ELF Object File Format

Version 4.3 DRAFT

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Jan 11, 2025

Contents

Foreword

The SVR4 ABI

The System V Release 4 (SVR4) Application Binary Interface (ABI) is composed of several components, ranging from a high-level specification of the programming interface to the low-level machine details. The ABI contains the following chapters:

- **Chapter 1: Introduction**.
- **Chapter 2: Software Installation** covers installation media, and physical distribution formats.
- **Chapter 3: Low Level System Information**. This processor-dependent chapter covers the machine details, data representation, calling conventions, parameter passing, register usage, stack frame layout, stack unwinding, and dynamic linking conventions.
- **Chapter 4: Object Files** covers the ELF object file format and relocatable objects.
- **Chapter 5: Program Loading and Dynamic Linking** covers the ELF object file format, and executable and shared objects.
- **Chapter 6: Libraries** covers the processor-independent API available to the program, and the processor-specific binding of the API to the binary interface. It provides structure layouts, values for symbolic contants, and other implementation-specific details left unspecified by the API document.
- **Chapter 7: Development Environment** covers the development and packaging tools.
- **Chapter 8: Execution Environment** covers the runtime environment, file system structure, and system services available to the running application.

The SVR4 ABI is published in two parts: a *generic* ABI document (gABI), which covers the machine-independent components of the ABI, and a processor-specific ABI supplement (psABI), published separately for each machine architecture supported by the SVR4 ABI.

The SVR4 gABI and several other ABIs share ELF as a common object file format, and the official specification of the ELF object file format is published here. This specification replaces the material that was contained in Chapters 4 and 5 of the SVR4 gABI document.

Chapter 1

Introduction

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; the file specifies how the system (e.g., `exec()`) creates a program's process image.
- A *shared object file* holds code and data suitable for linking in two contexts. First, the link editor processes the shared object file 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.

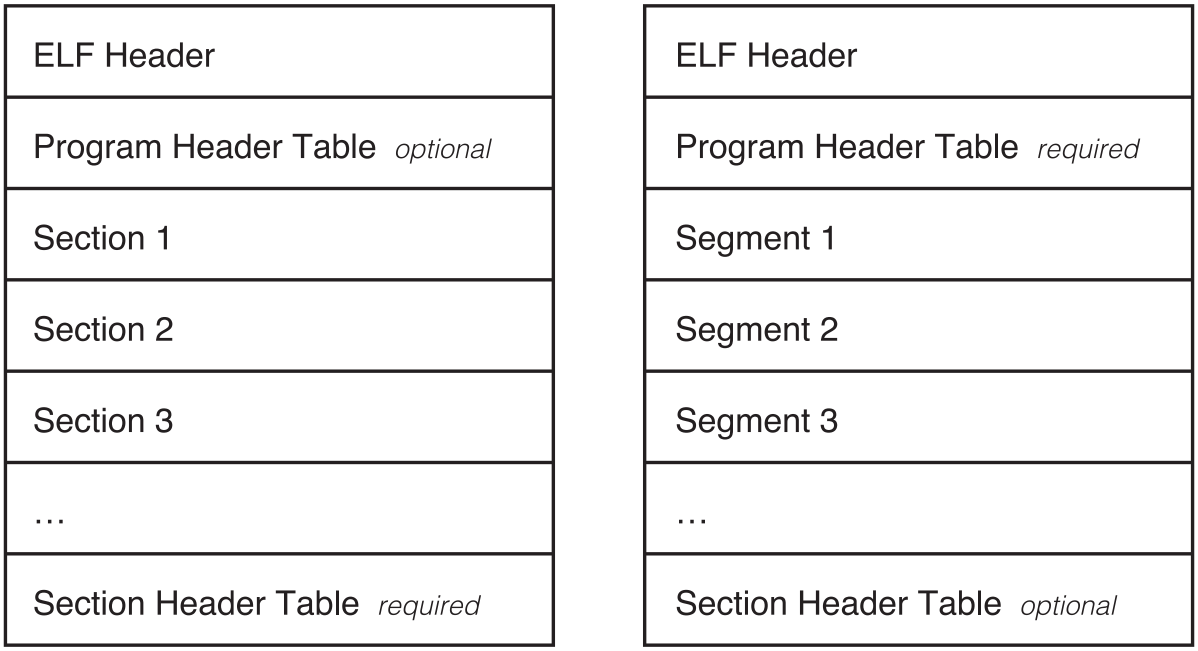
Created by the assembler and link editor, object files are binary representations of programs intended to be executed directly on a processor. Programs that require other abstract machines, such as shell scripts, are excluded.

1.1 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 those activities. Figure 1.1 shows an object file's organization.

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. Chapter 7, Program Loading, discusses *segments* and the program execution view of the file.

A *program header table* 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.



(a) Linking View (b) Execution View

Figure 1.1: ELF Object File Format

> **Note**
>
> Although Figure 1.1 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.

1.2 Data Representation

As described here, the object file format supports various processors with 8-bit bytes and either 32-bit or 64-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.

Table 1.1: 32-Bit Data Types

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

Table 1.2: 64-Bit Data Types

Name	Size	Alignment	Purpose
`Elf64_Addr`	8	8	Unsigned program address
`Elf64_Off`	8	8	Unsigned file offset
`Elf64_Half`	2	2	Unsigned medium integer
`Elf64_Word`	4	4	Unsigned integer
`Elf64_Sword`	4	4	Signed integer
`Elf64_Xword`	8	8	Unsigned long integer
`Elf64_Sxword`	8	8	Signed long 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 8-byte alignment for 8-byte objects, 4-byte alignment for 4-byte objects, to force structure sizes to a multiple of 4 or 8, and so forth. 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.

1.3 Extensibility

The ELF header contains a version number, which can be incremented for major changes to the object file format. ELF has been designed, however, so that such major changes are rare, and the file format can be extended in several ways that do not require a version number change.

Most object file structures are contained within sections (see Section 3, Sections), and are designated with special section types. Additional control structures can be defined by defining new section types.

Many control structures have fields with enumerated values, and the standard sets aside certain ranges of values for these fields for implementation-specific uses. These extensions can fall into one of two classes: processor-specific extensions, which depend on the machine architecture (see `e_machine` in Section 2.1, Contents of the ELF Header); and OSABI-specific extensions, which depend on the operating system and psABI (see `EI_OSABI` in Section 2.2, ELF Identification).

ELF assigns meaning to fields and constant values, throughout the specification. Any unassigned bits or values not explicitly delegated to the psABI or OSABI are reserved to the ELF standard for potential future use. Implementations must not assign meaning, or otherwise make use of, any unassigned items.

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. This form of extension is reserved for future revisions of the ELF standard, and must not be used for implementation-specific purposes.

1.4 Required Features

The ELF standard assigns meaning to a number of features, such as special sections, symbol types, and program header entries, but an implementation is not required to support all features defined in this specification. The psABI supplement should designate which features are required for a particular implementation.

Chapter 2

ELF Header

The ELF header resides at the beginning of an ELF file. It identifies the file as an ELF file and contains the information necessary for interpreting the contents of the file and locating the other components of the file.

2.1 Contents of the ELF Header

Listing 2.1: ELF Header

```c
#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;

typedef struct {
        unsigned char   e_ident[EI_NIDENT];
        Elf64_Half      e_type;
        Elf64_Half      e_machine;
        Elf64_Word      e_version;
        Elf64_Addr      e_entry;
        Elf64_Off       e_phoff;
        Elf64_Off       e_shoff;
        Elf64_Word      e_flags;
```

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```
        Elf64_Half      e_ehsize;
        Elf64_Half      e_phentsize;
        Elf64_Half      e_phnum;
        Elf64_Half      e_shentsize;
        Elf64_Half      e_shnum;
        Elf64_Half      e_shstrndx;
} Elf64_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 Section 2.2, ELF Identification.

e_type

This member identifies the object file type.

Table 2.1: Object File Types

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_LOOS	0xfe00	Operating system-specific
ET_HIOS	0xfeff	Operating system-specific
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. Values from `ET_LOOS` through `ET_HIOS` (inclusive) are reserved for operating system-specific semantics. Values from `ET_LOPROC` through `ET_HIPROC` (inclusive) are reserved for processor-specific semantics. If meanings are specified, the psABI supplement explains them. 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.

See *Appendix A* (page 67) for currently-assigned values for this field. 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.

Table 2.2: Object File Version Numbers

Name	Value	Meaning
EV_NONE	0	Invalid version
EV_CURRENT	1	Current version

The value 1 signifies the original file format; extensions will create new versions with higher numbers. Although the value of EV_CURRENT is shown as 1 in the previous table, it 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.

If the number of sections is greater than or equal to SHN_LORESERVE (`0xff00`), this member has the value zero and the actual number of section header table entries is contained in the `sh_size` field of the section header at index `0`. (Otherwise, the `sh_size` member of the initial entry contains `0`.)

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 Chapter 3, Sections, and Chapter 4, String Table, for more information.

If the section name string table section index is greater than or equal to SHN_LORESERVE (`0xff00`), this member has the value SHN_XINDEX (`0xffff`) and the actual index of the section name string table section is contained in the `sh_link` field of the section header at index `0`. (Otherwise, the `sh_link` member of the initial entry contains `0`.)

2.2 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.

Table 2.3: `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_OSABI`	7	Operating system/ABI identification
`EI_ABIVERSION`	8	ABI version
`EI_PAD`	9	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.

Table 2.4: ELF Magic Numbers

Name	Value	Position
`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.

Table 2.5: ELF Class

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. The class of the file defines the basic types used by the data structures of the object file container itself. The data contained in object file sections may follow a different programming model. If so, the psABI supplement describes the model used.

Class ELFCLASS32 supports machines with 32-bit architectures. It uses the basic types defined in Table 1.1 in Section 1.2, Data Representation.

Class ELFCLASS64 supports machines with 64-bit architectures. It uses the basic types defined in Table 1.2 in Section 1.2, Data Representation.

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 encoding of both the data structures used by object file container and data contained in object file sections. The following encodings are currently defined.

Table 2.6: ELF Data Encoding

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

Other values are reserved and will be assigned to new encodings as necessary.

> **Note**
>
> Primarily for the convenience of code that looks at the ELF file at runtime, the ELF data structures are intended to have the same byte order as that of the running program.

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_OSABI
Byte e_ident[EI_OSABI] identifies the OS- or ABI-specific ELF extensions used by this file. Some fields in other ELF structures have flags and values that have operating system and/or ABI specific meanings; the interpretation of those fields is determined by the value of this byte. If the object file does not use any extensions, it is recommended that this byte be set to 0. If the value for this byte is 64 through 255, its meaning depends on the value of the e_machine header member. The psABI supplement for an architecture can define its own associated set of values for this byte in this range. If the psABI supplement does not specify a set of values, one of the values defined in *Appendix B* (page 73) shall be used, where 0 (ELFOSABI_NONE) can also be taken to mean *unspecified*.

EI_ABIVERSION
Byte e_ident[EI_ABIVERSION] identifies the version of the ABI to which the object is targeted. This field is used to distinguish among incompatible versions of an ABI. The interpretation of this version number is dependent on the ABI identified by the EI_OSABI field. If no values are specified for the EI_OSABI field by the psABI supplement or no version values are specified for the ABI determined by a particular value of the EI_OSABI byte, the value 0 shall be used for the EI_ABIVERSION byte; it indicates *unspecified*.

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.

2.3 Data Encoding

A file's data encoding specifies how to interpret the basic objects in a file. Class `ELFCLASS32` files use objects that occupy 1, 2, and 4 bytes. Class `ELFCLASS64` files use objects that occupy 1, 2, 4, and 8 bytes. Under the defined encodings, objects are represented as shown below.

Encoding `ELFDATA2LSB` specifies 2's complement values, with the least significant byte occupying the lowest address. Encoding `ELFDATA2MSB` specifies 2's complement values, with the most significant byte occupying the lowest address. See Figure 2.1.

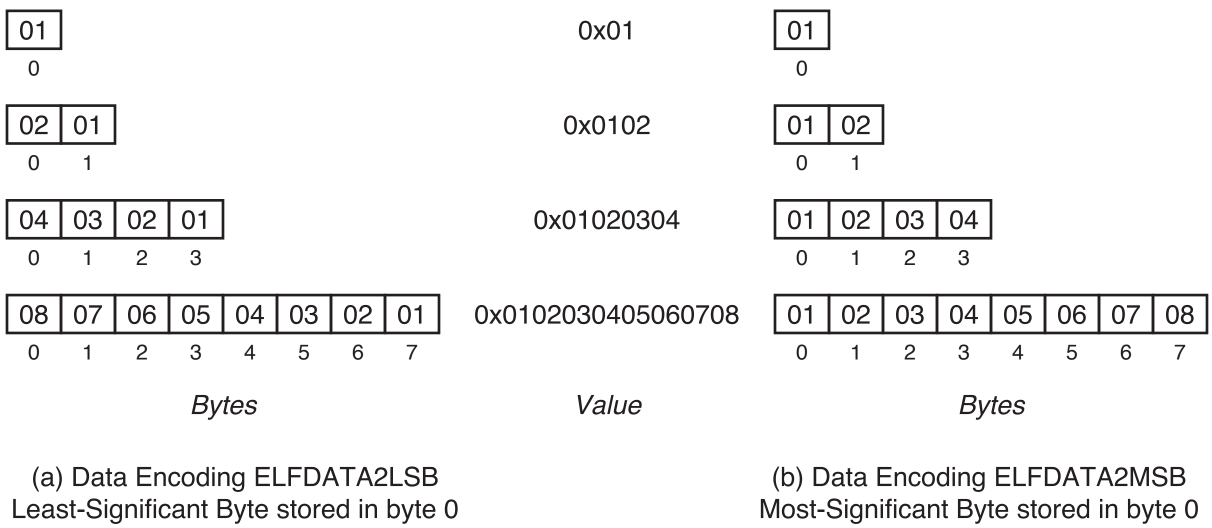

Figure 2.1: Data Encodings for 8-, 16-, 32-, and 64-bit Values

Chapter 3

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 or Elf64_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 normally tells how many entries the section header table contains. e_shentsize gives the size in bytes of each entry.

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.

> **Note**
>
> A common example of inactive space is the padding placed between sections to ensure proper alignment for the subsequent section.

If the number of sections is greater than or equal to SHN_LORESERVE (0xff00), e_shnum has the value SHN_UNDEF (0) and the actual number of section header table entries is contained in the sh_size field of the section header at index 0 (otherwise, the sh_size member of the initial entry contains 0).

3.1 Special Section Indexes

Some section header table indexes are reserved in contexts where index size is restricted, for example, the st_shndx member of a symbol table entry and the e_shnum and e_shstrndx members of the ELF header. In such contexts, the reserved values do not represent actual sections in the object file. Also in such contexts, an escape value indicates that the actual section index is to be found elsewhere, in a larger field.

Table 3.1: Special Section Indexes

Name	Value
`SHN_UNDEF`	`0`
`SHN_LORESERVE`	`0xff00`
`SHN_LOPROC`	`0xff00`
`SHN_HIPROC`	`0xff1f`
`SHN_LOOS`	`0xff20`
`SHN_HIOS`	`0xff3f`
`SHN_ABS`	`0xfff1`
`SHN_COMMON`	`0xfff2`
`SHN_XINDEX`	`0xffff`
`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. 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 in Section 3.6, First Section Header Table Entry.

`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_LOOS` through `SHN_HIOS`
: Values in this inclusive range are reserved for operating system-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_XINDEX`
: This value is an escape value. It indicates that the actual section header index is too large to fit in the containing field and is to be found in another location (specific to the structure where it appears).

`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. The section header table does not contain entries for the reserved indexes.

3.2 Section Header Table Entry

A section header has the following structure.

Listing 3.1: 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;

typedef struct {
    Elf64_Word  sh_name;
    Elf64_Word  sh_type;
    Elf64_Xword sh_flags;
    Elf64_Addr  sh_addr;
    Elf64_Off   sh_offset;
    Elf64_Xword sh_size;
    Elf64_Word  sh_link;
    Elf64_Word  sh_info;
    Elf64_Xword sh_addralign;
    Elf64_Xword sh_entsize;
} Elf64_Shdr;
```

`sh_name`
: This member specifies the name of the section. Its value is an index into the section header string table section (see Chapter 4, String Table), 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. If the sh_flags field for this section header includes the attribute SHF_INFO_LINK, then this member represents a section header table index.

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. 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.

3.3 Section Type

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

Table 3.2: 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_INIT_ARRAY	14
SHT_FINI_ARRAY	15
SHT_PREINIT_ARRAY	16
SHT_GROUP	17
SHT_SYMTAB_SHNDX	18
SHT_RELR	19
SHT_LOOS	0x60000000
SHT_HIOS	0x6fffffff
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. 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" below for details.

SHT_STRTAB
The section holds a string table. An object file may have multiple string table sections. See Chapter 4, String Table, for details.

SHT_RELA
The section holds relocation entries with explicit addends, such as type Elf32_Rela for the 32-bit class of object files or type Elf64_Rela for the 64-bit class of object files. An object file may have multiple relocation sections. See Chapter 6, Relocation, for details.

SHT_HASH
The section holds a symbol hash table. Currently, an object file may have only one hash table, but this restriction may be relaxed in the future. See Section 8.5, Hash Table, for details.

SHT_DYNAMIC
The section holds information for dynamic linking. Currently, an object file may have only one dynamic section, but this restriction may be relaxed in the future. See Section 8.3, Dynamic Section, for details.

SHT_NOTE
The section holds information that marks the file in some way. See Section 7.6, Note Sections, for details.

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 or type Elf64_Rel for the 64-bit class of object files. An object file may have multiple relocation sections. See Chapter 6, Relocation, for details.

SHT_SHLIB
This section type is reserved but has unspecified semantics.

SHT_INIT_ARRAY
This section contains an array of pointers to initialization functions, as described in Section 8.6, Initialization and Termination Functions. Each pointer in the array is taken as a parameterless procedure with a void return.

SHT_FINI_ARRAY
This section contains an array of pointers to termination functions, as described in Section 8.6, Initialization and Termination Functions. Each pointer in the array is taken as a parameterless procedure with a void return.

SHT_PREINIT_ARRAY
This section contains an array of pointers to functions that are invoked before all other initializa-

tion functions, as described in Section 8.6, Initialization and Termination Functions. Each pointer in the array is taken as a parameterless procedure with a void return.

SHT_GROUP
This section defines a section group. A section group is a set of sections that are related and that must be treated specially by the linker (see below for further details). Sections of type SHT_GROUP may appear only in relocatable objects (objects with the ELF header e_type member set to ET_REL). The section header table entry for a group section must appear in the section header table before the entries for any of the sections that are members of the group.

SHT_SYMTAB_SHNDX
This section is associated with a symbol table section and is required if any of the section header indexes referenced by that symbol table contain the escape value SHN_XINDEX. The section is an array of Elf32_Word/Elf64_Word values. Each value corresponds one to one with a symbol table entry and appear in the same order as those entries. The values represent the section header indexes against which the symbol table entries are defined. Only if the corresponding symbol table entry's st_shndx field contains the escape value SHN_XINDEX will the matching word hold the actual section header index; otherwise, the entry must be SHN_UNDEF (0).

SHT_RELR
The section holds an array of relocation entries, used to encode relative relocations that do not require explicit addends or other information. Array elements are of type Elf32_Relr for ELFCLASS32 objects, and Elf64_Relr for ELFCLASS64 objects. SHT_RELR sections are for dynamic linking, and may only appear in object files of type ET_EXEC or ET_DYN. An object file may have multiple relocation sections. See Chapter 6, Relocation for details.

SHT_LOOS through SHT_HIOS
Values in this inclusive range are reserved for operating system-specific 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.

3.4 Section Flags

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

Table 3.3: Section Attribute Flags

Name	Value
`SHF_WRITE`	`0x1`
`SHF_ALLOC`	`0x2`
`SHF_EXECINSTR`	`0x4`
`SHF_MERGE`	`0x10`
`SHF_STRINGS`	`0x20`
`SHF_INFO_LINK`	`0x40`
`SHF_LINK_ORDER`	`0x80`
`SHF_OS_NONCONFORMING`	`0x100`
`SHF_GROUP`	`0x200`
`SHF_TLS`	`0x400`
`SHF_COMPRESSED`	`0x800`
`SHF_MASKOS`	`0x0ff00000`
`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_MERGE`
The data in the section may be merged to eliminate duplication. Unless the `SHF_STRINGS` flag is also set, the data elements in the section are of a uniform size. The size of each element is specified in the section header's `sh_entsize` field. If the `SHF_STRINGS` flag is also set, the data elements consist of null-terminated character strings. The size of each character is specified in the section header's `sh_entsize` field.

Each element in the section is compared against other elements in sections with the same name, type and flags. Elements that would have identical values at program run-time may be merged. Relocations referencing elements of such sections must be resolved to the merged locations of the referenced values. Note that any relocatable values, including values that would result in run-time relocations, must be analyzed to determine whether the run-time values would actually be identical. An ABI-conforming object file may not depend on specific elements being merged, and an ABI-conforming link editor may choose not to merge specific elements.

`SHF_STRINGS`
The data elements in the section consist of null-terminated character strings. The size of each character is specified in the section header's `sh_entsize` field.

`SHF_INFO_LINK`
The `sh_info` field of this section header holds a section header table index.

`SHF_LINK_ORDER`
This flag adds special ordering requirements for link editors. The requirements apply to the referenced section identified by the `sh_link` field of this section's header. If this section is combined with other sections in the output file, the section must appear in the same relative order with re-

spect to those sections, as the referenced section appears with respect to sections the referenced section is combined with.

> **Note**
>
> A typical use of this flag is to build a table that references text or data sections in address order.

In addition to adding ordering requirements, `SHF_LINK_ORDER` indicates that the section contains metadata describing the referenced section. When performing unused section elimination, the link editor should ensure that both the section and the referenced section are retained or discarded together. Furthermore, relocations from this section into the referenced section should not be taken as evidence that the referenced section should be retained.

SHF_OS_NONCONFORMING
: This section requires special OS-specific processing (beyond the standard linking rules) to avoid incorrect behavior. If this section has either an `sh_type` value or contains `sh_flags` bits in the OS-specific ranges for those fields, and a link editor processing this section does not recognize those values, then the link editor should reject the object file containing this section with an error.

SHF_GROUP
: This section is a member (perhaps the only one) of a section group. The section must be referenced by a section of type `SHT_GROUP`. The `SHF_GROUP` flag may be set only for sections contained in relocatable objects (objects with the ELF header `e_type` member set to `ET_REL`). See below for further details.

SHF_TLS
: This section holds *Thread-Local Storage*, meaning that each separate execution flow has its own distinct instance of this data. Implementations need not support this flag.

SHF_COMPRESSED
: This flag identifies a section containing compressed data. In ET_EXEC and ET_DYN files, SHF_COMPRESSED cannot be used in conjunction with SHF_ALLOC. In addition, SHF_COMPRESSED cannot be applied to sections of type SHT_NOBITS. See Section 3.7, Compressed Sections, below.

SHF_MASKOS
: All bits included in this mask are reserved for operating system-specific semantics.

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

3.5 The sh_link and sh_info Fields

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

Table 3.4: `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 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 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).
SHT_GROUP	The section header index of the associated symbol table.	The symbol table index of an entry in the associated symbol table. The name of the specified symbol table entry provides a signature for the section group.
SHT_SYMTAB_SHNDX	The section header index of the associated symbol table section.	0

3.6 First Section Header Table Entry

As mentioned before, the section header at index 0 (SHN_UNDEF) exists, even though the index marks undefined section references. This entry holds the following.

Table 3.5: First Section Header Table Entry

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 offset
sh_size	Unspecified	If non-zero, the actual number of section header entries
sh_link	Unspecified	If non-zero, the index of the section header string table section
sh_info	0	No auxiliary information
sh_addralign	0	No alignment
sh_entsize	0	No entries

3.7 Compressed Sections

The SHF_COMPRESSED section header flag indicates a section that has been compressed to save space in the object file.

All relocations to a compressed section specify offsets to the uncompressed section data. It is therefore necessary to decompress the section data before relocations can be applied. Each compressed section specifies the algorithm independently. It is permissible for different sections in a given ELF object to employ different compression algorithms.

Compressed sections begin with a compression header structure that identifies the compression algorithm.

Listing 3.2: Compression Header

```
typedef struct {
    Elf32_Word  ch_type;
    Elf32_Word  ch_size;
    Elf32_Word  ch_addralign;
} Elf32_Chdr;

typedef struct {
    Elf64_Word  ch_type;
    Elf64_Word  ch_reserved;
    Elf64_Xword ch_size;
    Elf64_Xword ch_addralign;
} Elf64_Chdr;
```

`ch_type`
: This member specifies the compression algorithm. Supported algorithms and their descriptions are listed in the ELF Compression Types table below.

`ch_size`
: This member provides the size in bytes of the uncompressed data. See `sh_size`.

`ch_addralign`
: Specifies the required alignment for the uncompressed data. See `sh_addralign`.

The `sh_size` and `sh_addralign` fields of the section header for a compressed section reflect the requirements of the compressed section. The `ch_size` and `ch_addralign` fields in the compression header provide the corresponding values for the uncompressed data, thereby supplying the values that `sh_size` and `sh_addralign` would have had if the section had not been compressed.

The layout and interpretation of the data that follows the compression header is specific to each algorithm, and is defined below for each value of `ch_type`. This area may contain algorithm specific parameters and alignment padding in addition to compressed data bytes.

A compression header's `ch_type` member specifies the compression algorithm employed, as shown in the following table.

Table 3.6: ELF Compression Types, `ch_type`

Name	Value
ELFCOMPRESS_ZLIB	1
ELFCOMPRESS_ZSTD	2
ELFCOMPRESS_LOOS	0x60000000
ELFCOMPRESS_HIOS	0x6fffffff
ELFCOMPRESS_LOPROC	0x70000000
ELFCOMPRESS_HIPROC	0x7fffffff

`ELFCOMPRESS_ZLIB`
: The section data is compressed with the ZLIB algorithm. The compressed ZLIB data bytes begin with the byte immediately following the compression header, and extend to the end of the

section. Additional documentation for ZLIB may be found at http://zlib.net.

ELFCOMPRESS_ZSTD
The section data is compressed with the Zstandard algorithm. The compressed Zstandard data bytes begin with the byte immediately following the compression header, and extend to the end of the section. Additional documentation for Zstandard may be found at http://www.zstandard.org.

ELFCOMPRESS_LOOS - ELFCOMPRESS_HIOS
Values in this inclusive range are reserved for operating system-specific semantics.

ELFCOMPRESS_LOPROC - ELF_COMPRESS_HIPROC
Values in this inclusive range are reserved for processor-specific semantics.

3.8 Rules for Linking Unrecognized Sections

If a link editor encounters sections whose headers contain OS-specific values it does not recognize in the `sh_type` or `sh_flags` fields, the link editor should combine those sections as described below.

If the section's `sh_flags` bits include the attribute `SHF_OS_NONCONFORMING`, then the section requires special knowledge to be correctly processed, and the link editor should reject the object containing the section with an error.

Unrecognized sections that do not have the `SHF_OS_NONCONFORMING` attribute, are combined in a two-phase process. As the link editor combines sections using this process, it must honor the alignment constraints of the input sections (asserted by the `sh_addralign` field), padding between sections with zero bytes, if necessary, and producing a combination with the maximum alignment constraint of its component input sections.

1. In the first phase, input sections that match in name, type and attribute flags should be concatenated into single sections. The concatenation order should satisfy the requirements of any known input section attributes (e.g, `SHF_MERGE` and `SHF_LINK_ORDER`). When not otherwise constrained, sections should be emitted in input order.
2. In the second phase, sections should be assigned to segments or other units based on their attribute flags. Sections of each particular unrecognized type should be assigned to the same unit unless prevented by incompatible flags, and within a unit, sections of the same unrecognized type should be placed together if possible.

Non OS-specific processing (e.g. relocation) should be applied to unrecognized section types. An output section header table, if present, should contain entries for unknown sections. Any unrecognized section attribute flags should be removed.

> **Note**
>
> It is recommended that link editors follow the same two-phase ordering approach described above when linking sections of known types. Padding between such sections may have values different from zero, where appropriate.

3.9 Section Groups

Some sections occur in interrelated groups. For example, an out-of-line definition of an inline function might require, in addition to the section containing its executable instructions, a read-only data section containing literals referenced, one or more debugging information sections and other informational sections. Furthermore, there may be internal references among these sections that would not make sense if one of the sections were removed or replaced by a duplicate from another object. Therefore, such groups must be included or omitted from the linked object as a unit. A section cannot be a member of more than one group.

A section of type `SHT_GROUP` defines such a grouping of sections. The name of a symbol from one of the containing object's symbol tables provides a signature for the section group. The section header of the `SHT_GROUP` section specifies the identifying symbol entry, as described above: the `sh_link` member contains the section header index of the symbol table section that contains the entry. The `sh_info` member contains the symbol table index of the identifying entry. The `sh_flags` member of the section header contains `0`. The name of the section (`sh_name`) is not specified.

The referenced signature symbol is not restricted. Its containing symbol table section need not be a member of the group, for example.

The section data of a `SHT_GROUP` section is an array of `Elf32_Word/Elf64_Word` entries. The first entry is a flag word. The remaining entries are a sequence of section header indices.

The following flags are currently defined:

Table 3.7: Section Group Flags

Name	Value
GRP_COMDAT	0x1
GRP_MASKOS	0x0ff00000
GRP_MASKPROC	0xf0000000

GRP_COMDAT
This is a COMDAT group. It may duplicate another COMDAT group in another object file, where duplication is defined as having the same group signature. In such cases, only one of the duplicate groups may be retained by the linker, and the members of the remaining groups must be discarded.

GRP_MASKOS
All bits included in this mask are reserved for operating system-specific semantics.

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

The section header indices in the `SHT_GROUP` section identify the sections that make up the group. Each such section must have the `SHF_GROUP` flag set in its `sh_flags` section header member. If the linker decides to remove the section group, it must remove all members of the group.

> **Note**
>
> This requirement is not intended to imply that special case behavior like removing debugging information requires removing the sections to which that information refers, even if they are part of the same group.

To facilitate removing a group without leaving dangling references and with only minimal processing of the symbol table, the following rules must be followed:

- A symbol table entry with `STB_GLOBAL` or `STB_WEAK` binding that is defined relative to one of a group's sections, and that is contained in a symbol table section that is not part of the group, must be converted to an undefined symbol (its section index must be changed to `SHN_UNDEF`) if the group members are discarded. References to this symbol table entry from outside the group are allowed.

- A symbol table entry with `STB_LOCAL` binding that is defined relative to one of a group's sections, and that is contained in a symbol table section that is not part of the group, must be discarded if the group members are discarded. References to this symbol table entry from outside the group are not allowed.
- An undefined symbol that is referenced only from one or more sections that are part of a particular group, and that is contained in a symbol table section that is not part of the group, is not removed when the group members are discarded. In other words, the undefined symbol is not removed even if no references to that symbol remain.
- There may not be non-symbol references to the sections comprising a group from outside the group, for example, use of a group member's section header index in an `sh_link` or `sh_info` member.

3.10 Special Sections

Various sections hold program and control information.

The following table shows sections that are used by the system and have the indicated types and attributes.

Table 3.8: 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
`.dynstr`	`SHT_STRTAB`	`SHF_ALLOC`
`.dynsym`	`SHT_DYNSYM`	`SHF_ALLOC`
`.fini`	`SHT_PROGBITS`	`SHF_ALLOC+SHF_EXECINSTR`
`.fini_array`	`SHT_FINI_ARRAY`	`SHF_ALLOC+SHF_WRITE`
`.got`	`SHT_PROGBITS`	see below
`.hash`	`SHT_HASH`	`SHF_ALLOC`
`.init`	`SHT_PROGBITS`	`SHF_ALLOC+SHF_EXECINSTR`
`.init_array`	`SHT_INIT_ARRAY`	`SHF_ALLOC+SHF_WRITE`
`.interp`	`SHT_PROGBITS`	see below
`.line`	`SHT_PROGBITS`	none
`.note`	`SHT_NOTE`	none
`.plt`	`SHT_PROGBITS`	see below
`.preinit_array`	`SHT_PREINIT_ARRAY`	`SHF_ALLOC+SHF_WRITE`
`.rel`*name*	`SHT_REL`	see below
`.rela`*name*	`SHT_RELA`	see below
`.relr.dyn`	`SHT_RELR`	`SHF_ALLOC`
`.rodata`	`SHT_PROGBITS`	`SHF_ALLOC`
`.rodata1`	`SHT_PROGBITS`	`SHF_ALLOC`
`.shstrtab`	`SHT_STRTAB`	none
`.strtab`	`SHT_STRTAB`	see below

continues on next page

Table 3.8 – continued from previous page

Name	Type	Attributes
.symtab	SHT_SYMTAB	see below
.symtab_shndx	SHT_SYMTAB_SHNDX	see below
.tbss	SHT_NOBITS	SHF_ALLOC+SHF_WRITE+SHF_TLS
.tdata	SHT_PROGBITS	SHF_ALLOC+SHF_WRITE+SHF_TLS
.tdata1	SHT_PROGBITS	SHF_ALLOC+SHF_WRITE+SHF_TLS
.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 in the ABI.

.dynamic
: This section holds dynamic linking information. The section's attributes will include the `SHF_ALLOC` bit. Whether the `SHF_WRITE` bit is set is processor specific. See Section 8.3, Dynamic Section, for more information.

.dynstr
: This section holds strings needed for dynamic linking, most commonly the strings that represent the names associated with symbol table entries. See Section 8.3, Dynamic Section, for more information.

.dynsym
: This section holds the dynamic linking symbol table, as described in Chapter 5, Symbol Table, and Chapter 8, Dynamic Linking.

.fini
: This section holds executable instructions that contribute to the process termination code. That is, when a program exits normally, the system arranges to execute the code in this section.

.fini_array
: This section holds an array of function pointers that contributes to a single termination array for the executable or shared object containing the section.

.got
: This section holds the global offset table. See the psABI supplement for more information.

.hash
: This section holds a symbol hash table. See Section 8.5, Hash Table, for more information.

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

.init_array
: This section holds an array of function pointers that contributes to a single initialization array for

the executable or shared object containing the section.

`.interp`
: This section holds the path name of a program interpreter. 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. See Section 8.1, Program Interpreter, for more information.

`.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 as described in Section 7.6, Note Sections.

`.plt`
: This section holds the procedure linkage table. See the psABI supplement for more information.

`.preinit_array`
: This section holds an array of function pointers that contributes to a single pre-initialization array for the executable or shared object containing the section.

`.rel`*name* and `.rela`*name*
: These sections hold relocation information, as described in Chapter 6, Relocation. 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`.

`.relr.dyn`
: This section holds relative relocation information for dynamic linking, compactly encoded as described in Section 6.2, Relative Relocation Table. The relocations in this section are processed before other relocations in any `SHT_REL` or `SHT_RELA` section.

`.rodata` and `.rodata1`
: These sections hold read-only data that typically contribute to a non-writable segment in the process image. See Chapter 7, Program Loading 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 the 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 described in Chapter 5, Symbol Table. If the 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.

`.symtab_shndx`
: This section holds the special symbol table section index array, as described above. The section's attributes will include the `SHF_ALLOC` bit if the associated symbol table section does; otherwise that bit will be off.

`.tbss`
: This section holds uninitialized *thread-local data* that contribute to the program's memory image. By definition, the system initializes the data with zeros when the data is instantiated for each new execution flow. The section occupies no file space, as indicated by the section type, `SHT_NOBITS`. Implementations need not support thread-local storage.

.tdata
: This section holds initialized *thread-local data* that contributes to the program's memory image. A copy of its contents is instantiated by the system for each new execution flow. Implementations need not support thread-local storage.

.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 shown in the previous list. An object file may have more than one section with the same name.

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.

Table 3.9: **Pre-existing Extensions**

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

> **Note**
>
> For information on processor-specific sections, see the psABI supplement for the desired processor.

Chapter 4

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.

\0	n	a	m	e	.	\0	V	a	r	i	a	b	l	e	\0
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

a	b	l	e	\0	\0	x	x	\0
16	17	18	19	20	21	22	23	24

Figure 4.1: Example String Table

Table 4.1: String Table Indexes

Index	String
0	*none*
1	“`name.`”
7	“`Variable`”
11	“`able`”
16	“`able`”
22	“`xx`”
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.

Chapter 5

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 in Section 5.6, First Symbol Table Entry.

Table 5.1: Special Symbol Table Index

Name	Value
STN_UNDEF	0

5.1 Symbol Table Entry

A symbol table entry has the following format.

Listing 5.1: 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;

typedef struct {
    Elf64_Word     st_name;
    unsigned char  st_info;
    unsigned char  st_other;
    Elf64_Half     st_shndx;
    Elf64_Addr     st_value;
    Elf64_Xword    st_size;
} Elf64_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. 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.

`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 for both 32 and 64-bit objects.

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

#define ELF64_ST_BIND(i)   ((i)>>4)
#define ELF64_ST_TYPE(i)   ((i)&0xf)
#define ELF64_ST_INFO(b,t) (((b)<<4)+((t)&0xf))
```

`st_other`
This member currently specifies a symbol's visibility. A list of the values and meanings appears below. The following code shows how to manipulate the values for both 32 and 64-bit objects. Other bits contain 0 and have no defined meaning.

```
#define ELF32_ST_VISIBILITY(o) ((o)&0x7)
#define ELF64_ST_VISIBILITY(o) ((o)&0x7)
```

`st_shndx`
Every symbol table entry is *defined* in relation to some section. This member holds the relevant section header table index. As described in Section 3.1, Special Section Indexes, some section indexes indicate special meanings.

If this member contains `SHN_XINDEX`, then the actual section header index is too large to fit in this field. The actual value is contained in the associated section of type `SHT_SYMTAB_SHNDX`.

5.2 Symbol Binding

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

Table 5.2: Symbol Binding

Name	Value
STB_LOCAL	0
STB_GLOBAL	1
STB_WEAK	2
STB_LOOS	10
STB_HIOS	12
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_LOOS through STB_HIOS
Values in this inclusive range are reserved for operating system-specific semantics.

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

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.

> **Note**
>
> The behavior of weak symbols in areas not specified by this document is implementation defined. Weak symbols are intended primarily for use in system software. Applications using weak symbols are unreliable since changes in the runtime environment might cause the execution to fail.

In each symbol table, all symbols with `STB_LOCAL` binding precede the weak and global symbols. As described in Chapter 3, Sections, a symbol table section's `sh_info` section header member holds the symbol table index for the first non-local symbol.

5.3 Symbol Type

A symbol's type provides a general classification for the associated entity.

Table 5.3: Symbol Types

Name	Value
STT_NOTYPE	0
STT_OBJECT	1
STT_FUNC	2
STT_SECTION	3
STT_FILE	4
STT_COMMON	5
STT_TLS	6
STT_LOOS	10
STT_HIOS	12
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_FILE
Conventionally, the symbol's name gives the name of the source file associated with the object 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.

STT_COMMON
The symbol labels an uninitialized common block. See below for details.

STT_TLS
The symbol specifies a *Thread-Local Storage* entity. When defined, it gives the assigned offset for the symbol, not the actual address. Symbols of type STT_TLS can be referenced by only special thread-local storage relocations and thread-local storage relocations can only reference symbols with type STT_TLS. Implementations need not support thread-local storage.

STT_LOOS through STT_HIOS
Values in this inclusive range are reserved for operating system-specific semantics.

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

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.

Symbols with type `STT_COMMON` label uninitialized common blocks. In relocatable objects, these symbols are not allocated and must have the special section index `SHN_COMMON` (see below). In shared objects and executables these symbols must be allocated to some section in the defining object.

In relocatable objects, symbols with type `STT_COMMON` are treated just as other symbols with index `SHN_COMMON`. If the link-editor allocates space for the `SHN_COMMON` symbol in an output section of the object it is producing, it must preserve the type of the output symbol as `STT_COMMON`.

When the dynamic linker encounters a reference to a symbol that resolves to a definition of type `STT_COMMON`, it may (but is not required to) change its symbol resolution rules as follows: instead of binding the reference to the first symbol found with the given name, the dynamic linker searches for the first symbol with that name with type other than `STT_COMMON`. If no such symbol is found, it looks for the `STT_COMMON` definition of that name that has the largest size.

5.4 Symbol Visibility

A symbol's visibility, although it may be specified in a relocatable object, defines how that symbol may be accessed once it has become part of an executable or shared object.

Table 5.4: Symbol Visibility

Name	Value
STV_DEFAULT	0
STV_INTERNAL	1
STV_HIDDEN	2
STV_PROTECTED	3
STV_EXPORTED	4
STV_SINGLETON	5
STV_ELIMINATE	6

STV_DEFAULT

The visibility of symbols with the `STV_DEFAULT` attribute is as specified by the symbol's binding type. That is, global and weak symbols are visible outside of their defining *component* (executable file or shared object). Local symbols are *hidden*, as described below. Global and weak symbols are also *preemptable*, that is, they may by preempted by definitions of the same name in another component.

> **Note**
>
> An implementation may restrict the set of global and weak symbols that are externally visible.

STV_PROTECTED

A symbol defined in the current component is *protected* if it is visible in other components but not preemptable, meaning that any reference to such a symbol from within the defining component must be resolved to the definition in that component, even if there is a definition in another component that would preempt by the default rules. A symbol with `STB_LOCAL` binding may not have `STV_PROTECTED` visibility.

If a symbol definition with `STV_PROTECTED` visibility from a shared object is taken as resolving a reference from an executable or another shared object, the `SHN_UNDEF` symbol table entry created has `STV_DEFAULT` visibility.

> **Note**
>
> The presence of the `STV_PROTECTED` flag on a symbol in a given load module does not affect the symbol resolution rules for references to that symbol from outside the containing load module.

`STV_HIDDEN`
: A symbol defined in the current component is *hidden* if its name is not visible to other components. Such a symbol is necessarily protected. This attribute may be used to control the external interface of a component. Note that an object named by such a symbol may still be referenced from another component if its address is passed outside.

  A hidden symbol contained in a relocatable object must be either removed or converted to `STB_LOCAL` binding by the link-editor when the relocatable object is included in an executable file or shared object.

`STV_INTERNAL`
: The meaning of this visibility attribute may be defined by psABI supplements to further constrain hidden symbols. A psABI supplement's definition should be such that generic tools can safely treat internal symbols as hidden.

  An internal symbol contained in a relocatable object must be either removed or converted to `STB_LOCAL` binding by the link-editor when the relocatable object is included in an executable file or shared object.

`STV_EXPORTED`
: This visibility attribute ensures that a symbol remains global. Unlike `STV_DEFAULT` symbols, whose visibility can be affected by other visibility requests, the `STV_EXPORTED` attribute ensures that the visibility of the symbol is not reduced by any other visibility request.

`STV_SINGLETON`
: This visibility attribute is reserved to the psABI supplements. If implemented, it ensures that all references within a process bind to a single instance of the symbol definition.

`STV_ELIMINATE`
: This visibility attribute is reserved to the psABI supplements. If implemented, it prevents the symbol from being written to the dynamic symbol table. Otherwise, it can be treated the same as `STV_HIDDEN`.

None of the visibility attributes affects resolution of symbols within an executable or shared object during link-editing – such resolution is controlled by the binding type. Once the link-editor has chosen its resolution, these attributes impose two requirements, both based on the fact that references in the code being linked may have been optimized to take advantage of the attributes.

- First, all of the non-default visibility attributes, when applied to a symbol reference, imply that a definition to satisfy that reference must be provided within the current executable or shared object. If such a symbol reference has no definition within the component being linked, then the reference must have `STB_WEAK` binding and is resolved to zero.
- Second, if any reference to or definition of a name is a symbol with a non-default visibility attribute, the visibility attribute must be propagated to the resolving symbol in the linked object. If different visibility attributes are specified for distinct references to or definitions of a symbol, the most constraining visibility attribute must be propagated to the resolving symbol in the linked object. The attributes, ordered from least to most constraining, are: `STV_PROTECTED`, `STV_HIDDEN`, `STV_INTERNAL`, and `STV_EXPORTED`.

5.5 Section Index

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.

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. 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. Symbols with section index `SHN_COMMON` may appear only in relocatable objects.

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.

SHN_XINDEX
: This value is an escape value. It indicates that the symbol refers to a specific location within a section, but that the section header index for that section is too large to be represented directly in the symbol table entry. The actual section header index is found in the associated `SHT_SYMTAB_SHNDX` section. The entries in that section correspond one to one with the entries in the symbol table. Only those entries in `SHT_SYMTAB_SHNDX` that correspond to symbol table entries with `SHN_XINDEX` will hold valid section header indexes; all other entries will have value `0`.

5.6 First Symbol Table Entry

The symbol table entry for index 0 (`STN_UNDEF`) is reserved; it holds the following.

Table 5.5: First Symbol Table Entry

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`	Default visibility
`st_shndx`	`SHN_UNDEF`	No section

5.7 Symbol Value

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. `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.

Despite this difference in interpretation, the `st_value` for a given symbol conveys the same meaning across the different ELF object types. The different interpretation for relocatable, and the other object types, allows for efficient access by the link-editor, as well as by the runtime linker, in their respective contexts.

Chapter 6

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. Relocatable files must have relocation entries, which describe how to modify the section contents, thus allowing executable and shared object files to hold the right information for a process's program image.

Executable files may also have relocation entries, which are necessary when the code has unbound references to a shared object, or when the code is position-independent.

Most relocations are *symbolic,* computing the value of an expression involving a symbol and an offset (called the *addend*), applying the result to a location in the object code. A *relocation type* encodes an *operation* (how the expression is computed) and a *format* (how the result is to be applied at the location).

In executable files, some relocations are *relative.* A relative relocation marks a location that holds a 32-bit or 64-bit address that must be relocated when a program segment is loaded at a runtime address that is different from its link-time address. These relocations do not require a symbol or an addend.

6.1 Relocation Entry

Relocation entries have the following formats.

Listing 6.1: 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;

typedef struct {
    Elf64_Addr   r_offset;
    Elf64_Xword  r_info;
```

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```
} Elf64_Rel;

typedef struct {
    Elf64_Addr   r_offset;
    Elf64_Xword  r_info;
    Elf64_Sxword r_addend;
} Elf64_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 psABI supplement. When the text below refers to a relocation entry's relocation type or symbol table index, it means the result of applying `ELF32_R_TYPE` (or `ELF64_R_TYPE`) or `ELF32_R_SYM` (or `ELF64_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))

#define ELF64_R_SYM(i)     ((i)>>32)
#define ELF64_R_TYPE(i)    ((i)&0xffffffffL)
#define ELF64_R_INFO(s,t)  (((s)<<32)+((t)&0xffffffffL))
```

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

As specified previously, only `Elf32_Rela` and `Elf64_Rela` entries contain an explicit addend. Entries of type `Elf32_Rel` and `Elf64_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 Section 3.5, The sh_link and sh_info Fields, 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. 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.

The typical application of an ELF relocation is to determine the referenced symbol value, extract the addend (either from the field to be relocated or from the addend field contained in the relocation record, as appropriate for the type of relocation record), apply the expression implied by the relocation type to the symbol and addend, extract the desired part of the expression result, and place it in the field to be relocated.

If multiple *consecutive* relocation records are applied to the same relocation location (`r_offset`), they are *composed* instead of being applied independently, as described above. By *consecutive*, we mean that the relocation records are contiguous within a single relocation section. By *composed*, we mean that the standard application described above is modified as follows:

- In all but the last relocation operation of a composed sequence, the result of the relocation expression is retained, rather than having part extracted and placed in the relocated field. The result is retained at full pointer precision of the applicable psABI supplement.
- In all but the first relocation operation of a composed sequence, the addend used is the retained result of the previous relocation operation, rather than that implied by the relocation type.

Note that a consequence of the above rules is that the location specified by a relocation type is relevant for the first element of a composed sequence (and then only for relocation records that do not contain an explicit addend field) and for the last element, where the location determines where the relocated value will be placed. For all other relocation operands in a composed sequence, the location specified is ignored.

A psABI supplement may specify individual relocation types that always stop a composition sequence, or always start a new one.

6.2 Relative Relocation Table

Listing 6.2: Relative Relocation Table Entries

```
typedef Elf32_Word Elf32_Relr;
typedef Elf64_Xword Elf64_Relr;
```

Relative relocations are used to identify virtual-address-sized storage units within the object whose contents are independent of any dynamic binding, but must still be relocated at load time to support position independence. Before the program can begin execution, these locations must be relocated by reading their contents and adding a relocation factor, which is computed as the difference between the object's actual load-time virtual address and its link-time virtual address. If the object is loaded at the address for which it was linked, the relocation factor is 0, and relative relocations may be ignored.

A relative relocation table is encoded as a sequence of `Elf32_Relr` entries for `ELFCLASS32` objects or `Elf64_Relr` entries for `ELFCLASS64` objects. The relative relocation table entries decode to a list of virtual addresses that refer to storage units within the object. Each of these storage units is the size of an `Elf32_Addr` (in the case of `ELFCLASS32` objects) or an `Elf64_Addr` (in the case of `ELFCLASS64` objects).

Note

Relative relocations could be represented simply as a list of virtual addresses that require relocation, which would be considerably more compact than using `Elf32_Rel` or `Elf32_rela` relocations. Because many such relocations occur in clusters, however, we can use a simple encoding scheme to compress the relative relocation table even further.

A relative relocation table cannot describe relocations at odd addresses. For such relocations, a `Rel`- or `Rela`-style relocation must be used.

The encoded sequence of `Elf32_Relr` or `Elf64_Relr` entries starts with an address entry (which must have a 0 in the least-significant bit). This encodes one relative relocation at that address. This address entry may be followed by zero or more bitmap entries, each of which has a 1 in the least-significant bit.

Bitmap entries describe a block of `Elf32_Addr` or `Elf64_Addr` consecutive storage units immediately following the one to which the address entry applied. Each bitmap entry covers 31 (for `Elf32_Relr`) or 63 (for `Elf64_Relr`) storage units. Each bit in the bitmap entry, excluding the least-significant bit, corresponds to a storage unit in the block, the second-least-significant bit corresponding to the first, and the most-significant bit corresponding to the last. For each 1 in the bitmap entry, the corresponding storage unit is relocatable.

> **Note**
>
> This encoding scheme has the property that a simple list of (even) addresses is a valid encoding.

Chapter 7

Program Loading

This chapter and the next describe the object file information and system actions that create running programs. Some information here applies to all systems; information specific to one processor resides in sections marked accordingly.

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 is described by the psABI supplement for the specific machine.

This chapter discusses the following:

- Program Header. The program header complements the Section Header Table (Chapter 3, Sections), 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.
- Program Loading. Given an object file, the system must load it into memory for the program to run.

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*, as described in Section 7.5, Segment Contents. 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 Chapter 2, ELF Header for more information.

Segment entries may appear in any order, except as explicitly noted below.

7.1 Program Header Entry

Listing 7.1: Program Header

```
typedef struct {
    Elf32_Word  p_type;
    Elf32_Off   p_offset;
    Elf32_Addr  p_vaddr;
    Elf32_Addr  p_paddr;
    Elf32_Word  p_filesz;
```

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```
    Elf32_Word  p_memsz;
    Elf32_Word  p_flags;
    Elf32_Word  p_align;
} Elf32_Phdr;

typedef struct {
    Elf64_Word  p_type;
    Elf64_Word  p_flags;
    Elf64_Off   p_offset;
    Elf64_Addr  p_vaddr;
    Elf64_Addr  p_paddr;
    Elf64_Xword p_filesz;
    Elf64_Xword p_memsz;
    Elf64_Xword p_align;
} Elf64_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. Because System V ignores physical addressing for application programs, this member has unspecified contents for executable files and shared objects.

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 no alignment is required. Otherwise, `p_align` should be a positive, integral power of 2, and `p_vaddr` should equal `p_offset`, modulo `p_align`.

7.2 Segment Types

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

Defined segment type values are listed in Table 7.1; other values are reserved for future use.

Table 7.1: 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_TLS	7
PT_LOOS	0x60000000
PT_HIOS	0x6fffffff
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 Section 8.3, Dynamic Section, 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 Section 8.1, Program Interpreter, for more information.

PT_NOTE
The array element specifies the location and size of auxiliary information. See Section 7.6, Note Sections, for more 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 ABI.

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.

PT_TLS
The array element specifies the *Thread-Local Storage* template. Implementations need not support this program table entry. See Section 7.7, Thread-Local Storage, for more information.

PT_LOOS through PT_HIOS

Values in this inclusive range are reserved for operating system-specific semantics.

`PT_LOPROC` **through** `PT_HIPROC`
: Values in this inclusive range are reserved for processor-specific semantics. If meanings are specified, the psABI supplement explains them.

> **Note**
>
> Unless specifically required elsewhere, all program header segment types are optional. A file's program header table may contain only those elements relevant to its contents.

7.3 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. On some platforms, while the system chooses virtual addresses for individual processes, it maintains the *relative* position of one segment to another within any one shared object. Because position-independent code on those platforms uses relative addressing between segments, the difference between virtual addresses in memory must match the difference between virtual addresses in the file. The differences 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 file during dynamic linking.

An executable or shared object file's base address (on platforms that support the concept) 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.

See the psABI supplement for more information and examples.

7.4 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.

Table 7.2: Segment Flag Bits, `p_flags`

Name	Value	Meaning
`PF_X`	`0x1`	Execute
`PF_W`	`0x2`	Write
`PF_R`	`0x4`	Read
`PF_MASKOS`	`0x0ff00000`	Unspecified
`PF_MASKPROC`	`0xf0000000`	Unspecified

All bits included in the `PF_MASKOS` mask are reserved for operating system-specific semantics.

All bits included in the `PF_MASKPROC` mask are reserved for processor-specific semantics. If meanings are specified, the psABI 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. ABI-conforming systems may provide either.

Table 7.3: Segment Permissions

Flags	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.

7.5 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. See the psABI supplement for details.

Text segments contain read-only instructions and data, typically including the following sections (see Section 3.10, Special Sections):

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

Other sections may also reside in loadable segments; these examples are not meant to give complete and exclusive segment contents.

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

- `.data`

- `.dynamic`
- `.got`
- `.bss`

A `PT_DYNAMIC` program header element points at the `.dynamic` section, explained in Section 8.3, Dynamic Section. The `.got` and `.plt` sections also hold information related to position-independent code and dynamic linking. Although the `.plt` appears in a text segment in the previous table, it may reside in a text or a data segment, depending on the processor. See "Global Offset Table" and "Procedure Linkage Table" in the psABI supplement for details.

As Chapter 3, 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` in the associated program header element.

7.6 Note Sections

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 a variable amount of entries. In 64-bit objects (files with `e_ident[EI_CLASS]` equal to `ELFCLASS64`), each entry is an array of 8-byte words in the format of the target processor. In 32-bit objects (files with `e_ident[EI_CLASS]` equal to `ELFCLASS32`), each entry 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.

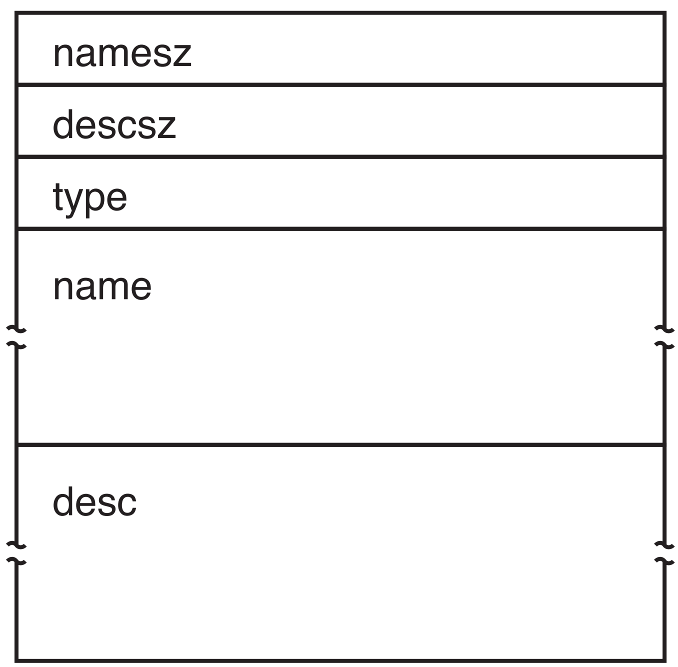

Figure 7.1: Note Information

`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 8 or 4-byte alignment for the descriptor (depending on whether the file is a 64-bit or 32-bit object). Such padding is not included in `namesz`.

`descsz` and `desc`

The first `descsz` bytes in `desc` hold the note descriptor. The ABI places no constraints on a descriptor's contents. If no descriptor is present, `descsz` contains 0. Padding is present, if necessary, to ensure 8 or 4-byte alignment for the next note entry (depending on whether the file is a 64-bit or 32-bit object). 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 recognize a descriptor. Types currently must be non-negative. The ABI does not define what descriptors mean.

To illustrate, the following (`ELFCLASS32`) note segment holds two entries. Both have a 7-byte `name` field of "xyz co" (counting the null terminator). The first has a `type` field of 1 and no descriptor, and the second has a `type` field of 3 with 8 bytes of descriptor data (with no null terminator). Note that the word-size fields `namesz`, `descsz` and `type` are stored with the byte order specified in the ELF Header (see *EI_DATA* in Section 2.2, ELF Identification).

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.

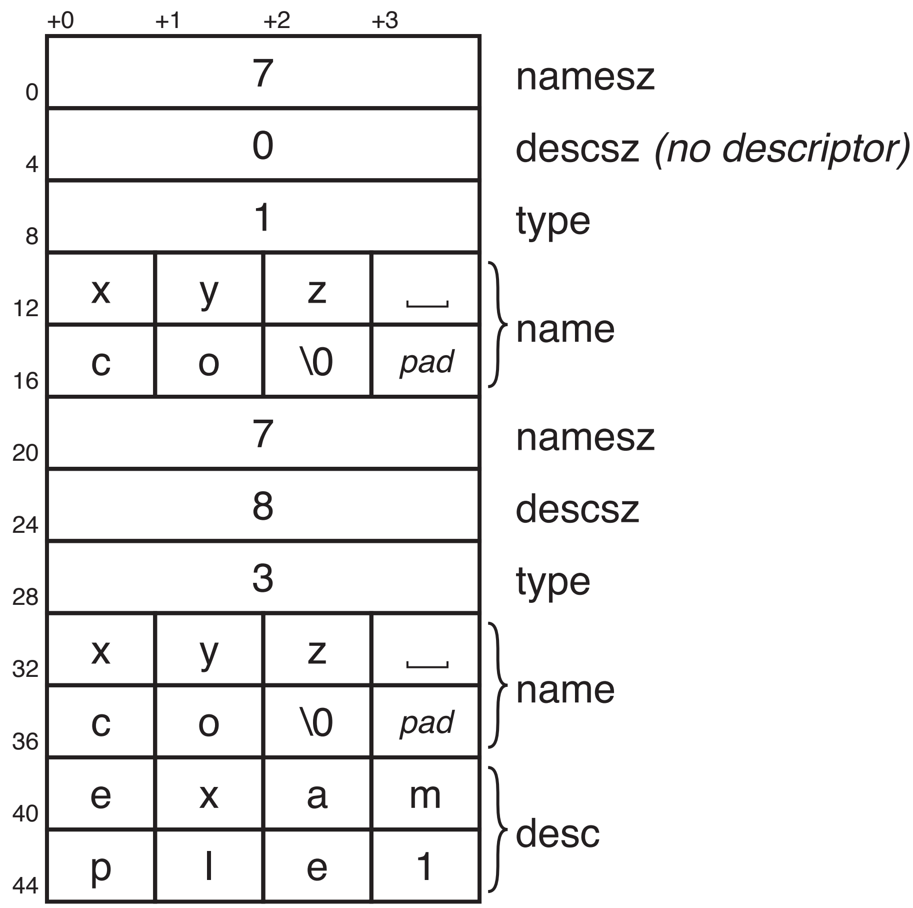

Figure 7.2: Example `ELFCLASS32` Note Segment

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

7.7 Thread-Local Storage

To permit association of separate copies of data allocated at compile-time with individual threads of execution, thread-local storage sections can be used to specify the size and initial contents of such data. Implementations need not support thread-local storage. A `PT_TLS` program entry has the following members:

Table 7.4: Contents of the `PT_TLS` Entry

Member	Value
`p_offset`	File offset of the TLS initialization image
`p_vaddr`	Virtual memory address of the TLS initialization image
`p_paddr`	reserved
`p_filesz`	Size of the TLS initialization image
`p_memsz`	Total size of the TLS template
`p_flags`	`PF_R`
`p_align`	Alignment of the TLS template

The *TLS template* is formed from the combination of all sections with the flag `SHF_TLS`. The portion of the TLS template that holds initialized data is the *TLS initialization image*. (The remaining portion of the TLS template is one or more sections of type `SHT_NOBITS`.)

Chapter 8

Dynamic Linking

After the system loads the program, it must complete the process image by resolving symbolic references among the object files that compose the process. This chapter discusses the object file structures that pertain to dynamic linking.

> **Note**
>
> The psABI supplement defines a naming convention 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. Pre-existing processor extensions not using this convention will be supported.

Pre-Existing Extensions
`DT_JUMP_REL`

8.1 Program Interpreter

An executable file that participates in dynamic linking shall have one `PT_INTERP` program header element. During process startup (e.g., `exec()`), 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 typically 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. See the psABI supplement for additional information.

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` and related services. Consequently, a shared object interpreter typically will not conflict with the original executable file's original segment addresses.

An executable file may be loaded at fixed addresses; if so, 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.

8.2 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 system loader (e.g., `exec()`) 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 system loader.

The link editor also constructs various data that assist the dynamic linker for executable and shared object files. As shown in Chapter 7, Program Loading, this data resides in loadable segments, making them available during execution. (Once again, recall the exact segment contents are processor-specific. See the psABI supplement for complete information).

- 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. The psABI supplement discusses how 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 ABI-conforming program imports the basic system services from a shared object library, the dynamic linker participates in every ABI-conforming program execution.

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 relocations 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. See the psABI supplement for more information.

8.3 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.

Listing 8.1: 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[];

typedef struct {
    Elf64_Sxword    d_tag;
    union {
        Elf64_Xword d_val;
        Elf64_Addr  d_ptr;
    } d_un;
} Elf64_Dyn;

extern Elf64_Dyn    _DYNAMIC[];
```

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

`d_val`
: These objects represent integer values with various interpretations.

`d_ptr`
: These 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.

To make it simpler for tools to interpret the contents of dynamic section entries, the value of each tag, except for those in two special compatibility ranges, will determine the interpretation of the `d_un` union. A tag whose value is an even number indicates a dynamic section entry that uses `d_ptr`. A tag whose value is an odd number indicates a dynamic section entry that uses `d_val` or that uses neither `d_ptr` nor `d_val`. Tags whose values are less than the special value `DT_ENCODING` and tags whose values fall between `DT_HIOS` and `DT_LOPROC` do not follow these rules.

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

Table 8.1: 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_INIT_ARRAY	25	d_ptr	optional	optional
DT_FINI_ARRAY	26	d_ptr	optional	optional
DT_INIT_ARRAYSZ	27	d_val	optional	optional
DT_FINI_ARRAYSZ	28	d_val	optional	optional
DT_RUNPATH	29	d_val	optional	optional
DT_FLAGS	30	d_val	optional	optional
DT_ENCODING	32	unspecified	unspecified	unspecified
DT_PREINIT_ARRAY	32	d_ptr	optional	ignored
DT_PREINIT_ARRAYSZ	33	d_val	optional	ignored
DT_SYMTAB_SHNDX	34	d_ptr	optional	optional
DT_RELRSZ	35	d_val	optional	optional
DT_RELR	36	d_ptr	optional	optional
DT_RELRENT	37	d_val	optional	optional
DT_SYMTABSZ	39	d_val	optional†	optional†
DT_LOOS	0x6000000D	unspecified	unspecified	unspecified
DT_HIOS	0x6ffff000	unspecified	unspecified	unspecified
DT_LOPROC	0x70000000	unspecified	unspecified	unspecified

continues on next page

Table 8.1 – continued from previous page

Name	Value	d_un	Executable	Shared Object
DT_HIPROC	0x7fffffff	unspecified	unspecified	unspecified

* Signifies an entry that has been deprecated.
† DT_HASH is optional if DT_SYMTABSZ is provided.

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 code. See Section 8.4, 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. See the psABI supplement for details.

DT_HASH
This element holds the address of the symbol hash table, described in Section 8.5, Hash Table. This hash table refers to the symbol table referenced by the DT_SYMTAB element.

DT_HASH is normally mandatory. The psABI supplement is allowed to override this requirement by providing an alternative hash mechanism. In such cases, DT_SYMTABSZ, which is normally optional, becomes mandatory.

DT_STRTAB
This element holds the address of the string table, described in Chapter 4, String Table. Symbol names, library names, and other strings reside in this table.

DT_SYMTAB
This element holds the address of the dynamic linking symbol table, as described in Chapter 5, Symbol Table, with Elf32_Sym entries for the 32-bit class of files and Elf64_Sym entries for the 64-bit class of files.

DT_RELA
This element holds the address of a relocation table, described in Chapter 6, Relocation. Entries in the table have explicit addends (Elf32_Rela for the 32-bit file class or Elf64_Rela for the 64-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 concatenates 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 Section 8.6, Initialization and Termination Functions.

DT_FINI
This element holds the address of the termination function, discussed in Section 8.6, Initialization and Termination Functions.

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 Section 8.4, Shared Object Dependencies 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 Section 8.4, Shared Object Dependencies. The offset is an index into the table recorded in the DT_STRTAB entry. This entry is deprecated; its use has been superseded by DT_RUNPATH.

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. This entry is deprecated; its use has been superseded by the DF_SYMBOLIC flag.

DT_REL
This element is similar to DT_RELA, except its table has implicit addends (Elf32_Rel for the 32-bit file class or Elf64_Rel for the 64-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 for the ABI; programs that access this entry are not ABI-conforming.

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. This entry is deprecated; its use has been superseded by the `DF_TEXTREL` flag.

DT_JMPREL
: If present, this entry's `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()`. This entry is deprecated; its use has been superseded by the `DF_BIND_NOW` flag.

DT_INIT_ARRAY
: This element holds the address of the array of pointers to initialization functions, discussed in Section 8.6, Initialization and Termination Functions.

DT_FINI_ARRAY
: This element holds the address of the array of pointers to termination functions, discussed in Section 8.6, Initialization and Termination Functions.

DT_INIT_ARRAYSZ
: This element holds the size in bytes of the array of initialization functions pointed to by the `DT_INIT_ARRAY` entry. If an object has a `DT_INIT_ARRAY` entry, it must also have a `DT_INIT_ARRAYSZ` entry.

DT_FINI_ARRAYSZ
: This element holds the size in bytes of the array of termination functions pointed to by the `DT_FINI_ARRAY` entry. If an object has a `DT_FINI_ARRAY` entry, it must also have a `DT_FINI_ARRAYSZ` entry.

DT_RUNPATH
: This element holds the string table offset of a null-terminated library search path string discussed in Section 8.4, Shared Object Dependencies. The offset is an index into the table recorded in the `DT_STRTAB` entry.

DT_FLAGS
: This element holds flag values specific to the object being loaded. Each flag value will have the name `DF_`*flag_name*. Defined values and their meanings are described below. All other values are reserved.

DT_PREINIT_ARRAY
: This element holds the address of the array of pointers to pre-initialization functions, discussed in Section 8.6, Initialization and Termination Functions. The `DT_PREINIT_ARRAY` table is processed only in an executable file; it is ignored if contained in a shared object.

DT_PREINIT_ARRAYSZ
: This element holds the size in bytes of the array of pre-initialization functions pointed to by the `DT_PREINIT_ARRAY` entry. If an object has a `DT_PREINIT_ARRAY` entry, it must also have a `DT_PREINIT_ARRAYSZ` entry. As with `DT_PREINIT_ARRAY`, this entry is ignored if it appears in a shared object.

DT_SYMTAB_SHNDX
: This element holds the address of the `SHT_SYMTAB_SHNDX` section associated with the dynamic symbol table referenced by the `DT_SYMTAB` element.

DT_RELR
: This element holds the address of an SHT_RELR relocation table, described in Section 6.2, Relative Relocation Table. This table will hold entries of either Elf32_Relr for the 32-bit file class or Elf64_Relr for the 64-bit file class. If this element is present, the dynamic structure must also have DT_RELRSZ and DT_RELRENT elements. During dynamic linking, a DT_RELR element is processed before any DT_REL or DT_RELA elements in the same object file.

DT_RELRSZ
: This element holds the total size, in bytes, of the DT_RELR relocation table.

DT_RELRENT
: This element holds the size, in bytes, of the DT_RELR relocation entry.

DT_SYMTABSZ
: This element holds the size, in bytes, of the DT_SYMTAB dynamic linking symbol table. It must be provided if the DT_HASH symbol hash table is omitted.

DT_ENCODING
: Values greater than or equal to DT_ENCODING and less than DT_LOOS follow the rules for the interpretation of the d_un union described above.

DT_LOOS through DT_HIOS
: Values in this inclusive range are reserved for operating system-specific semantics. All such values follow the rules for the interpretation of the d_un union described above.

DT_LOPROC through DT_HIPROC
: Values in this inclusive range are reserved for processor-specific semantics. If meanings are specified, the psABI supplement explains them. All such values follow the rules for the interpretation of the d_un union described above.

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.

Table 8.2: DT_FLAGS values

Name	Value
DF_ORIGIN	0x1
DF_SYMBOLIC	0x2
DF_TEXTREL	0x4
DF_BIND_NOW	0x8
DF_STATIC_TLS	0x10

DF_ORIGIN
: This flag signifies that the object being loaded may make reference to the $ORIGIN substitution string (see Section 8.4.1, Substitution Sequences). The dynamic linker must determine the pathname of the object containing this entry when the object is loaded.

DF_SYMBOLIC
: If this flag is set in a shared object library, the dynamic linker's symbol resolution algorithm for references within the library is changed. 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.

DF_TEXTREL
: If this flag is not set, 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 flag is set, one or

more relocation entries might request modifications to a non-writable segment, and the dynamic linker can prepare accordingly.

DF_BIND_NOW
If set in a shared object or executable, this flag 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()`.

DF_STATIC_TLS
If set in a shared object or executable, this flag instructs the dynamic linker to reject attempts to load this file dynamically. It indicates that the shared object or executable contains code using a *static thread-local storage* scheme. Implementations need not support any form of thread-local storage.

8.4 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.

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), and 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` or `directory/file`, the dynamic linker uses that string directly as the path name. If the name has no slashes, such as `lib1`, three facilities specify shared object path searching.

- The dynamic array tag `DT_RUNPATH` gives 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.

  The set of directories specified by a given `DT_RUNPATH` entry is used to find only the immediate dependencies of the executable or shared object containing the `DT_RUNPATH` entry. That is, it is used only for those dependencies contained in the `DT_NEEDED` entries of the dynamic structure containing the `DT_RUNPATH` entry, itself. One object's `DT_RUNPATH` entry does not affect the search for any other object's dependencies.

- A variable called LD_LIBRARY_PATH in the process environment 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/usr/lib:/home/dir2/usr/lib:
  - LD_LIBRARY_PATH=/home/dir/usr/lib;/home/dir2/usr/lib:
  - LD_LIBRARY_PATH=/home/dir/usr/lib:/home/dir2/usr/lib:;

  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 previously.

  All LD_LIBRARY_PATH directories are searched before those from DT_RUNPATH.
- Finally, if the other two groups of directories fail to locate the desired library, the dynamic linker searches the default directories, /usr/lib or such other directories as may be specified by the psABI supplement.

When the dynamic linker is searching for shared objects, it is not a fatal error if an ELF file with the wrong attributes is encountered in the search. Instead, the dynamic linker shall exhaust the search of all paths before determining that a matching object could not be found. For this determination, the relevant attributes are contained in the following ELF header fields: e_ident[EI_DATA], e_ident[EI_CLASS], e_ident[EI_OSABI], e_ident[EI_ABIVERSION], e_machine, e_type, e_flags and e_version.

Note

For security, the dynamic linker ignores LD_LIBRARY_PATH for set-user and set-group ID programs. It does, however, search DT_RUNPATH directories and the default directories. The same restriction may be applied to processes that have more than minimal privileges on systems with installed extended security mechanisms.

Note

A fourth search facility, the dynamic array tag DT_RPATH, has been deprecated. It provides a colon-separated list of directories to search. Directories specified by DT_RPATH are searched before directories specified by LD_LIBRARY_PATH.

If both DT_RPATH and DT_RUNPATH entries appear in a single object's dynamic array, the dynamic linker processes only the DT_RUNPATH entry.

8.4.1 Substitution Sequences

Within a string provided by dynamic array entries with the DT_NEEDED or DT_RUNPATH tags and in pathnames passed as parameters to the dlopen() routine, a dollar sign ($) introduces a substitution sequence. This sequence consists of the dollar sign immediately followed by either the longest *name* sequence or a name contained within left and right braces ({) and (}). A name is a sequence of bytes that start with either a letter or an underscore followed by zero or more letters, digits or underscores. If a dollar sign is not immediately followed by a name or a brace-enclosed name, the behavior of the dynamic linker is unspecified.

If the name is "ORIGIN", then the substitution sequence is replaced by the dynamic linker with the absolute pathname of the directory in which the object containing the substitution sequence originated.

Moreover, the pathname will contain no symbolic links or use of "." or ".." components. Otherwise (when the name is not "ORIGIN") the behavior of the dynamic linker is unspecified.

When the dynamic linker loads an object that uses $ORIGIN, it must calculate the pathname of the directory containing the object. Because this calculation can be computationally expensive, implementations may want to avoid the calculation for objects that do not use $ORIGIN. If an object calls dlopen() with a string containing $ORIGIN and does not use $ORIGIN in one if its dynamic array entries, the dynamic linker may not have calculated the pathname for the object until the dlopen() actually occurs. Since the application may have changed its current working directory before the dlopen() call, the calculation may not yield the correct result. To avoid this possibility, an object may signal its intention to reference $ORIGIN by setting the DF_ORIGIN flag. An implementation may reject an attempt to use $ORIGIN within a dlopen() call from an object that did not set the DF_ORIGIN flag and did not use $ORIGIN within its dynamic array.

Note

For security, the dynamic linker does not allow use of $ORIGIN substitution sequences for set-user and set-group ID programs. For such sequences that appear within strings specified by DT_RUNPATH dynamic array entries, the specific search path containing the $ORIGIN sequence is ignored (though other search paths in the same string are processed). $ORIGIN sequences within a DT_NEEDED entry or path passed as a parameter to dlopen() are treated as errors. The same restrictions may be applied to processes that have more than minimal privileges on systems with installed extended security mechanisms.

8.5 Hash Table

A hash table of Elf32_Word objects supports symbol table access. The same table layout is used for both the 32-bit and 64-bit file class. Labels appear below to help explain the hash table organization, but they are not part of the specification.

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 compute a 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.

Listing 8.2: 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;
```

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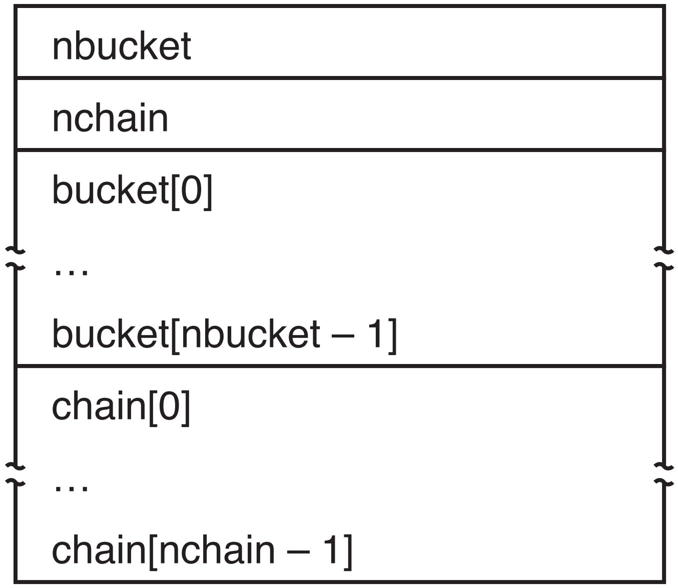

Figure 8.1: Hash Table

(continued from previous page)

```
    }
    return h;
}
```

8.6 Initialization and Termination Functions

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

Before the initialization functions for any object A is called, the initialization functions 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 functions for an object are 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 psABI 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).

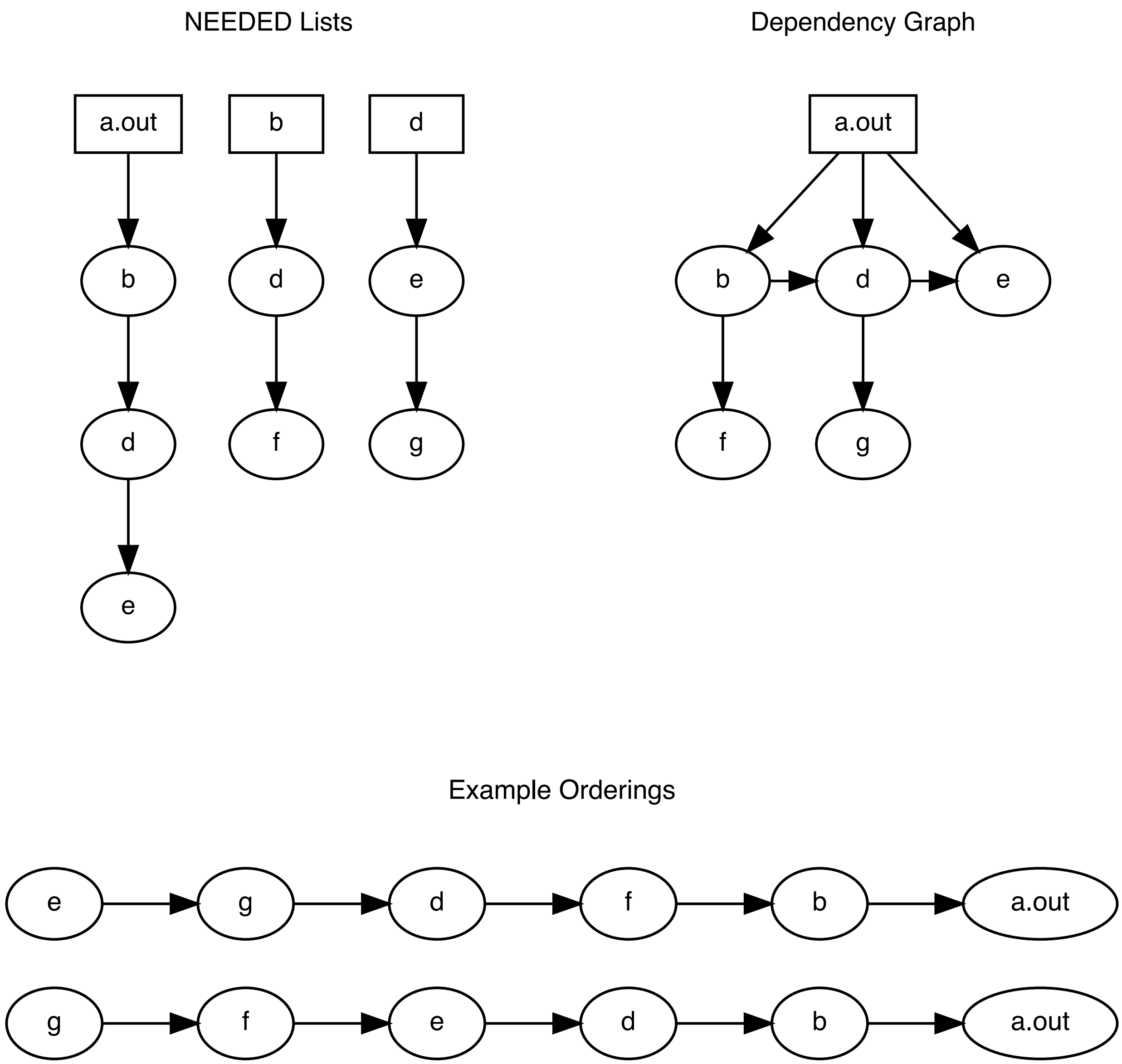

Figure 8.2: Initialization Ordering Example

Similarly, shared objects and executable files may have termination functions, which are executed with the `atexit()` mechanism after the base process begins its termination sequence. The termination functions for any object A must be called before the termination functions for any other objects that object A depends on. 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 termination for circular dependencies is undefined.

Finally, an executable file may have pre-initialization functions. These functions are executed after the dynamic linker has built the process image and performed relocations but before any shared object initialization functions. Pre-initialization functions are not permitted in shared objects.

> **Note**
>
> Complete initialization of system libraries may not have occurred when pre-initializations are executed, so some features of the system may not be available to pre-initialization code. In general, use of pre-initialization code can be considered portable only if it has no dependencies on system libraries.

The dynamic linker ensures that it will not execute any initialization, pre-initialization, or termination functions more than once.

Shared objects designate their initialization and termination code in one of two ways. First, they may specify the address of a function to execute via the `DT_INIT` and `DT_FINI` entries in the dynamic structure, described in Section 8.3, Dynamic Section.

> **Note**
>
> Note that the address of a function need not be the same as a pointer to a function as defined by the psABI supplement.

Shared objects may also (or instead) specify the address and size of an array of function pointers. Each element of this array is a pointer to a function to be executed by the dynamic linker. Each array element is the size of a pointer in the programming model followed by the object containing the array. The address of the array of initialization function pointers is specified by the `DT_INIT_ARRAY` entry in the dynamic structure. Similarly, the address of the array of pre-initialization functions is specified by `DT_PREINIT_ARRAY` and the address of the array of termination functions is specified by `DT_FINI_ARRAY`. The size of each array is specified by the `DT_INIT_ARRAYSZ`, `DT_PREINIT_ARRAYSZ`, and `DT_FINI_ARRAYSZ` entries.

> **Note**
>
> The addresses contained in the initialization and termination arrays are function pointers as defined by the psABI supplement for each processor. On some architectures, a function pointer may not contain the actual address of the function.

The functions pointed to in the arrays specified by `DT_INIT_ARRAY` and by `DT_PREINIT_ARRAY` are executed by the dynamic linker in the same order in which their addresses appear in the array; those specified by `DT_FINI_ARRAY` are executed in reverse order.

If an object contains both `DT_INIT` and `DT_INIT_ARRAY` entries, the function referenced by the `DT_INIT` entry is processed before those referenced by the `DT_INIT_ARRAY` entry for that object. If an object contains both `DT_FINI` and `DT_FINI_ARRAY` entries, the functions referenced by the `DT_FINI_ARRAY` entry are processed before the one referenced by the `DT_FINI` entry for that object.

> **Note**
>
> Although the `atexit()` 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()` or if the process dies because it received a signal that it neither caught nor ignored.

The psABI supplement for each processor specifies whether the dynamic linker is responsible for calling the executable file's initialization function or registering the executable file's termination function with `atexit()`. Termination functions specified by users via the `atexit()` mechanism must be executed before any termination functions of shared objects.

Appendix A

Assigned Machine Values

The table below lists all assigned `e_machine` values. This list is updated as new values are assigned, without updating the document version number.

To request assignment of an `e_machine` value for a new architecture, please email your request to registry@xinuos.com. Please include your contact information (preferably a company email address, not a free email provider), the name of the company, the name of the architecture with a brief description, your preferred `EM_xxx` name, and a link (if available) to any public information about the architecture.

Table A.1: `e_machine` Values

Name	Value	Meaning
EM_NONE	0	No machine
EM_M32	1	AT&T WE 32100
EM_SPARC	2	SPARC
EM_386	3	Intel 80386
EM_68K	4	Motorola 68000
EM_88K	5	Motorola 88000
EM_IAMCU	6	Intel MCU
EM_860	7	Intel 80860
EM_MIPS	8	MIPS I Architecture
EM_S370	9	IBM System/370 Processor
EM_MIPS_RS3_LE	10	MIPS RS3000 Little-endian
reserved	11–14	Reserved for future use
EM_PARISC	15	Hewlett-Packard PA-RISC
reserved	16	Reserved for future use
EM_VPP500	17	Fujitsu VPP500
EM_SPARC32PLUS	18	Enhanced instruction set SPARC
EM_960	19	Intel 80960
EM_PPC	20	PowerPC
EM_PPC64	21	64-bit PowerPC
EM_S390	22	IBM System/390 Processor
EM_SPU	23	IBM SPU/SPC
reserved	24–35	Reserved for future use
EM_V800	36	NEC V800
EM_FR20	37	Fujitsu FR20
EM_RH32	38	TRW RH-32
EM_RCE	39	Motorola RCE

continues on next page

Table A.1 – continued from previous page

Name	Value	Meaning
EM_ARM	40	ARM 32-bit architecture (AARCH32)
EM_ALPHA	41	Digital Alpha
EM_SH	42	Hitachi SH
EM_SPARCV9	43	SPARC Version 9
EM_TRICORE	44	Siemens TriCore embedded processor
EM_ARC	45	Argonaut RISC Core, Argonaut Technologies Inc.
EM_H8_300	46	Hitachi H8/300
EM_H8_300H	47	Hitachi H8/300H
EM_H8S	48	Hitachi H8S
EM_H8_500	49	Hitachi H8/500
EM_IA_64	50	Intel IA-64 processor architecture
EM_MIPS_X	51	Stanford MIPS-X
EM_COLDFIRE	52	Motorola ColdFire
EM_68HC12	53	Motorola M68HC12
EM_MMA	54	Fujitsu MMA Multimedia Accelerator
EM_PCP	55	Siemens PCP
EM_NCPU	56	Sony nCPU embedded RISC processor
EM_NDR1	57	Denso NDR1 microprocessor
EM_STARCORE	58	Motorola Star*Core processor
EM_ME16	59	Toyota ME16 processor
EM_ST100	60	STMicroelectronics ST100 processor
EM_TINYJ	61	Advanced Logic Corp. TinyJ embedded processor family
EM_X86_64	62	AMD x86-64 architecture
EM_PDSP	63	Sony DSP Processor
EM_PDP10	64	Digital Equipment Corp. PDP-10
EM_PDP11	65	Digital Equipment Corp. PDP-11
EM_FX66	66	Siemens FX66 microcontroller
EM_ST9PLUS	67	STMicroelectronics ST9+ 8/16 bit microcontroller
EM_ST7	68	STMicroelectronics ST7 8-bit microcontroller
EM_68HC16	69	Motorola MC68HC16 Microcontroller
EM_68HC11	70	Motorola MC68HC11 Microcontroller
EM_68HC08	71	Motorola MC68HC08 Microcontroller
EM_68HC05	72	Motorola MC68HC05 Microcontroller
EM_SVX	73	Silicon Graphics SVx
EM_ST19	74	STMicroelectronics ST19 8-bit microcontroller
EM_VAX	75	Digital VAX
EM_CRIS	76	Axis Communications 32-bit embedded processor
EM_JAVELIN	77	Infineon Technologies 32-bit embedded processor
EM_FIREPATH	78	Element 14 64-bit DSP Processor
EM_ZSP	79	LSI Logic 16-bit DSP Processor
EM_MMIX	80	Donald Knuth's educational 64-bit processor
EM_HUANY	81	Harvard University machine-independent object files
EM_PRISM	82	SiTera Prism
EM_AVR	83	Atmel AVR 8-bit microcontroller
EM_FR30	84	Fujitsu FR30
EM_D10V	85	Mitsubishi D10V
EM_D30V	86	Mitsubishi D30V
EM_V850	87	NEC v850
EM_M32R	88	Mitsubishi M32R

continues on next page

Table A.1 – continued from previous page

Name	Value	Meaning
EM_MN10300	89	Matsushita MN10300
EM_MN10200	90	Matsushita MN10200
EM_PJ	91	picoJava
EM_OPENRISC	92	OpenRISC 32-bit embedded processor
EM_ARC_COMPACT	93	ARC International ARCompact processor (old spelling/synonym: EM_ARC_A5)
EM_XTENSA	94	Tensilica Xtensa Architecture
EM_VIDEOCORE	95	Alphamosaic VideoCore processor
EM_TMM_GPP	96	Thompson Multimedia General Purpose Processor
EM_NS32K	97	National Semiconductor 32000 series
EM_TPC	98	Tenor Network TPC processor
EM_SNP1K	99	Trebia SNP 1000 processor
EM_ST200	100	STMicroelectronics (www.st.com) ST200 microcontroller
EM_IP2K	101	Ubicom IP2xxx microcontroller family
EM_MAX	102	MAX Processor
EM_CR	103	National Semiconductor CompactRISC microprocessor
EM_F2MC16	104	Fujitsu F2MC16
EM_MSP430	105	Texas Instruments embedded microcontroller msp430
EM_BLACKFIN	106	Analog Devices Blackfin (DSP) processor
EM_SE_C33	107	S1C33 Family of Seiko Epson processors
EM_SEP	108	Sharp embedded microprocessor
EM_ARCA	109	Arca RISC Microprocessor
EM_UNICORE	110	Microprocessor series from PKU-Unity Ltd. and MPRC of Peking University
EM_EXCESS	111	eXcess: 16/32/64-bit configurable embedded CPU
EM_DXP	112	Icera Semiconductor Inc. Deep Execution Processor
EM_ALTERA_NIOS2	113	Altera Nios II soft-core processor
EM_CRX	114	National Semiconductor CompactRISC CRX microprocessor
EM_XGATE	115	Motorola XGATE embedded processor
EM_C166	116	Infineon C16x/XC16x processor
EM_M16C	117	Renesas M16C series microprocessors
EM_DSPIC30F	118	Microchip Technology dsPIC30F Digital Signal Controller
EM_CE	119	Freescale Communication Engine RISC core
EM_M32C	120	Renesas M32C series microprocessors
reserved	121–130	Reserved for future use
EM_TSK3000	131	Altium TSK3000 core
EM_RS08	132	Freescale RS08 embedded processor
EM_SHARC	133	Analog Devices SHARC family of 32-bit DSP processors
EM_ECOG2	134	Cyan Technology eCOG2 microprocessor
EM_SCORE7	135	Sunplus S+core7 RISC processor
EM_DSP24	136	New Japan Radio (NJR) 24-bit DSP Processor
EM_VIDEOCORE3	137	Broadcom VideoCore III processor
EM_LATTICEMICO32	138	RISC processor for Lattice FPGA architecture
EM_SE_C17	139	Seiko Epson C17 family
EM_TI_C6000	140	The Texas Instruments TMS320C6000 DSP family
EM_TI_C2000	141	The Texas Instruments TMS320C2000 DSP family
EM_TI_C5500	142	The Texas Instruments TMS320C55x DSP family

continues on next page

Table A.1 – continued from previous page

Name	Value	Meaning
EM_TI_ARP32	143	Texas Instruments Application Specific RISC Processor, 32bit fetch
EM_TI_PRU	144	Texas Instruments Programmable Realtime Unit
reserved	145–159	Reserved for future use
EM_MMDSP_PLUS	160	STMicroelectronics 64bit VLIW Data Signal Processor
EM_CYPRESS_M8C	161	Cypress M8C microprocessor
EM_R32C	162	Renesas R32C series microprocessors
EM_TRIMEDIA	163	NXP Semiconductors TriMedia architecture family
EM_QDSP6	164	QUALCOMM DSP6 Processor
EM_8051	165	Intel 8051 and variants
EM_STXP7X	166	STMicroelectronics STxP7x family of configurable and extensible RISC processors
EM_NDS32	167	Andes Technology compact code size embedded RISC processor family
EM_ECOG1	168	Cyan Technology eCOG1X family
EM_ECOG1X	168	Cyan Technology eCOG1X family
EM_MAXQ30	169	Dallas Semiconductor MAXQ30 Core Micro-controllers
EM_XIMO16	170	New Japan Radio (NJR) 16-bit DSP Processor
EM_MANIK	171	M2000 Reconfigurable RISC Microprocessor
EM_CRAYNV2	172	Cray Inc. NV2 vector architecture
EM_RX	173	Renesas RX family
EM_METAG	174	Imagination Technologies META processor architecture
EM_MCST_ELBRUS	175	MCST Elbrus general purpose hardware architecture
EM_ECOG16	176	Cyan Technology eCOG16 family
EM_CR16	177	National Semiconductor CompactRISC CR16 16-bit microprocessor
EM_ETPU	178	Freescale Extended Time Processing Unit
EM_SLE9X	179	Infineon Technologies SLE9X core
EM_L10M	180	Intel L10M
EM_K10M	181	Intel K10M
reserved	182	Reserved for future Intel use
EM_AARCH64	183	ARM 64-bit architecture (AARCH64)
reserved	184	Reserved for future ARM use
EM_AVR32	185	Atmel Corporation 32-bit microprocessor family
EM_STM8	186	STMicroeletronics STM8 8-bit microcontroller
EM_TILE64	187	Tilera TILE64 multicore architecture family
EM_TILEPRO	188	Tilera TILEPro multicore architecture family
EM_MICROBLAZE	189	Xilinx MicroBlaze 32-bit RISC soft processor core
EM_CUDA	190	NVIDIA CUDA architecture
EM_TILEGX	191	Tilera TILE-Gx multicore architecture family
EM_CLOUDSHIELD	192	CloudShield architecture family
EM_COREA_1ST	193	KIPO-KAIST Core-A 1st generation processor family
EM_COREA_2ND	194	KIPO-KAIST Core-A 2nd generation processor family
EM_ARC_COMPACT2	195	Synopsys ARCompact V2
EM_OPEN8	196	Open8 8-bit RISC soft processor core
EM_RL78	197	Renesas RL78 family
EM_VIDEOCORE5	198	Broadcom VideoCore V processor
EM_78KOR	199	Renesas 78KOR family
EM_56800EX	200	Freescale 56800EX Digital Signal Controller (DSC)

continues on next page

Table A.1 – continued from previous page

Name	Value	Meaning
EM_BA1	201	Beyond BA1 CPU architecture
EM_BA2	202	Beyond BA2 CPU architecture
EM_XCORE	203	XMOS xCORE processor family
EM_MCHP_PIC	204	Microchip 8-bit PIC(r) family
EM_INTEL205	205	Reserved by Intel
EM_INTEL206	206	Reserved by Intel
EM_INTEL207	207	Reserved by Intel
EM_INTEL208	208	Reserved by Intel
EM_INTEL209	209	Reserved by Intel
EM_KM32	210	KM211 KM32 32-bit processor
EM_KMX32	211	KM211 KMX32 32-bit processor
EM_KMX16	212	KM211 KMX16 16-bit processor
EM_KMX8	213	KM211 KMX8 8-bit processor
EM_KVARC	214	KM211 KVARC processor
EM_CDP	215	Paneve CDP architecture family
EM_COGE	216	Cognitive Smart Memory Processor
EM_COOL	217	Bluechip Systems CoolEngine
EM_NORC	218	Nanoradio Optimized RISC
EM_CSR_KALIMBA	219	CSR Kalimba architecture family
EM_Z80	220	Zilog Z80
EM_VISIUM	221	Controls and Data Services VISIUMcore processor
EM_FT32	222	FTDI Chip FT32 high performance 32-bit RISC architecture
EM_MOXIE	223	Moxie processor family
EM_AMDGPU	224	AMD GPU architecture
reserved	225–242	Reserved for future use
EM_RISCV	243	RISC-V
EM_LANAI	244	Lanai processor
EM_CEVA	245	CEVA Processor Architecture Family
EM_CEVA_X2	246	CEVA X2 Processor Family
EM_BPF	247	Linux BPF – in-kernel virtual machine
EM_GRAPHCORE_IPU	248	Graphcore Intelligent Processing Unit
EM_IMG1	249	Imagination Technologies
EM_NFP	250	Netronome Flow Processor (NFP)
EM_VE	251	NEC Vector Engine
EM_CSKY	252	C-SKY processor family
EM_ARC_COMPACT3_64	253	Synopsys ARCv2.3 64-bit
EM_MCS6502	254	MOS Technology MCS 6502 processor
EM_ARC_COMPACT3	255	Synopsys ARCv2.3 32-bit
EM_KVX	256	Kalray VLIW core of the MPPA processor family
EM_65816	257	WDC 65816/65C816
EM_LOONGARCH	258	Loongson Loongarch
EM_KF32	259	ChipON KungFu32
EM_U16_U8CORE	260	LAPIS nX-U16/U8
EM_TACHYUM	261	Reserved for Tachyum processor
EM_56800EF	262	NXP 56800EF Digital Signal Controller (DSC)
EM_SBF	263	Solana Bytecode Format
EM_AIENGINE	264	AMD/Xilinx AIEngine architecture
EM_SIMA_MLA	265	SiMa MLA
EM_BANG	266	Cambricon BANG

continues on next page

Table A.1 – continued from previous page

Name	Value	Meaning
EM_LOONGGPU	267	Loongson LoongGPU

Appendix B

Assigned OSABI Values

The table below lists all assigned EI_OSABI values. This list is updated as new values are assigned, without updating the document version number.

Values in the architecture-specific value range may be used for a specific e_machine value, without registration. It is advisable to coordinate with other potential users of that architecture to avoid conflicts.

To request assignment of an EI_OSABI value for a new OSABI, please email your request to registry@xinuos.com. Please include your contact information (preferably a company email address, not a free email provider), the name of the company, the name of the operating system with a brief description, your preferred ELFOSABI_xxx name, and a link (if available) to any public information about the OS.

Table B.1: EI_OSABI Values

Name	Value	Meaning
ELFOSABI_NONE	0	No extensions or unspecified
ELFOSABI_HPUX	1	Hewlett-Packard HP-UX
ELFOSABI_NETBSD	2	NetBSD
ELFOSABI_GNU	3	GNU
ELFOSABI_LINUX	3	Linux (*historical—alias for ELFOSABI_GNU*)
ELFOSABI_SOLARIS	6	Sun Solaris
ELFOSABI_AIX	7	AIX
ELFOSABI_IRIX	8	IRIX
ELFOSABI_FREEBSD	9	FreeBSD
ELFOSABI_TRU64	10	Compaq TRU64 UNIX
ELFOSABI_MODESTO	11	Novell Modesto
ELFOSABI_OPENBSD	12	Open BSD
ELFOSABI_OPENVMS	13	Open VMS
ELFOSABI_NSK	14	Hewlett-Packard Non-Stop Kernel
ELFOSABI_AROS	15	Amiga Research OS
ELFOSABI_FENIXOS	16	The FenixOS highly scalable multi-core OS
ELFOSABI_CLOUDABI	17	Nuxi CloudABI
ELFOSABI_OPENVOS	18	Stratus Technologies OpenVOS
	64-255	Architecture-specific value range

Appendix C

Revision History

First Draft (Published May 14, 1998)

Second Draft (Published May 3, 1999)

- New values introduced for ELF header `e_machine` field.
- Revised language for `EI_OSABI` and `EI_ABIVERSION` fields of the ELF header `e_ident` array.
- New section flags `SHF_MERGE` and `SHF_STRINGS` added.
- New values added to a symbol table entry's `st_other` field to describe a symbol's visibility.
- New dynamic section tags `DT_RUNPATH` and `DT_FLAGS` added. Deprecated dynamic section tag `DT_RPATH`.
- New semantics for shared object path searching, including new "Substitution Sequences".

Third Draft (Published May 12, 1999)

- A new symbol type, `STT_COMMON`, has been added.
- Added language restricting the types of objects that may contain symbols with the section index `SHN_COMMON`.
- Dynamic section entries `DT_SYMBOLIC`, `DT_TEXTREL` and `DT_BIND_NOW` have been deprecated. New `DT_FLAGS` values `DF_SYMBOLIC`, `DF_TEXTREL` and `DF_BIND_NOW` have been added as replacements.
- New rules for interpreting dynamic section tag encodings have been added.
- The OS and processor specific ranges for `DT_FLAGS` have been removed.
- The language motivating the use of `DF_ORIGIN` has been changed.

Fourth Draft (Published July 6, 1999)

- New language has been added warning about the use of WEAK symbols in application programs.
- New rules have been defined for composition of consecutive relocation entries that reference the same location.
- Language has been added clarifying the order of execution for functions specified by initialization and termination arrays.

Fifth Draft (Published July 21, 1999)

- New section types and section names added for init arrays, fini arrays, and pre-init arrays.

- An object may now have both DT_INIT and DT_INIT_ARRAY entries (and both DT_FINI and DT_FINI_ARRAY entries). The relative execution order is specified.
- The language describing the order of execution for termination functions has been revised.
- A new pre-initialization mechanism has been added.
- It is now up to the psABI supplement for each processor to specify whether the dynamic linker must invoke the executable file's init and fini routines.

Sixth Draft (Published September 14, 1999)

- Changed the numbering of some new section types previously added to account for type numbers already in use in particular vendor implementations.
- Increased the number of section flag bits available in the OS specific range.

Seventh Draft (Published October 4, 1999)

- Changed the values used for some new section attribute flags to accommodate platforms already using previously assigned values.
- Added new section attribute flags SHF_INFO_LINK, SHF_LINK_ORDER, and SHF_OS_NONCONFORMING
- Added rules for linkers when linking sections with unrecognized types or flags.

Eighth Draft (Published March 30, 2000)

- Added the concept of section groups.
- Removed the macros for ELF32_ST_OTHER and ELF64_ST_OTHER.

Ninth Draft (Published March 30, 2000)

- Added language clarifying the semantics of symbols marked as STV_PROTECTED.
- Added language clarifying the contents of the initialization and termination arrays.

Tenth Draft (Published 22 June 2000)

- Added a sentence spelling out the behavior when resolving a symbol to a STV_PROTECTED definition from a shared object.
- Added support for more than 65,000 sections in the ELF header, and with SHT_SYMTAB_SHNDX sections, and in symbol tables.

Eleventh Draft (Published 24 April 2001)

- Updated table of EM_* entries.
- Added GRP_MASKOS and GRP_MASKPROC. Changed section group description in a few ways, clarifying some fuzzy points and rewriting the rules for symbols referencing into section groups.
- Changed the warning about using weak to be stronger.
- Reworded the EI_OSABI byte description to make its use clearer.
- Added the table of now generic EI_OSABI values.
- Added SHF_TLS, PT_TLS and its contents, DF_STATIC_TLS, STT_TLS, .tbss, and .tdata.
- Changed the rules for SHT_SYMTAB_SHNDX contents to require 0 when the corresponding st_shndx field is not SHN_XINDEX.

Twelfth Draft (Published 26 March 2007)

- Updated table of EM_* entries.

Thirteenth Draft (Published 03 November 2009)

- Updated table of EM_* entries.
- Added `ELFOSABI_FENIXOS` to the `EI_OSABI` values.
- Added `ELFOSABI_GNU` to the `EI_OSABI` values; aliased to `ELFOSABI_LINUX`.

Fourteenth Draft (Published 10 June 2013)

- Added `SHF_COMPRESSED` to the Section Attribute Flags.
- Updated table of EM_* entries.

Fifteenth Draft (Published 23 July 2015)

- Clarified the description of `SHT_SYMTAB_SHNDX`; allow usage with any symbol table section.
- Added `DT_SYMTAB_SHNDX` to the Dynamic Array Tags.

Version 4.2 (Published 2025)

- Converted to ReStructuredText.
- ELF specification is now separate from the gABI document.
- Removed empty placeholders for psABI sections.

Version 4.3 (DRAFT)

- Added extra requirements for `SHF_LINKORDER` flag.
- Added relative relocation table (`Elf32_Relr` and `Elf64_Relr`).
- Changed the symbol visibility attribute to use the lower 3 bits of `st_other` (instead of 2 bits).
- Added `DT_SYMTABSZ` entry, and made `DT_HASH` optional if `DT_SYMTABSZ` is provided.
- Changed `SHF_COMPRESSED` to allow with `SHF_ALLOC` sections in `ET_REL` objects.