shared object in a given process. This difference is the *base address*. One use of the base address is to relocate the memory image of the program during dynamic linking.

An executable or shared object file's base address is calculated during execution from three values: the virtual memory load address, the maximum page size, and the lowest virtual address of a program's loadable segment. To compute the base address, one determines the memory address associated with the lowest p_vaddr value for a PT_LOAD segment. This address is truncated to the nearest multiple of the maximum page size. The corresponding p_vaddr value itself is also truncated to the nearest multiple of the maximum page size. The base address is the difference between the truncated memory address and the truncated p_vaddr value.

## Segment Permissions

A program to be loaded by the system must have at least one loadable segment (although this is not required by the file format). When the system creates loadable segments' memory images, it gives access permissions as specified in the p_flags member.

**Figure 2-2. Segment Flag Bits,** p_flags

| Name | Value | Meaning |
|---|---:|---|
| PF_X | 0x1 | Execute |
| PF_W | 0x2 | Write |
| PF_R | 0x4 | Read |
| PF_MASKPROC | 0xf0000000 | Unspecified |

All bits included in the PF_MASKPROC mask are reserved for processor-specific semantics. If meanings are specified, the processor supplement explains them.

If a permission bit is 0, that type of access is denied. Actual memory permissions depend on the memory management unit, which may vary from one system to another. Although all flag combinations are valid, the system may grant more access than requested. In no case, however, will a segment have write permission unless it is specified explicitly. The following table shows both the exact flag interpretation and the allowable flag interpretation. TIS-conforming systems may provide either.

**Figure 2-3. Segment Permissions**

| Flag | Value | Exact | Allowable |
|---|---|---|---|
| none | `0` | All access denied | All access denied |
| `PF_X` | `1` | Execute only | Read, execute |
| `PF_W` | `2` | Write only | Read, write, execute |
| `PF_W + PF_X` | `3` | Write, execute | Read, write, execute |
| `PF_R` | `4` | Read only | Read, execute |
| `PF_R + PF_X` | `5` | Read, execute | Read, execute |
| `PF_R + PF_W` | `6` | Read, write | Read, write, execute |
| `PF_R + PF_W + PF_X` | `7` | Read, write, execute | Read, write, execute |

For example, typical text segments have read and execute —but not write —permissions. Data segments normally have read, write, and execute permissions.

## Segment Contents

An object file segment comprises one or more sections, though this fact is transparent to the program header. Whether the file segment holds one or many sections also is immaterial to program loading. Nonetheless, various data must be present for program execution, dynamic linking, and so on. The diagrams below illustrate segment contents in general terms. The order and membership of sections within a segment may vary; moreover, processor-specific constraints may alter the examples below.

Text segments contain read-only instructions and data, typically including the following sections. Other sections may also reside in loadable segments; these examples are not meant to give complete and exclusive segment contents.

**Figure 2-4. Text Segment**

| |
|---|
| `.text` |
| `.rodata` |
| `.hash` |
| `.dynsym` |
| `.dynstr` |
| `.plt` |
| `.rel.got` |

Data segments contain writable data and instructions, typically including the following sections.

**Figure 2-5. Data Segment**

| |
|---|
| `.data` |
| `.dynamic` |
| `.got` |
| `.bss` |

A `PT_DYNAMIC` program header element points at the `.dynamic` section, explained in "Dynamic Section" below. The `.got` and `.plt` sections also hold information related to position-independent code and dynamic linking. Although the `.plt` appears in a text segment above, it may reside in a text or a data segment, depending on the processor.

As "Sections" describes, the `.bss` section has the type `SHT_NOBITS`. Although it occupies no space in the file, it contributes to the segment's memory image. Normally, these uninitialized data reside at the end of the segment, thereby making `p_memsz` larger than `p_filesz`.

## Dynamic Linking

### Program Interpreter

An executable file that participates in dynamic linking shall have one `PT_INTERP` program header element. During exec (BA_OS), the system retrieves a path name from the `PT_INTERP` segment and creates the initial process image from the interpreter file's segments. That is, instead of using the original executable file's segment images, the system composes a memory image for the interpreter. It then is the interpreter's responsibility to receive control from the system and provide an environment for the application program.

The interpreter receives control in one of two ways. First, it may receive a file descriptor to read the executable file, positioned at the beginning. It can use this file descriptor to read and/or map the executable file's segments into memory. Second, depending on the executable file format, the system may load the executable file into memory instead of giving the interpreter an open file descriptor. With the possible exception of the file descriptor, the interpreter's initial process state matches what the executable file would have received. The interpreter itself may not require a second interpreter. An interpreter may be either a shared object or an executable file.

- A shared object (the normal case) is loaded as position-independent, with addresses that may vary from one process to another; the system creates its segments in the dynamic segment area used by `mmap` (KE_OS) and related services. Consequently, a shared object interpreter typically will not conflict with the original executable file's original segment addresses.
- An executable file is loaded at fixed addresses; the system creates its segments using the virtual addresses from the program header table. Consequently, an executable file interpreter's virtual addresses may collide with the first executable file; the interpreter is responsible for resolving conflicts.

### Dynamic Linker

When building an executable file that uses dynamic linking, the link editor adds a program header element of type `PT_INTERP` to an executable file, telling the system to invoke the dynamic linker as the program interpreter.

*NOTE. The locations of the system provided dynamic linkers are processor—specific.*

The executable file and the dynamic linker cooperate to create the process image for the program, which entails the following actions:

- Adding the executable file's memory segments to the process image;
- Adding shared object memory segments to the process image;
- Performing relocations for the executable file and its shared objects;
- Closing the file descriptor that was used to read the executable file, if one was given to the dynamic linker;
- Transferring control to the program, making it look as if the program had received control directly from the executable file.

The link editor also constructs various data that assist the dynamic linker for executable and shared object files. As shown above in "Program Header," these data reside in loadable segments, making them available during execution. (Note that the exact segment contents are processor-specific.)

- A `.dynamic` section with type `SHT_DYNAMIC` holds various data. The structure residing at the beginning of the section holds the addresses of other dynamic linking information.
- The `.hash` section with type `SHT_HASH` holds a symbol hash table.
- The `.got` and `.plt` sections with type `SHT_PROGBITS` hold two separate tables: the global offset table and the procedure linkage table. Programs use the global offset table for position-independent code. Sections below explain how the dynamic linker uses and changes the tables to create memory images for object files.

Because every UNIX System V conforming program imports the basic system services from a shared object library, the dynamic linker participates in every TIS ELF-conforming program execution.

As "Program Loading" explains in the appendix at the end of this book, shared objects may occupy virtual memory addresses that are different from the addresses recorded in the file's program header table. The dynamic linker relocates the memory image, updating absolute addresses before the application gains control. Although the absolute address values would be correct if the library were loaded at the addresses specified in the program header table, this normally is not the case.

If the process environment contains a variable named `LD_BIND_NOW` with a non-null value, the dynamic linker processes all relocation before transferring control to the program.. For example, all the following environment entries would specify this behavior.

- `LD_BIND_NOW=1`
- `LD_BIND_NOW=on`
- `LD_BIND_NOW=off`

Otherwise, `LD_BIND_NOW` either does not occur in the environment or has a null value. The dynamic linker is permitted to evaluate procedure linkage table entries lazily, thus avoiding symbol resolution and relocation overhead for functions that are not called.

## Dynamic Section

If an object file participates in dynamic linking, its program header table will have an element of type PT_DYNAMIC. This "segment" contains the .dynamic section.  A special symbol, _DYNAMIC, labels the section, which contains an array of the following structures.

### Figure 2-6.  Dynamic Structure

```
typedef struct {
          Elf32_Sword   d_tag;
          union {
                 Elf32_Word    d_val;
                 Elf32_Addr    d_ptr;
          } d_un;
} Elf32_Dyn;
extern Elf32_Dyn _DYNAMIC[];
```

For each object with this type, d_tag controls the interpretation of d_un.

d_val These Elf32_Word objects represent integer values with various interpretations.

d_ptr These Elf32_Addr objects represent program virtual addresses. As mentioned previously, a file's virtual addresses might not match the memory virtual addresses during execution. When interpreting addresses contained in the dynamic structure, the dynamic linker computes actual addresses, based on the original file value and the memory base address.  For consistency, files do *not* contain relocation entries to "correct" addresses in the dynamic structure.

The following table summarizes the tag requirements for executable and shared object files. If a tag is marked "mandatory," then the dynamic linking array for a TIS ELF conforming file must have an entry of that type. Likewise, "optional" means an entry for the tag may appear but is not required.

**Figure 2-7. Dynamic Array Tags,** `d_tag`

| Name | Value | d_un | Executable | Shared Object |
|---|---|---|---|---|
| DT_NULL | 0 | ignored | mandatory | mandatory |
| DT_NEEDED | 1 | d_val | optional | optional |
| DT_PLTRELSZ | 2 | d_val | optional | optional |
| DT_PLTGOT | 3 | d_ptr | optional | optional |
| DT_HASH | 4 | d_ptr | mandatory | mandatory |
| DT_STRTAB | 5 | d_ptr | mandatory | mandatory |
| DT_SYMTAB | 6 | d_ptr | mandatory | mandatory |
| DT_RELA | 7 | d_ptr | mandatory | optional |
| DT_RELASZ | 8 | d_val | mandatory | optional |
| DT_RELAENT | 9 | d_val | mandatory | optional |
| DT_STRSZ | 10 | d_val | mandatory | mandatory |
| DT_SYMENT | 11 | d_val | mandatory | mandatory |
| DT_INIT | 12 | d_ptr | optional | optional |
| DT_FINI | 13 | d_ptr | optional | optional |
| DT_SONAME | 14 | d_val | ignored | optional |
| DT_RPATH | 15 | d_val | optional | ignored |
| DT_SYMBOLIC | 16 | ignored | ignored | optional |
| DT_REL | 17 | d_ptr | mandatory | optional |
| DT_RELSZ | 18 | d_val | mandatory | optional |
| DT_RELENT | 19 | d_val | mandatory | optional |
| DT_PLTREL | 20 | d_val | optional | optional |
| DT_DEBUG | 21 | d_ptr | optional | ignored |
| DT_TEXTREL | 22 | ignored | optional | optional |
| DT_JMPREL | 23 | d_ptr | optional | optional |
| DT_BIND_NOW | 24 | ignored | optional | optional |
| DT_LOPROC | 0x70000000 | unspecified | unspecified | unspecified |
| DT_HIPROC | 0x7fffffff | unspecified | unspecified | unspecified |

DT_NULL An entry with a DT_NULL tag marks the end of the _DYNAMIC array.

DT_NEEDED This element holds the string table offset of a null-terminated string, giving the name of a needed library. The offset is an index into the table recorded in the DT_STRTAB entry. See "Shared Object Dependencies" for more information about these names. The dynamic array may contain multiple entries with this type. These entries' relative order is significant, though their relation to entries of other types is not.

DT_PLTRELSZ This element holds the total size, in bytes, of the relocation entries associated with the procedure linkage table. If an entry of type DT_JMPREL is present, a DT_PLTRELSZ must accompany it.

DT_PLTGOT This element holds an address associated with the procedure linkage table and/or the global offset table.

DT_HASH This element holds the address of the symbol hash table, described in "Hash Table". This hash table refers to the symbol table referenced by the DT_SYMTAB element.

DT_STRTAB This element holds the address of the string table, described in Chapter 1. Symbol names, library names, and other strings reside in this table.

DT_SYMTAB This element holds the address of the symbol table, described in Chapter 1, with Elf32_Sym entries for the 32-bit class of files.

DT_RELA This element holds the address of a relocation table, described in Chapter 1. Entries in the table have explicit addends, such as Elf32_Rela for the 32-bit file class. An object file may have multiple relocation sections. When building the relocation table for an executable or shared object file, the link editor catenates those sections to form a single table. Although the sections remain independent in the object file, the dynamic linker sees a single table. When the dynamic linker creates the process image for an executable file or adds a shared object to the process image, it reads the relocation table and performs the associated actions. If this element is present, the dynamic structure must also have DT_RELASZ and DT_RELAENT elements. When relocation is "mandatory" for a file, either DT_RELA or DT_REL may occur (both are permitted but not required).

DT_RELASZ This element holds the total size, in bytes, of the DT_RELA relocation table.

DT_RELAENT This element holds the size, in bytes, of the DT_RELA relocation entry.

DT_STRSZ This element holds the size, in bytes, of the string table.

DT_SYMENT This element holds the size, in bytes, of a symbol table entry.

DT_INIT This element holds the address of the initialization function, discussed in "Initialization and Termination Functions" below.

DT_FINI This element holds the address of the termination function, discussed in "Initialization and Termination Functions" below.

DT_SONAME This element holds the string table offset of a null-terminated string, giving the name of the shared object. The offset is an index into the table recorded in the DT_STRTAB entry. See "Shared Object Dependencies" below for more information about these names.

DT_RPATH This element holds the string table offset of a null-terminated search library search path string, discussed in "Shared Object Dependencies". The offset is an index into the table recorded in the DT_STRTAB entry.

DT_SYMBOLIC This element's presence in a shared object library alters the dynamic linker's symbol resolution algorithm for references within the library. Instead of starting a symbol search with the executable file, the dynamic linker starts from the shared object itself. If the shared object fails to supply the referenced symbol, the dynamic linker then searches the executable file and other shared objects as usual.

DT_REL This element is similar to DT_RELA, except its table has implicit addends, such as Elf32_Rel for the 32-bit file class. If this element is present, the dynamic structure must also have DT_RELSZ and DT_RELENT elements.

DT_RELSZ This element holds the total size, in bytes, of the DT_REL relocation table.

DT_RELENT This element holds the size, in bytes, of the DT_REL relocation entry.

DT_PLTREL This member specifies the type of relocation entry to which the procedure linkage table refers. The d_val member holds DT_REL or DT_RELA, as appropriate. All relocations in a procedure linkage table must use the same relocation.

DT_DEBUG This member is used for debugging. Its contents are not specified in this document.

DT_TEXTREL This member's absence signifies that no relocation entry should cause a modification to a non-writable segment, as specified by the segment permissions in the program header table. If this member is present, one or more relocation entries might request modifications to a non-writable segment, and the dynamic linker can prepare accordingly.

DT_JMPREL If present, this entries d_ptr member holds the address of relocation entries associated solely with the procedure linkage table. Separating these relocation entries lets the dynamic linker ignore them during process initialization, if lazy binding is enabled. If this entry is present, the related entries of types DT_PLTRELSZ and DT_PLTREL must also be present.

DT_BIND_NOW If present in a shared object or executable, this entry instructs the dynamic linker to process all relocations for the object containing this entry before transferring control to the program. The presence of this entry takes precedence over a directive to use lazy binding for this object when specified through the environment or via dlopen(BA_LIB).

DT_LOPROC through DT_HIPROC

Values in this inclusive range are reserved for processor-specific semantics. If meanings are specified, the processor supplement explains them.

Except for the DT_NULL element at the end of the array, and the relative order of DT_NEEDED elements, entries may appear in any order. Tag values not appearing in the table are reserved.

## Shared Object Dependencies

When the link editor processes an archive library, it extracts library members and copies them into the output object file. These statically linked services are available during execution without involving the dynamic linker. Shared objects also provide services, and the dynamic linker must attach the proper shared object files to the process image for execution. Thus executable and shared object files describe their specific dependencies.

When the dynamic linker creates the memory segments for an object file, the dependencies (recorded in DT_NEEDED entries of the dynamic structure) tell what shared objects are needed to supply the program's services. By repeatedly connecting referenced shared objects and their dependencies, the dynamic linker builds a complete process image. When resolving symbolic references, the dynamic linker examines the symbol tables with a breadth-first search. That is, it first looks at the symbol table of the executable program itself, then at the symbol tables of the DT_NEEDED entries (in order), then at the second level DT_NEEDED entries, and so on. Shared object files must be readable by the process; other permissions are not required.

*NOTE. Even when a shared object is referenced multiple times in the dependency list, the dynamic linker will connect the object only once to the process.*

Names in the dependency list are copies either of the DT_SONAME strings or the path names of the shared objects used to build the object file. For example, if the link editor builds an executable file using one shared object with a DT_SONAME entry of lib1 and another shared object library with the path name /usr/lib/lib2, the executable file will contain lib1 and /usr/lib/lib2 in its dependency list.

If a shared object name has one or more slash (/) characters anywhere in the name, such as /usr/lib/lib2 above or directory/file, the dynamic linker uses that string directly as the path name. If the name has no slashes, such as lib1 above, three facilities specify shared object path searching, with the following precedence.

- First, the dynamic array tag DT_RPATH may give a string that holds a list of directories, separated by colons (:). For example, the string /home/dir/lib:/home/dir2/lib: tells the dynamic linker to search first the directory /home/dir/lib, then /home/dir2/lib, and then the current directory to find dependencies.
- Second, a variable called LD_LIBRARY_PATH in the process environment [see exec(BA_OS)] may hold a list of directories as above, optionally followed by a semicolon (;) and another directory list. The following values would be equivalent to the previous example:
  - LD_LIBRARY_PATH=/home/dir/lib:/home/dir2/lib:
  - LD_LIBRARY_PATH=/home/dir/lib;/home/dir2/lib:
  - LD_LIBRARY_PATH=/home/dir/lib:/home/dir2/lib:;

All LD_LIBRARY_PATH directories are searched after those from DT_RPATH. Although some programs (such as the link editor) treat the lists before and after the semicolon differently, the dynamic linker does not. Nevertheless, the dynamic linker accepts the semicolon notation, with the semantics described above.

- Finally, if the other two groups of directories fail to locate the desired library, the dynamic linker searches /usr/lib.

---

NOTE. *For security, the dynamic linker ignores environmental search specifications (such as* LD_LIBRARY_PATH*) for set-user and set-group ID programs. It does, however, search* DT_RPATH *directories and* /usr/lib*. The same restriction may be applied to processes that have more then minimal privileges on systems with installed extended security systems.*

---

## Global Offset Table

The Global Offset Table holds the absolute addresses in private data. This makes it possible to have the addresses available without compromising the position-independence and sharability of program text. This table is essential in the System V environment for the dynamic linking process to work. The actual contents and form of this table depend upon the processor, and are described in the appendix at the end of this book.

## Procedure Linkage Table

Similar to how the global offset table redirects position-independent address calculations to absolute locations, the procedure linkage table redirects position-independent function calls to absolute locations. The link editor cannot resolve execution transfers, such as function calls, from one executable or shared object to another. Consequently, the link editor arranges to have the program transfer control to entries in the procedure linkage table. The actual contents, layout and location of the procedure linkage table is determined by the processor and are described in the appendix at the end of this book.

## Hash Table

A hash table of Elf32_Word objects supports symbol table access. Labels appear below to help explain the hash table organization, but they are not part of the specification.

### Figure 2-8. Symbol Hash Table

| |
|---|
| nbucket |
| nchain |
| bucket[0]<br>. . .<br>bucket[nbucket-1] |
| chain[0]<br>. . .<br>chain[nchain-1] |

The bucket array contains nbucket entries, and the chain array contains nchain entries; indexes start at 0. Both bucket and chain hold symbol table indexes. Chain table entries parallel the symbol table. The number of symbol table entries should equal nchain; so symbol table indexes also select chain table entries. A hashing function (shown below) accepts a symbol name and returns a value that may be used to computea bucket index. Consequently, if the hashing function returns the value x for some name, bucket[x%nbucket] gives an index, y, into both the symbol table and the chain table. If the symbol table entry is not the one desired, chain[y] gives the next symbol table entry with the same hash value. One can follow the chain links until either the selected symbol table entry holds the desired name or the chain entry contains the value STN_UNDEF.

### Figure 2-9. Hashing Function

```
unsigned long
elf_hash(const unsigned char *name)
{
          unsigned long h = 0, g;
          while (*name)
          {
                 h = (h << 4) + *name++;
                 if (g = h & 0xf0000000)
                        h ^= g >> 24;
                 h &= ~g;
          }
          return h;
}
```

## Initialization and Termination Functions

After the dynamic linker has built the process image and performed the relocations, each shared object gets the opportunity to execute some initialization code. All shared object initializations happen before the executable file gains control.

Before the initialization code for any object A is called, the initialization code for any other objects that object A depends on are called. For these purposes, an object A depends on another object B, if B appears in A’s list of needed objects (recorded in the DT_NEEDED entries of the dynamic structure). The order of initialization for circular dependencies is undefined.

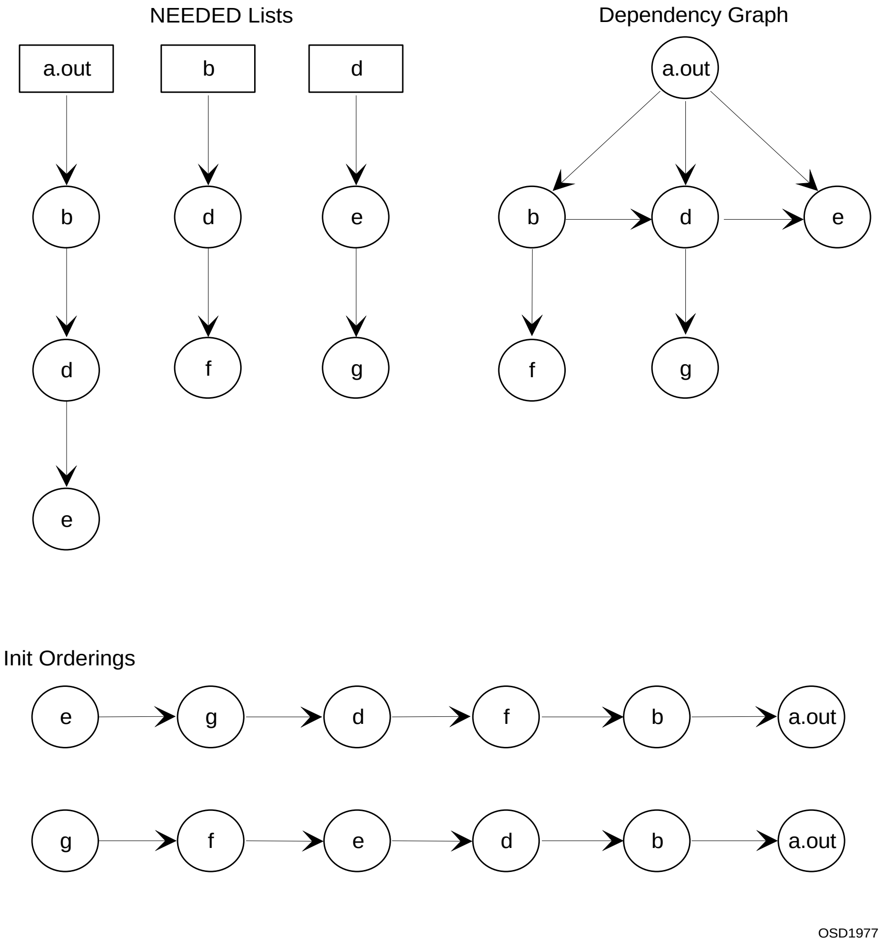
The initialization of objects occurs by recursing through the needed entries of each object. The initialization code for an object is invoked after the needed entries for that object have been processed. The order of processing among the entries of a particular list of needed objects is unspecified

*NOTE. Each processor supplement may optionally further restrict the algorithm used to determine the order of initialization. Any such restriction, however, may not conflict with the rules described by this specification.*

The following example illustrates two of the possible correct orderings which can be generated for the example NEEDED lists. In this example the a.out is dependent on b, d, and e. b is dependent on d and f, while d is dependent on e and g. From this information, a dependency graph can be drawn. The above algorithm on initialization will then allow the following specified initialization orderings among others.

.

## Figure 2-10. Initialization Ordering Example



Similarly, shared objects may have termination functions, which are executed with the `atexit`(BA_OS) mechanism after the base process begins its termination sequence. The order in which the dynamic linker calls termination functions is the exact reverse order of their corresponding initialization functions. If a shared object has a termination function, but no initialization function, the termination function will execute in the order it would have as if the shared object's initialization function was present. The dynamic linker ensures that it will not execute any initialization or termination functions more than once.

Shared objects designate their initialization and termination functions through the `DT_INIT` and `DT_FINI` entries in the dynamic structure, described in "Dynamic Section" above. Typically, the code for these functions resides in the `.init` and `.fini` sections, mentioned in "Sections" of Chapter 1.

---

*NOTE. Although the* `atexit`*(BA_OS) termination processing normally will be done, it is not guaranteed to have executed upon process death. In particular, the process will not execute the termination processing if it calls* `_exit` *[see exit (BA_OS)] or if the process dies because it received a signal that it neither caught nor ignored.*

---

The dynamic linker is not responsible for calling the executable file's `.init` section or registering the executable file's `.fini` section with `atexit`(BA_OS). Termination functions specified by users via the `atexit`(BA_OS) mechanism must be executed before any termination functions of shared objects.

## Introduction

This appendix describes the ELF features and functions that are both Intel Architecture and System V Release 4 dependent.

## Sections

### Special Sections

Various sections hold program and control information. Sections in the list below are used by the system and have the indicated types and attributes.

**Figure A-1. Special Sections**

| Name | Type | Attributes |
|---|---|---|
| `.got` | `SHT_PROGBITS` | `SHF_ALLOC+SHF_WRITE` |
| `.plt` | `SHT_PROGBITS` | `SHF_ALLOC+SHF_EXECINSTR` |

`.got` This section holds the global offset table. See "Global Offset Table" below for more information.

`.plt` This section holds the procedure linkage table. See "Procedure Linkage Table" Chapter 2 for more information.

## Symbol Table

### Symbol Values

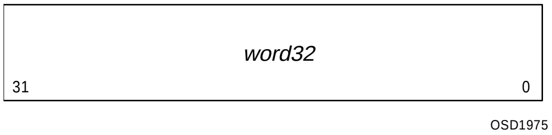
If an executable file contains a reference to a function defined in one of its associated shared objects, the symbol table section for that file will contain an entry for that symbol. The `st_shndx` member of that symbol table entry contains `SHN_UNDEF`. This signals to the dynamic linker that the symbol definition for that function is not contained in the executable file itself. If that symbol has been allocated a procedure linkage table entry in the executable file, and the `st_value` member for that symbol table entry is non-zero, the value will contain the virtual address of the first instruction of that procedure linkage table entry. Otherwise, the `st_value` member contains zero. This procedure linkage table entry address is used by the dynamic linker in resolving references to the address of the function. See "Function Addresses" below for details.

## Relocation

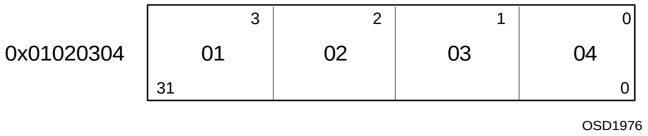
### Relocation Types

Relocation entries describe how to alter the following instruction and data fields (bit numbers appear in the lower box corners).

Figure A-2. Relocatable Fields



*word32* This specifies a 32-bit field occupying 4 bytes with arbitrary byte alignment. These values use the same byte order as other word values in the Intel architecture.



Calculations below assume the actions are transforming a relocatable file into either an executable or a shared object file. Conceptually, the link editor merges one or more relocatable files to form the output. It first decides how to combine and locate the input files, then updates the symbol values, and finally performs the relocation. Relocations applied to executable or shared object files are similar and accomplish the same result. Descriptions below use the following notation.

A This means the addend used to compute the value of the relocatable field.

B This means the base address at which a shared object has been loaded into memory during execution. Generally, a shared object file is built with a 0 base virtual address, but the execution address will be different.

G This means the offset into the global offset table at which the address of the relocation entry's symbol will reside during execution. See "Global Offset Table" below for more information.

GOT This means the address of the global offset table. See "Global Offset Table" below for more information.

L This means the place (section offset or address) of the procedure linkage table entry for a symbol. A procedure linkage table entry redirects a function call to the proper destination. The link editor builds the initial procedure linkage table, and the dynamic linker modifies the entries during execution. See "Procedure Linkage Table" below for more information.

P This means the place (section offset or address) of the storage unit being relocated (computed using r_offset ).

S This means the value of the symbol whose index resides in the relocation entry.

A relocation entry's r_offset value designates the offset or virtual address of the first byte of the affected storage unit. The relocation type specifies which bits to change and how to calculate their values. The Intel architecture uses only Elf32_Rel relocation entries, the field to be relocated holds the addend. In all cases, the addend and the computed result use the same byte order.

**Figure A-3. Relocation Types**

| Name | Value | Field | Calculation |
|---|---|---|---|
| R_386_GOT32 | 3 | *word32* | G + A |
| R_386_PLT32 | 4 | *word32* | L + A - P |
| R_386_COPY | 5 | none | none |
| R_386_GLOB_DAT | 6 | *word32* | S |
| R_386_JMP_SLOT | 7 | *word32* | S |
| R_386_RELATIVE | 8 | *word32* | B + A |
| R_386_GOTOFF | 9 | *word32* | S + A - GOT |
| R_386_GOTPC | 10 | *word32* | GOT + A - P |

Some relocation types have semantics beyond simple calculation.

R_386_GLOB_DAT This relocation type is used to set a global offset table entry to the address of the specified symbol. The special relocation type allows one to determine the correspondence between symbols and global offset table entries.

R_386_JMP_SLOT The link editor creates this relocation type for dynamic linking. Its offset member gives the location of a procedure linkage table entry. The dynamic linker modifies the procedure linkage table entry to transfer control to the designated symbol's address [see "Procedure Linkage Table" below].

R_386_RELATIVE The link editor creates this relocation type for dynamic linking. Its offset member gives a location within a shared object that contains a value representing a relative address. The dynamic linker computes the corresponding virtual address by adding the virtual address at which the shared object was loaded to the relative address. Relocation entries for this type must specify 0 for the symbol table index.

R_386_GOTOFF This relocation type computes the difference between a symbol's value and the address of the global offset table. It additionally instructs the link editor to build the global offset table.

| | |
|---|---|
| `R_386_GOTPC` | This relocation type resembles `R_386_PC32`, except it uses the address of the global offset table in its calculation. The symbol referenced in this relocation normally is `_GLOBAL_OFFSET_TABLE_`, which additionally instructs the link editor to build the global offset table. |

## Program Loading and Dynamic Linking

### Program Loading

As the system creates or augments a process image, it logically copies a file's segment to a virtual memory segment. When—and if— the system physically reads the file depends on the program's execution behavior, system load, and so on. A process does not require a physical page unless it references the logical page during execution, and processes commonly leave many pages unreferenced. Therefore delaying physical reads frequently obviates them, improving system performance. To obtain this efficiency in practice, executable and shared object files must have segment images whose file offsets and virtual addresses are congruent, modulo the page size.

Virtual addresses and file offsets for the Intel architecture segments are congruent modulo 4KB (0x1000) or larger powers of 2. Because 4KB is the maximum page size for the Intel Architecture, the files will be suitable for paging regardless of physical page size.

**Figure A-4. Executable File Example**

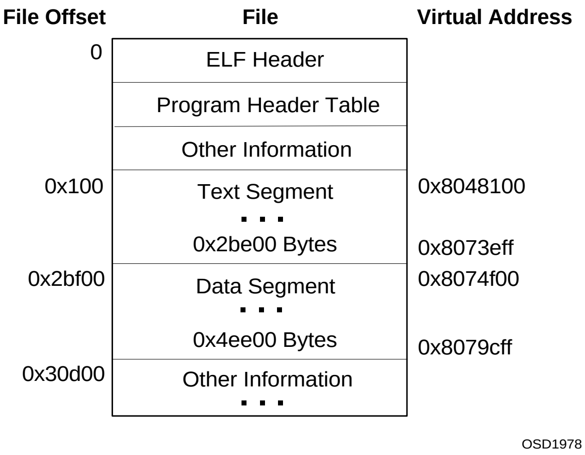


Figure A-5 describes the Executable File Example in Figure A-4.

### Figure A-5. Program Header Segments

| Member | Text | Data |
|---|---|---|
| p_type | PT_LOAD | PT_LOAD |
| p_offset | 0x100 | 0x2bf00 |
| p_vaddr | 0x8048100 | 0x8074f00 |
| p_paddr | unspecified | unspecified |
| p_filesz | 0x2be00 | 0x4e00 |
| p_memsz | 0x2be00 | 0x5e24 |
| p_flags | PF_R+PF_X | PF_R+PF_W+PF_X |
| p_align | 0x1000 | 0x1000 |

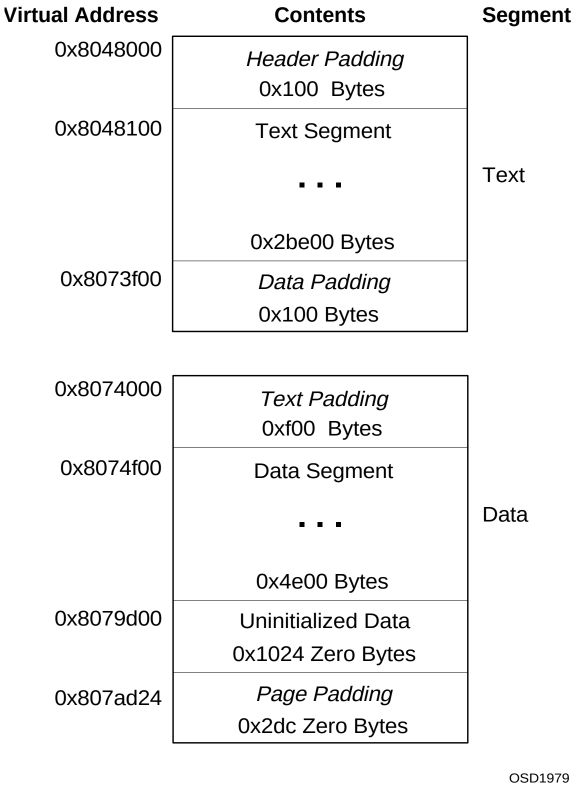
Although the example's file offsets and virtual addresses are congruent modulo 4KB for both text and data, up to four file pages hold impure text or data (depending on page size and file system block size).

- The first text page contains the ELF header, the program header table, and other information.
- The last text page holds a copy of the beginning of data.
- The first data page has a copy of the end of text.
- The last data page may contain file information not relevant to the running process.

Logically, the system enforces the memory permissions as if each segment were complete and separate; segments' addresses are adjusted to ensure each logical page in the address space has a single set of permissions. In the example above, the region of the file holding the end of text and the beginning of data will be mapped twice: at one virtual address for text and at a different virtual address for data.

The end of the data segment requires special handling for uninitialized data, which the system defines to begin with zero values. Thus if a file's last data page includes information not in the logical memory page, the extraneous data must be set to zero, not the unknown contents of the executable file. "Impurities" in the other three pages are not logically part of the process image; whether the system expunges them is unspecified. The memory image for this program follows, assuming 4 KB (0x1000 pages).

## Figure A-6. Process Image Segments Example



One aspect of segment loading differs between executable files and shared objects. Executable file segments typically contain absolute code. To let the process execute correctly, the segments must reside at the virtual addresses used to build the executable file. Thus the system uses the `p_vaddr` values unchanged as virtual addresses.

On the other hand, shared object segments typically contain position-independent code. This lets a segment's virtual address change from one process to another, without invalidating execution behavior. Though the system chooses virtual addresses for individual processes, it maintains the segments *relative positions*. Because position-independent code uses relative addressing between segments, the difference between virtual addresses in memory must match the difference between virtual addresses in the file. The following table shows possible shared object virtual address assignments for several processes, illustrating constant relative positioning. The table also illustrates the base address computations.

**Figure A-7. Shared Object Segment Addresses Example**

| Source | Text | Data | Base Address |
|---|---|---|---|
| File | `0x200` | `0x2a400` | `0x0` |
| Process 1 | `0x80000200` | `0x8002a400` | `0x80000000` |
| Process 2 | `0x80081200` | `0x800ab400` | `0x80081000` |
| Process 3 | `0x900c0200` | `0x900ea400` | `0x900c0000` |
| Process 4 | `0x900c6200` | `0x900f0400` | `0x900c6000` |

## Dynamic Linking

### Dynamic Section

Dynamic section entries give information to the dynamic linker. Some of this information is processor-specific, including the interpretation of some entries in the dynamic structure.

`DT_PLTGOT` On the Intel architecture, this entry's `d_ptr` member gives the address of the first entry in the global offset table. As mentioned below, the first three global offset table entries are reserved, and two are used to hold procedure linkage table information.

### Global Offset Table

Position-independent code cannot, in general, contain absolute virtual addresses. Global offset tables hold absolute addresses in private data, thus making the addresses available without compromising the position-independence and sharability of a program's text. A program references its global offset table using position-independent addressing and extracts absolute values, thus redirecting position-independent references to absolute locations.

Initially, the global offset table holds information as required by its relocation entries [see "Relocation" in Chapter 1]. After the system creates memory segments for a loadable object file, the dynamic linker processes the relocation entries, some of which will be type `R_386_GLOB_DAT` referring to the global offset table. The dynamic linker determines the associated symbol values, calculates their absolute addresses, and sets the appropriate memory table entries to the proper values. Although the absolute addresses are unknown when the link editor builds an object file, the dynamic linker knows the addresses of all memory segments and can thus calculate the absolute addresses of the symbols contained therein.

If a program requires direct access to the absolute address of a symbol, that symbol will have a global offset table entry. Because the executable file and shared objects have separate global offset tables, a symbol's address may appear in several tables. The dynamic linker processes all the global offset table relocations before giving control to any code in the process image, thus ensuring the absolute addresses are available during execution.

The table's entry zero is reserved to hold the address of the dynamic structure, referenced with the symbol _DYNAMIC. This allows a program, such as the dynamic linker, to find its own dynamic structure without having yet processed its relocation entries. This is especially important for the dynamic linker, because it must initialize itself without relying on other programs to relocate its memory image. On the Intel architecture, entries one and two in the global offset table also are reserved. "Procedure Linkage Table" below describes them.

The system may choose different memory segment addresses for the same shared object in different programs; it may even choose different library addresses for different executions of the same program. Nonetheless, memory segments do not change addresses once the process image is established. As long as a process exists, its memory segments reside at fixed virtual addresses.

A global offset table's format and interpretation are processor-specific. For the Intel architecture, the symbol _GLOBAL_OFFSET_TABLE_ may be used to access the table.

**Figure A-8. Global Offset Table**

```
extern  Elf32_Addr    _GLOBAL_OFFSET_TABLE_[];
```

The symbol _GLOBAL_OFFSET_TABLE_ may reside in the middle of the .got section, allowing both negative and non-negative "subscripts" into the array of addresses.

### Function Addresses

References to the address of a function from an executable file and the shared objects associated with it might not resolve to the same value. References from within shared objects will normally be resolved by the dynamic linker to the virtual address of the function itself. References from within the executable file to a function defined in a shared object will normally be resolved by the link editor to the address of the procedure linkage table entry for that function within the executable file.

To allow comparisons of function addresses to work as expected, if an executable file references a function defined in a shared object, the link editor will place the address of the procedure linkage table entry for that function in its associated symbol table entry. [See "Symbol Values" in Chapter 1]. The dynamic linker treats such symbol table entries specially. If the dynamic linker is searching for a symbol, and encounters a symbol table entry for that symbol in the executable file, it normally follows the rules below.

1. If the st_shndx member of the symbol table entry is not SHN_UNDEF, the dynamic linker has found a definition for the symbol and uses its st_value member as the symbol's address.
2. If the st_shndx member is SHN_UNDEF and the symbol is of type STT_FUNC and the st_value member is not zero, the dynamic linker recognizes this entry as special and uses the st_value member as the symbol's address.
3. Otherwise, the dynamic linker considers the symbol to be undefined within the executable file and continues processing.

Some relocations are associated with procedure linkage table entries. These entries are used for direct function calls rather than for references to function addresses. These relocations are not treated in the special way described above because the dynamic linker must not redirect procedure linkage table entries to point to themselves.

### Procedure Linkage Table

Much as the global offset table redirects position-independent address calculations to absolute locations, the procedure linkage table redirects position-independent function calls to absolute locations. The link editor cannot resolve execution transfers (such as function calls) from one executable or shared object to another. Consequently, the link editor arranges to have the program transfer control to entries in the procedure linkage table. On the Intel architecture, procedure linkage tables reside in shared text, but they use addresses in the private global offset table. The dynamic linker determines the destinations' absolute addresses and modifies the global offset table's memory image accordingly. The dynamic linker thus can redirect the entries without compromising the position-independence and sharability of the program's text. Executable files and shared object files have separate procedure linkage tables.

**Figure A-9. Absolute Procedure Linkage Table**

```
.PLT0:    pushl   got_plus_4
          jmp     *got_plus_8
          nop; nop
          nop; nop
.PLT1:    jmp     *name1_in_GOT
          pushl   $offset
          jmp     .PLT0@PC
.PLT2:    jmp     *name2_in_GOT
          pushl   $offset
          jmp     .PLT0@PC
          ...
```

**Figure A-10. Position-Independent Procedure Linkage Table**

```
.PLT0:    pushl   4(%ebx)
          jmp     *8(%ebx)
          nop; nop
          nop; nop
.PLT1:    jmp     *name1@GOT(%ebx)
          pushl   $offset
          jmp     .PLT0@PC
.PLT2:    jmp     *name2@GOT(%ebx)
          pushl   $offset
          jmp     .PLT0@PC
          ...
```

*NOTE. As the figures show, the procedure linkage table instructions use different operand addressing modes for absolute code and for position-independent code. Nonetheless, their interfaces to the dynamic linker are the same.*

Following the steps below, the dynamic linker and the program "cooperate" to resolve symbolic references through the procedure linkage table and the global offset table.

1. When first creating the memory image of the program, the dynamic linker sets the second and the third entries in the global offset table to special values. Steps below explain more about these values.
2. If the procedure linkage table is position-independent, the address of the global offset table must reside in `%ebx` . Each shared object file in the process image has its own procedure linkage table, and control transfers to a procedure linkage table entry only from within the same object file. Consequently, the calling function is responsible for setting the global offset table base register before calling the procedure linkage table entry.
3. For illustration, assume the program calls `name1`, which transfers control to the label `.PLT1` .
4. The first instruction jumps to the address in the global offset table entry for `name1`. Initially, the global offset table holds the address of the following `pushl` instruction, not the real address of `name1`.
5. Consequently, the program pushes a relocation offset (*`offset`*) on the stack. The relocation offset is a 32-bit, non-negative byte offset into the relocation table. The designated relocation entry will have type `R_386_JMP_SLOT`, and its offset will specify the global offset table entry used in the previous `jmp` instruction. The relocation entry also contains a symbol table index, thus telling the dynamic linker what symbol is being referenced, `name1` in this case.
6. After pushing the relocation offset, the program then jumps to `.PLT0`, the first entry in the procedure linkage table. The `pushl` instruction places the value of the second global offset table entry (*`got_plus_4`* or 4(%ebx)) on the stack, thus giving the dynamic linker one word of identifying information. The program then jumps to the address in the third global offset table entry (*`got_plus_8`* or 8(%ebx)), which transfers control to the dynamic linker.
7. When the dynamic linker receives control, it unwinds the stack, looks at the designated relocation entry, finds the symbol's value, stores the "real" address for `name1` in its global offset table entry, and transfers control to the desired destination.
8. Subsequent executions of the procedure linkage table entry will transfer directly to `name1`, without calling the dynamic linker a second time. That is, the `jmp` instruction at `.PLT1` will transfer to `name1`, instead of "falling through" to the `pushl` instruction.

The `LD_BIND_NOW` environment variable can change dynamic linking behavior. If its value is non-null, the dynamic linker evaluates procedure linkage table entries before transferring control to the program. That is, the dynamic linker processes relocation entries of type `R_3862_JMP_SLOT` during process initialization. Otherwise, the dynamic linker evaluates procedure linkage table entries lazily, delaying symbol resolution and relocation until the first execution of a table entry.

---

*NOTE. Lazy binding generally improves overall application performance, because unused symbols do not incur the dynamic linking overhead. Nevertheless, two situations make lazy binding undesirable for some applications. First, the initial reference to a shared object function takes longer than subsequent calls, because the dynamic linker intercepts the call to resolve the symbol. Some applications cannot tolerate this unpredictability. Second, if an error occurs and the dynamic linker cannot resolve the symbol, the dynamic linker will terminate the program. Under lazy binding, this might occur at arbitrary times. Once again, some applications cannot tolerate this unpredictability. By turning off lazy binding, the dynamic linker forces the failure to occur during process initialization, before the application receives control.*

---

## Program Interpreter

There is one valid program interpreter for programs conforming to the ELF specification for the Intel architecture: `/usr/lib/libc.so.1`

# Index

## Book I: Executable and Linkable Format