

ELF1 1E Symbol Table Section

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"Study of ELF loading and relocs", 1999

http://netwinder.osuosl.org/users/p/patb/public_html/elf_relocs.html

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Compiling 32-bit program on 64-bit gcc

- `gcc -v`
- `gcc -m32 t.c`
- `sudo apt-get install gcc-multilib`
- `sudo apt-get install g++-multilib`
- `gcc-multilib`
- `g++-multilib`
- `gcc -m32`
- `objdump -m i386`

uninitialized global variable (1)

gcc, in C mode:

- **uninitialised globals** which are not declared **extern** are treated as **common** symbols, not **weak** symbols.
- **common** symbols are merged at link time so that they all refer to the same storage;
 - if more than one object attempts to *initialise* such a symbol, you will get a *link-time error*
 - if they are not explicitly initialised anywhere, they will be placed in the **BSS**, i.e. initialised to **0**.

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

uninitialized global variable (2)

gcc, in C++ mode:

- not the same as in c mode
- there is no **common** symbols in C++
- **Uninitialised globals** which are not declared **extern** are implicitly initialised to a default value (0 for simple types, or default constructor).

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

uninitialized global variable (3)

- In either case,
a **weak** symbol allows an initialised symbol to be overridden by a **non-weak** initialised symbol of the same name at link time

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is-weak>

uninitialized global variable (4)

1. init

```
int global = 999;  
  
int main(void) { ... }
```

2. uninit

```
int global;  
  
int main(void) { ... }
```

3. uninit, extern

```
extern int global;  
  
int main(void) { ... }
```

4. init, weak

```
int global __attribute__((weak))  
    = 999;  
  
int main(void) { ... }
```

5. another init global

```
int global = 1234;
```

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

uninitialized global variable (5)

1. init

```
#include <stdio.h>
int global = 999;
int main(void) {
    printf("%d\n", global);
    return 0;
}
```

2. uninit

```
#include <stdio.h>
int global;
int main(void) {
    printf("%d\n", global);
    return 0;
}
```

3. uninit, extern

```
#include <stdio.h>
extern int global;
int main(void) {
    printf("%d\n", global);
    return 0;
}
```

4. init, weak

```
#include <stdio.h>
int global __attribute__((weak))
    = 999;
int main(void) {
    printf("%d\n", global);
    return 0;    }
```

5. another init global

```
int global = 1234;
```

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

1. init

```
$ gcc -o test uninit.c && ./test  
0
```

```
$ gcc -o test uninit.c another.c && ./test  
1234
```

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

2. uninit

```
$ gcc -o test init.c another.c && ./test
/tmp/cc5DQeaz.o:(.data+0x0): multiple definition of 'global'
/tmp/ccgyz6rL.o:(.data+0x0): first defined here
collect2: ld returned 1 exit status
```

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

3. uninit, extern

```
$ gcc -o test uninit_extern.c && ./test
/tmp/ccqdYUIr.o: In function 'main':
main_uninit_extern.c:(.text+0x12): undefined reference to 'global'
collect2: ld returned 1 exit status#end_src
```

```
$ gcc -o test main_uninit_extern.c another_def.c && ./test
1234
```

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

Case 4 init, weak

4. init, weak

```
$ gcc -o test init_weak.c && ./test  
999
```

```
$ gcc -o test init_weak.c another.c && ./test  
1234
```

<https://stackoverflow.com/questions/3691835/why-uninitialized-global-variable-is->

Case 5 weak, strong

weak.c

```
#include <stdio.h>

int weak; /* global, weak, zero */

int main(void) {
    printf("weak value is %d.\n", weak);
    return 0;
}
```

strong.c

```
int weak = 42; /* global, strong, 42 */
```

running

```
$ gcc weak.c
$ ./a.out
weak value is 0.
$ gcc weak.c strong.c
$ ./a.out
weak value is 42.
```

Weak symbols (1)

- **Weak symbol** references that remain unresolved, do not result in a fatal error condition, no matter what output file type is being generated.
- If a **static executable** is being generated, the symbol is converted to an **absolute symbol** with an assigned value of zero

<https://docs.oracle.com/cd/E19120-01/open.solaris/819-0690/chapter2-11/index.html>

Weak symbols (2)

- If a **dynamic executable** or **shared object** is being produced, the symbol is left as an undefined weak reference with an assigned value of zero
- During process execution, the **runtime linker** searches for this symbol.
- If the **runtime linker** does not find a match, the reference is bound to an address of zero instead of generating a fatal relocation error.

<https://docs.oracle.com/cd/E19120-01/open.solaris/819-0690/chapter2-11/index.html>

Weak symbols (3)

- Historically, these undefined **weak** referenced **symbols** have been employed as a mechanism to test for the existence of functionality.
- For example, the following C code fragment might have been used in the **shared object** `libfoo.so.1`

<https://docs.oracle.com/cd/E19120-01/open.solaris/819-0690/chapter2-11/index.html>

Weak symbols (4)

weak symbols

```
#pragma weak    foo

extern void    foo(char *);

void bar(char *path)
{
    void (*fptr)(char *);

    if ((fptr = foo) != 0)
        (*fptr)(path);
}
```

<https://docs.oracle.com/cd/E19120-01/open.solaris/819-0690/chapter2-11/index.html>

Weak symbols (5)

- When building an application that references `libfoo.so.1`, the **link-edit** completes successfully *regardless* of whether a definition for the symbol `foo` is found
- If during execution of the application the function address tests nonzero, the function is called.
- However, if the symbol definition is not found, the function address tests zero and therefore is not called.

<https://docs.oracle.com/cd/E19120-01/open.solaris/819-0690/chapter2-11/index.html>

Weak symbols (6)

- Compilation systems view this **address comparison** technique as having undefined semantics, which can result in the test statement being *removed* under optimization.
- In addition, the **runtime symbol binding** mechanism places other *restrictions* on the use of this technique.
- These *restrictions prevent* a consistent model from being made available for *all* dynamic objects

<https://docs.oracle.com/cd/E19120-01/open.solaris/819-0690/chapter2-11/index.html>

Common symbols (1)

- **common** symbols allow a programmer to *define* several variables of the same name in different source files
- the other way is to define a variable once in *one* source file, and reference it everywhere else in *other* source files, using **extern**

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

Common symbols (2)

- when **common** symbols are used, the linker will merge all symbols of the same name into a single memory location
- the size of which is the largest type of the individual **common** symbol definitions.

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

Common symbols (3)

- `fileA.c` defines an uninitialized 32-bit integer `myint`
- `fileB.c` defines an 8-bit character `myint`,
- then in the final executable, references to `myint` from both files will point to the same memory location (**common** location), and the linker will reserve 32 bits for that location.

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

Common symbols (4)

- COMMON symbols are contained only in relocatable object files, not in executable object files.
- they are generated by the compiler / assembler when creating an object file from a single source file.
- later, the linker will need to interpret these symbols.

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

Common symbols (5)

- Remember that ELF reserves a special section header table index for referring to a **COMMON** section:
- the index **COM**
 - just like the special indices ABS and UND,
 - these sections do not physically exist in the file
- **common** symbols defined in the symbol table of **relocatable** object files have their section index member set to **COM**

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-sym>

Common symbols (6)

- **common** symbols first appeared as a feature of the FORTRAN language.
- **common** symbols are present only for backward-compatibility with *old* source files where **extern** is not used
- nowadays, the best practice is to make use of *only one* definition of a variable, and use **extern** in all *other source files* that reference it

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

Common symbols (7)

- if a global variable is not initialized in a C source file,
- after compiling, we would expect the variable to go to the `.bss` section in the `relocatable` object file
- However, *by default*, GCC will put the symbol in the `COMMON` section of the file;
- that is, the option `-fcommon` is the default behaviour.

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

One file (1a) COMMON

- *by default*, the uninitialized variable `un_a` is put in the **common** section.

```
int un_a → COM un_a (common)
```

- when compile with **-fno-common**, the section of `un_a` is now at index 3, which is the **.bss** section

```
int un_a, -fno-common → 3 un_a (.bss)
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol>

One file (1b) COMMON

main.c

```
int un_a;    // common

int main() {
    return 0;
}
```

script

```
gcc -c -o main.o main.c
readelf -s main.o

gcc -c -o main.o main.c -fno-common
readelf -s main.o
```

results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
```

Symbol table '.symtab' contains 10 entries:

Num:	Value	Size	Type	Bind	Vis	Ndx	Name
8:	0000000000000004	4	OBJECT	GLOBAL	DEFAULT	COM	un_a

```
$> gcc -c -o main.o main.c -fno-common
$> readelf -s main.o
```

Symbol table '.symtab' contains 10 entries:

Num:	Value	Size	Type	Bind	Vis	Ndx	Name
8:	0000000000000000	4	OBJECT	GLOBAL	DEFAULT	3	un_a

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

One file (2a) .data

- if the variable is initialized to a certain value, then it is placed in the `.data` section in the output file by the compiler (actually the assembler)
- note that section index 2 corresponds to the `.data` section here:
`int un_a=9 → 2 un_a (.data)`
- use `-SW` options to `readelf` to list all sections

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

One file (2b) .data

main.c

```
int un_a = 9;    // .data

int main() {
    return 0;
}
```

script

```
$> gcc -c -o main.o main.c

$> readelf -s main.o
```

results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
Symbol table '.symtab' contains 10 entries:
   Num:      Value              Size Type      Bind   Vis      Ndx Name
     8: 0000000000000000         4 OBJECT GLOBAL DEFAULT    2 un_a
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol>

One file (3a) .bss

- If we define a global variable, and explicitly initialise it to **zero**, then it will be put in the **.bss** section
`int un_a=0 → 2 un_a (.bss)`
- although it is initialized and logically should go into **.data**, the compiler knows it is optimal to put it in the **.bss**, as in any case it will become initialized to **zero** at runtime, and in **.bss** will not consume *file space*

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbols/>

One fiel (3b) .bss

main.c

```
int un_a = 0;    // .bss

int main() {
    return 0;
}
```

script

```
$> gcc -c -o main.o main.c

$> readelf -s main.o
```

results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
Symbol table '.symtab' contains 10 entries:
```

Num:	Value	Size	Type	Bind	Vis	Ndx	Name
8:	0000000000000000	4	OBJECT	GLOBAL	DEFAULT	3	un_a

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two object files defining the same symbol

main.c		swap.c		prog
int un_a	COM	int un_a=0	.bss	.bss
int un_a	COM	extern int un_a	UND	.bss
int un_a	COM	int un_a	COM	.bss
int un_a	COM	int un_a=9	.data	multiple definition

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (1a) COMMON, .bss

- 1 Two object files defining the same symbol (COMMON, .bss)

main.c

```
int un_a;    // common

int main() {
    return 0;
}
```

swap.c

```
int un_a=0; // .bss

int swap() {
    return 108;
}
```

script

```
$> gcc -c -o main.o main.c
$> gcc -c -o swap.o swap.c
$> gcc -o prog main.o swap.o
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (1b) COMMON, .bss

- 1 Two object files defining the same symbol (COMMON, .bss)

script and results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
Symbol table '.symtab' contains 10 entries:
   Num:      Value              Size Type      Bind   Vis      Ndx Name
     8: 0000000000000004          4 OBJECT GLOBAL DEFAULT  COM un_a

$> gcc -c -o swap.o swap.c
$> readelf -s swap.o
     8: 0000000000000000          4 OBJECT GLOBAL DEFAULT   3 un_a

$> gcc -o prog main.o swap.o
$> readelf -s prog | grep 'un_a'
    49: 0000000000601030          4 OBJECT GLOBAL DEFAULT  25 un_a
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (2a) COMMON, undefined

- 2 Two object files defining the same symbol (COMMON, undefined)

main.c

```
int un_a;  
  
int main() {  
    return 0;  
}
```

swap.c

```
extern int un_a;  
  
int swap() {  
    int a = un_a;  
    return 108;  
}
```

script

```
$> gcc -c -o main.o main.c  
$> gcc -c -o swap.o swap.c  
$> gcc -o prog main.o swap.o
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (2b) COMMON, undefined

- Two object files defining the same symbol (COMMON, undefined)

script and results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
Symbol table '.symtab' contains 10 entries:
   Num:      Value              Size Type      Bind   Vis      Ndx Name
     8: 0000000000000004         4 OBJECT GLOBAL DEFAULT COM un_a

$> gcc -c -o swap.o swap.c
$> readelf -s swap.o
     9: 0000000000000000         0 NOTYPE GLOBAL DEFAULT UND un_a

$> gcc -o prog main.o swap.o
$> readelf -s prog | grep 'un_a'
   49: 0000000000601030         4 OBJECT GLOBAL DEFAULT 25 un_a
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (3a) COMMON, COMMON

- ③ Two object files defining the same symbol (COMMON, COMMON)

main.c

```
int un_a;  
  
int main() {  
    return 0;  
}
```

swap.c

```
int un_a;  
  
int swap() {  
    return 108;  
}
```

script

```
$> gcc -c -o main.o main.c  
$> gcc -c -o swap.o swap.c  
$> gcc -o prog main.o swap.o
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (3b) COMMON, COMMON

- 3 Two object files defining the same symbol (COMMON, COMMON)

script and results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
Symbol table '.symtab' contains 10 entries:
   Num:      Value              Size Type      Bind   Vis      Ndx Name
     8: 0000000000000004         4 OBJECT GLOBAL DEFAULT COM un_a

$> gcc -c -o swap.o swap.c
$> readelf -s swap.o
     8: 0000000000000004         4 OBJECT GLOBAL DEFAULT COM un_a

$> gcc -o prog main.o swap.o
$> readelf -s prog | grep 'un_a'
   49: 0000000000601030         4 OBJECT GLOBAL DEFAULT 25 un_a
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (4a) .bss, .data

- ④ Two object files defining the same symbol (.bss, .data)

main.c

```
int un_a=0;

int main() {
    return 0;
}
```

swap.c

```
int un_a=9;

int swap() {
    return 108;
}
```

script

```
$> gcc -c -o main.o main.c
$> gcc -c -o swap.o swap.c
$> gcc -o prog main.o swap.o
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

Two files (4b) .bss, .data

- ④ Two object files defining the same symbol (.bss, .data)

script and results

```
$> gcc -c -o main.o main.c
$> readelf -s main.o
Symbol table '.symtab' contains 10 entries:
   Num:      Value                Size Type      Bind   Vis      Ndx Name
     8: 0000000000000000          4 OBJECT GLOBAL DEFAULT    3 un_a

$> gcc -c -o swap.o swap.c
$> readelf -s swap.o
     8: 0000000000000000          4 OBJECT GLOBAL DEFAULT    2 un_a

$> gcc -o prog main.o swap.o
swap.o:(.data+0x0): multiple definition of 'un_a'
main.o:(.bss+0x0): first defined here
collect2: error: ld returned 1 exit status
```

<https://binarydodo.wordpress.com/2016/05/09/investigating-linking-with-common-symbol/>

TOC: Symbol table section

- uninitialized global variables
- Symbol table
- Global and weak symbols

TOC: Symbol table section

Symbol table (1)

- 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

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Symbol table (2)

- the first byte is index zero, holds a null character ($\backslash 0$)
- the last byte holds a null character ($\backslash 0$) ensuring null termination for all strings.
- A string with zero index specifies either no name or a null name, depending on the context.

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Elf32_Sym structure type

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

- **st_name** :
An index into the object
file's symbol **string table**

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Elf32_Sym field types (1) st_name, st_value

- **st_name**
 - an index into the object file's symbol string table, which holds the character representations of the symbol names.
 - if the value is nonzero, the value represents a string table index that gives the symbol name.
 - otherwise, the symbol table entry has no name.
- **st_value**
 - the value of the associated symbol.
 - the value can be an absolute value or an address, depending on the context. See Symbol Values.

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

- **st_size**
 - Many symbols have associated sizes.
 - For example, a data object's size is the number of bytes that are contained in the object.
 - This member holds the value zero if the symbol has no size or an unknown size.
- **st_info**
 - The symbol's type and binding attributes.
 - A list of the values and meanings appears in Table

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

- **st_shndx**
 - every **symbol table** entry is defined in relation to some section
 - **st_shndx** member holds the relevant **section header table** index
- 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 member.
 - The actual value is contained in the associated section of type SHT_SYMTAB_SHNDX

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Elf32_Sym fields type (4) st_other

- **st_other**
 - A symbol's **visibility**
 - Other bits are set to zero, and have no defined meaning.
- symbol binding

STB_LOCAL	0
STB_GLOBAL	1
STB_WEAK	2
STB_LOOS	10
STB_HIOS	12
STB_LOPROC	13
STB_HIPROC	15

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

ELF Symbol binding (1)

- **STB_LOCAL**: Local symbol.
 - These symbols are not visible outside the object file containing their definition.
 - Local symbols of the same name can exist in multiple files without interfering with each other.
- **STB_GLOBAL**: Global symbols.
 - These symbols are visible to all object files being combined.
 - One file's definition of a global symbol satisfies another file's undefined reference to the same global symbol.
- **STB_WEAK**: Weak symbols.
 - These symbols resemble global symbols, but their definitions have lower precedence.

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

ELF Symbol binding (2)

- **STB_LOOS - STB_HIOS**
 - Values in this inclusive range are reserved for operating system-specific semantics.
- **STB_LOPROC - STB_HIPROC**
 - Values in this inclusive range are reserved for processor-specific semantics.

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Global and weak symbols (1)

- 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.

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Global and weak symbols (2)

- Similarly, if a **common** symbol exists, the appearance of a **weak** symbol with the same name does not cause an error
- The link-editor uses the **common** definition and ignores the **weak** one.
- A **common** symbol has the `st_shndx` field holding **SHN_COMMON**

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Global and weak symbols (3)

- When the link-editor searches archive libraries it extracts archive members that contain definitions of undefined or tentative **global** symbols.
- The member's definition can be either a **global** or a **weak** symbol.
- The link-editor, by default, does not extract archive members to resolve undefined **weak** symbols.
- Unresolved **weak** symbols have a zero value.
- The use of `-z weakextract` overrides this default behavior.
- It enables **weak** references to cause the extraction of archive members.

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Section of type SHT_SYMTAB, SHT_DYNSYM (1)

`sh_type` = SHT_SYMTAB, SHT_DYNSYM

- identifies a **symbol table**
- typically a **SHT_SYMTAB section** provides symbols for link-editing
- as a complete symbol table, it can contain many symbols unnecessary for dynamic linking
- Consequently, an object file can also contain a **SHT_DYNSYM section**, which holds a minimal set of dynamic linking symbols, to save space

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

Section of type SHT_SYMTAB, SHT_DYNSYM (2)

`sh_type` = SHT_SYMTAB, SHT_DYNSYM

- `sh_link`
 - The `section header index` of the associated `string table`
- `sh_info`
 - One greater than the `symbol table index` of the last local symbol (binding STB_LOCAL) .

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>

the section header index of the associated symbol table

`sh_type =`

- SHT_HASH
- SHT_REL, SHT_RELA
- SHT_GROUP
- in these sections, `sh_link` represents the section header index of the associated `symbol table`

<https://docs.oracle.com/cd/E19683-01/816-1386/6m7qcoblh/index.html>