Linux Forensics
Binary analysis – Part2

Executable and **L**inkable **F**ormat
Approach

WHOAMI

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❑ Main focus on hunting badness

Executable and **L**inkable **F**ormat

Why Learning ELF Files?

Why should we know about ELF files?

ELF file analysis used by:

- Blue Teamers
- Incident Response
- Digital Forensics
- Malware Researchers
- Red Teamers

Definition

ELF (**Executable and Linkable For**mat) formerly named **Extensible Linking Format** standard file format for **executable files**, **object code**, **shared libraries**, and **core dumps**. First introduced with Unix system and is now standard executable file format on Linux, FreeBSD and any other device like micro controller and many other thinks. By design, the ELF format is flexible, extensible, and cross-platform. For instance it supports different endiannesses and address sizes so it does not exclude any particular central processing unit (CPU) or instruction set architecture.(7)

ELF Extension

ELF known file extensions

.axf | .bin | .elf | .o | .prx | .puff | .ko | .mod | .so

Anatomy of an Executable File

Each operating systems have two fundamental abstractions

Processes

processes can be viewed as a dynamic representation of resources.

Files

Binary or executable files can be viewed as static representation of resources

Definition

The process of transforming the static object (*binary executable files*) in a dynamic object (*process*) is called **loading**.

ELF files are used by two tools

Linker and Loader

Linker: *Linking* is the process of combining various pieces of code and data together to form a single executable that can be loaded in memory. Linking can be done at compile time, at load time (by loaders) and also at run time (by application programs).

Loader: The *loader* is a program called **execve**, which loads the code and data of the executable object file into memory and then runs the program by jumping to the first instruction.(3)

- in real environments, with dynamic linking, loading may require relocation. Why?
  - Because, if the file is dynamically linked it has to be linked again with all the shared libraries it depends on.

In the next part, I'll describe the full relocation and symbol resolution structure.

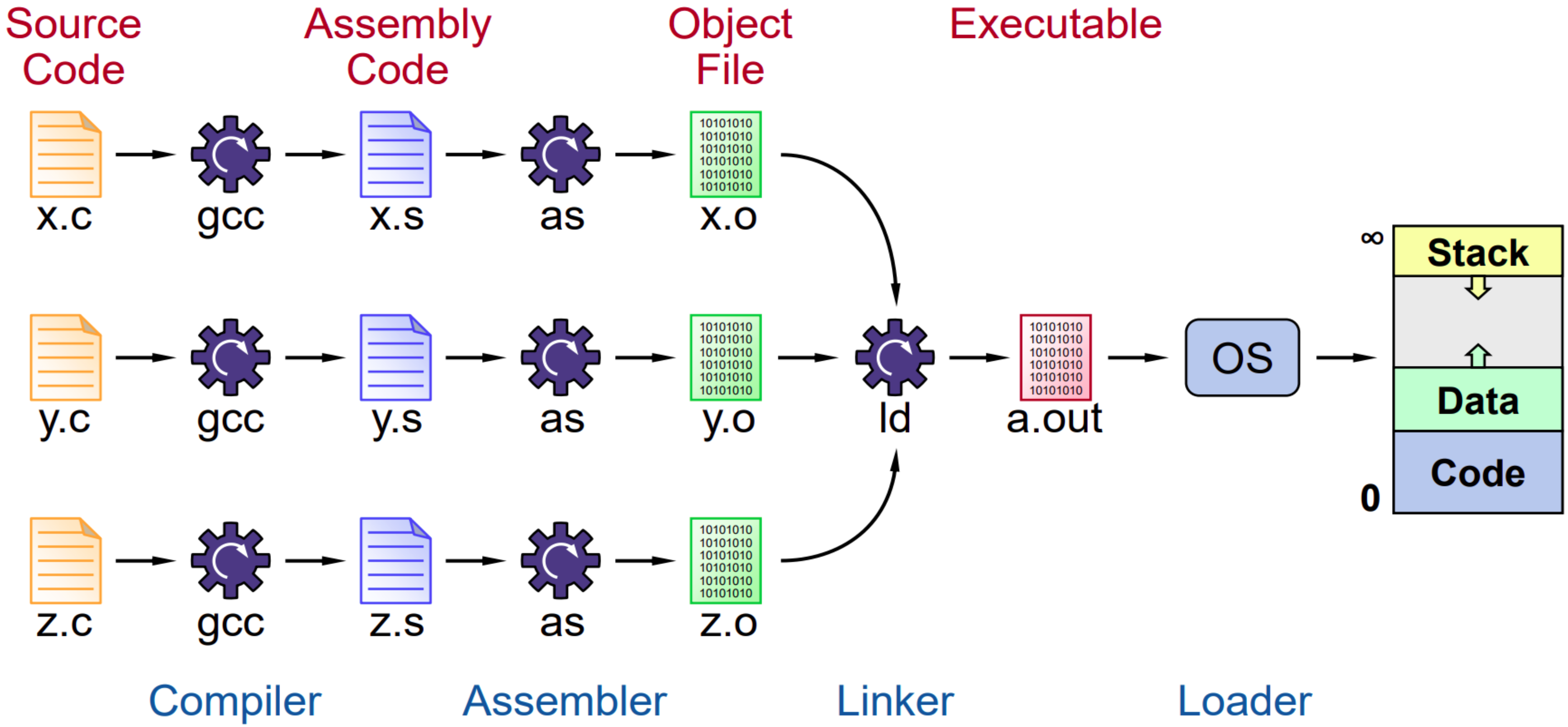
Linker and Loader

Linkers and loaders perform various related but conceptually different tasks:

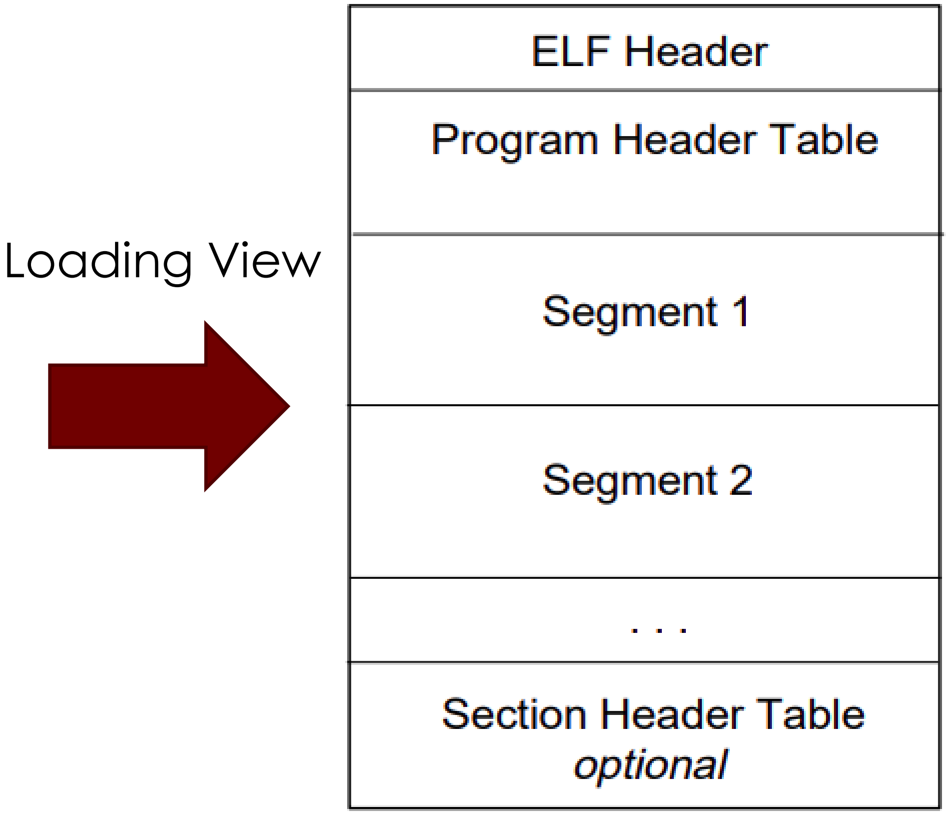
- **Program Loading**: This refers to copying a program image from hard disk to the main memory in order to put the program in a ready-to-run state. In some cases, program loading also might involve allocating storage space or mapping virtual addresses to disk pages.
- **Relocation:** Compilers and assemblers generate the object code for each input module with a starting address of zero. Relocation is the process of assigning load addresses to different parts of the program by merging all sections of the same type into one section. The code and data section also are adjusted so they point to the correct runtime addresses.
- **Symbol Resolution**: A program is made up of multiple subprograms; reference of one subprogram to another is made through symbols. A linker's job is to resolve the reference by noting the symbol's location and patching the caller's object code.(3)

In the next part, I’ll describe the full relocation and symbol resolution structure.

Creating a Process (borrow from index 5 of ref.)



An ELF file provides 2 views on the data, contains(4)



Loading View

ELF Header

Program Header Table

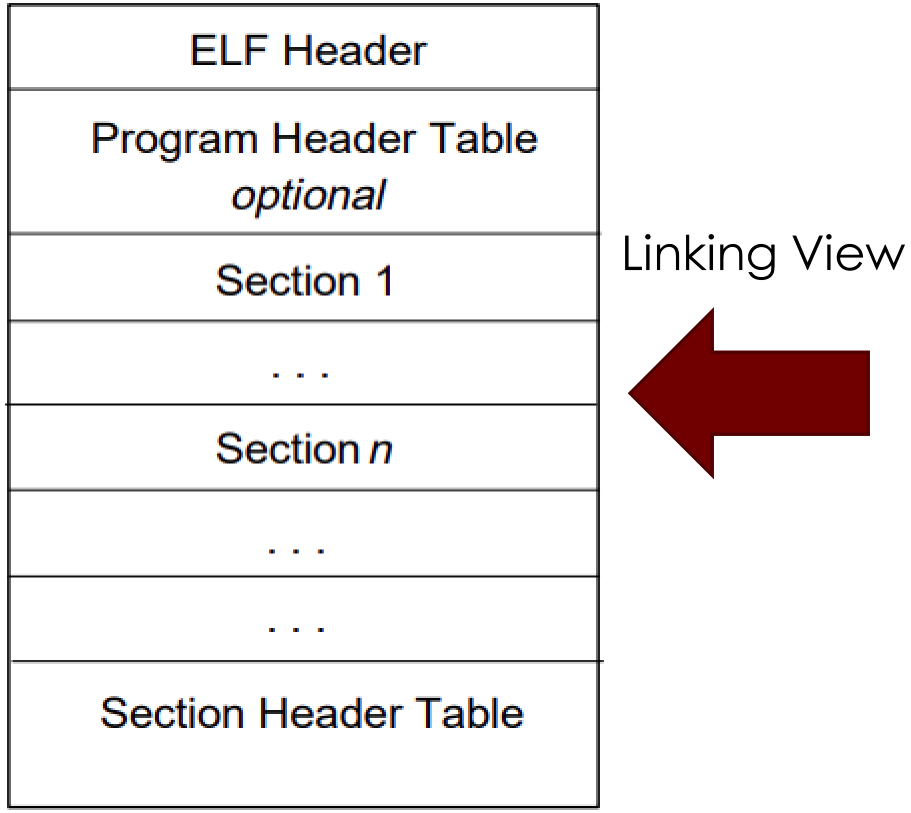
Segment 1

Segment 2

. . .

Section Header Table
optional

Only the ELF header has a fixed position in the file. The flexibility of the ELF format requires no specified order for header tables, sections or segments.



Linking View

ELF Header

Program Header Table
optional

Section 1

. . .

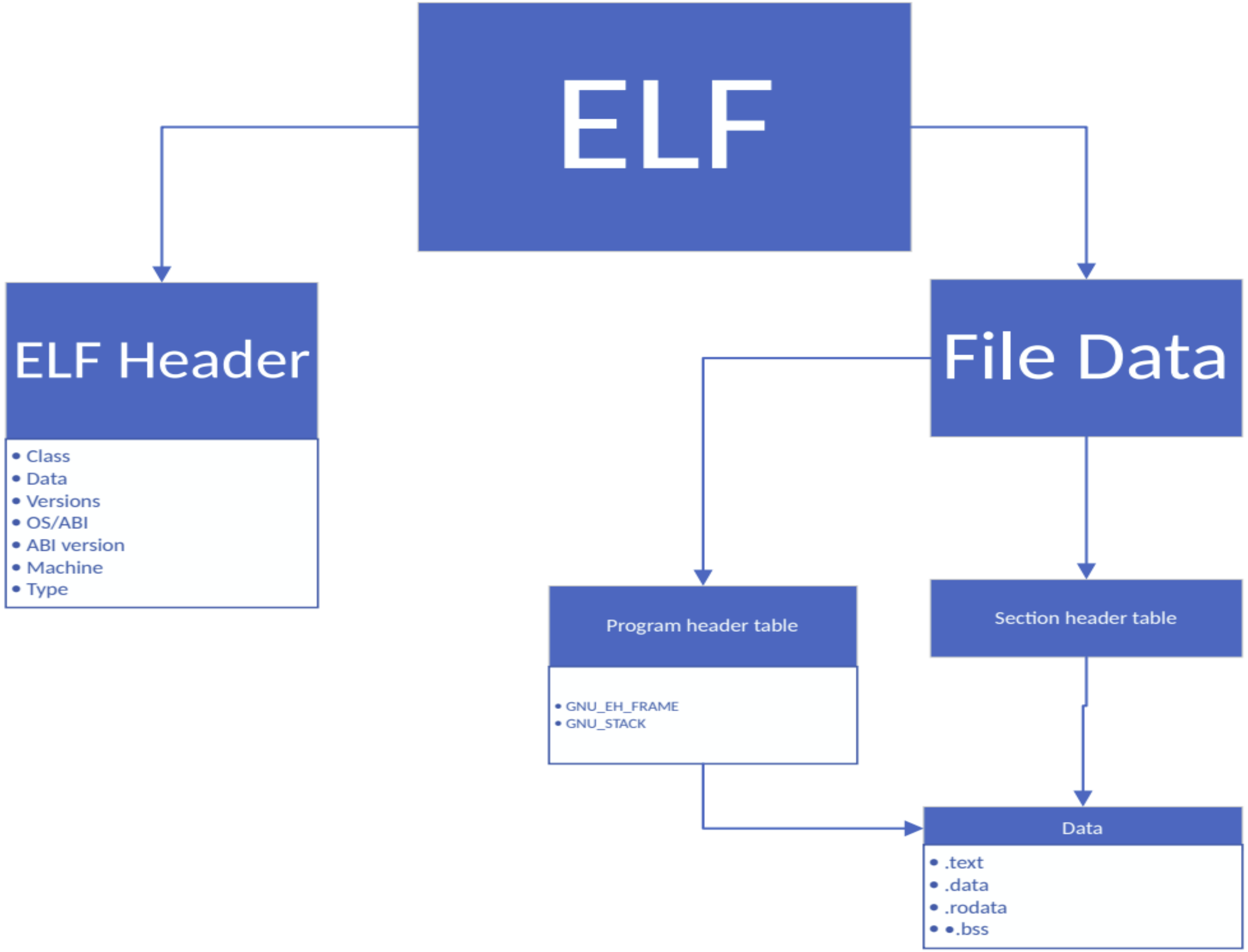
Section *n*

. . .

. . .

Section Header Table

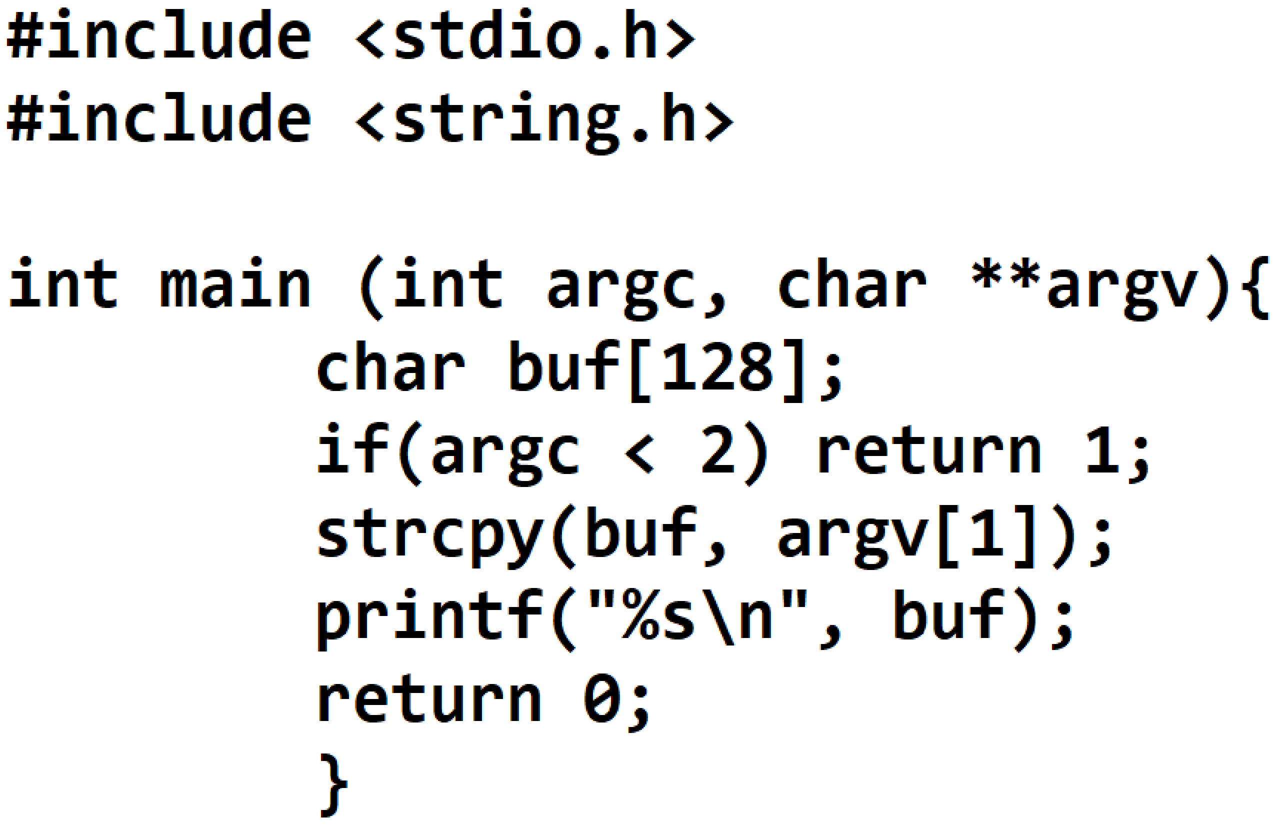
ELF Views



Simplified version of the structure of an ELF-file.(2)

Write Sample Program

I’ll write a test program with c languages and make elf format. Then I decided to analyze it.

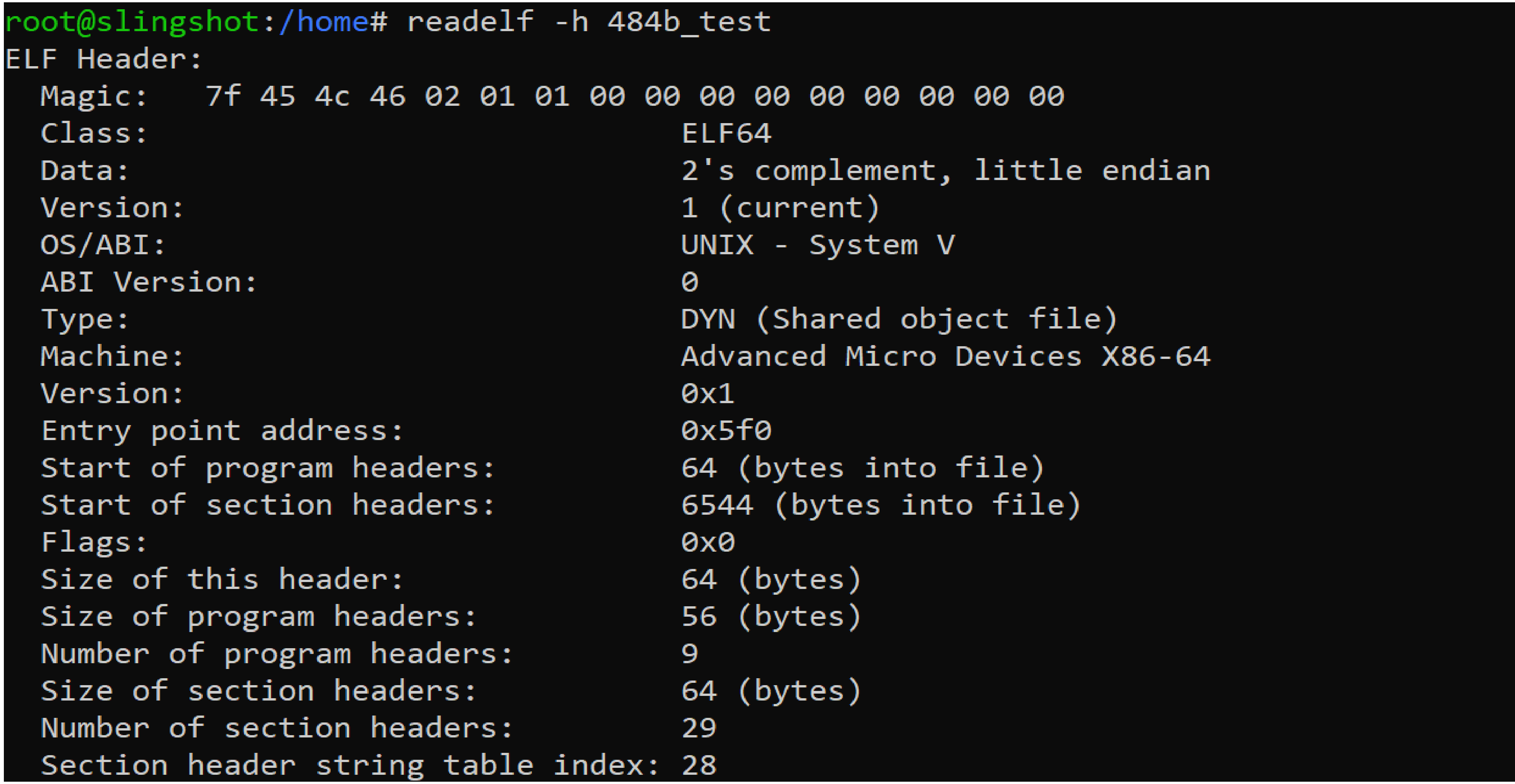


```
#include <stdio.h>
#include <string.h>

int main (int argc, char **argv){
        char buf[128];
        if(argc < 2) return 1;
        strcpy(buf, argv[1]);
        printf("%s\n", buf);
        return 0;
        }
```

ELF Header

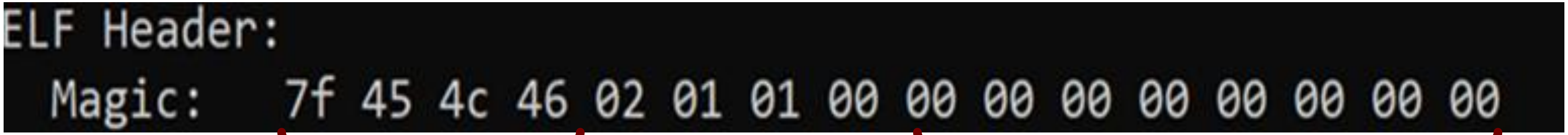
-> gcc 484_test.c –o 484_test

The ELF file header tells where program header table & section header table are.



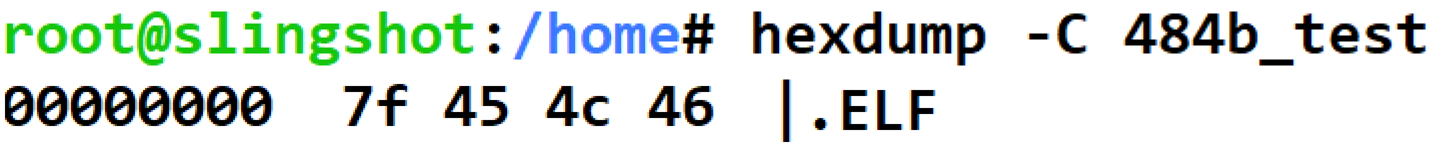
```
root@slingshot:/home# readelf -h 484b_test
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
  Class:                             ELF64
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - System V
  ABI Version:                       0
  Type:                              DYN (Shared object file)
  Machine:                           Advanced Micro Devices X86-64
  Version:                           0x1
  Entry point address:               0x5f0
  Start of program headers:          64 (bytes into file)
  Start of section headers:          6544 (bytes into file)
  Flags:                             0x0
  Size of this header:               64 (bytes)
  Size of program headers:           56 (bytes)
  Number of program headers:         9
  Size of section headers:           64 (bytes)
  Number of section headers:         29
  Section header string table index: 28
```

ELF Header Inspecting...

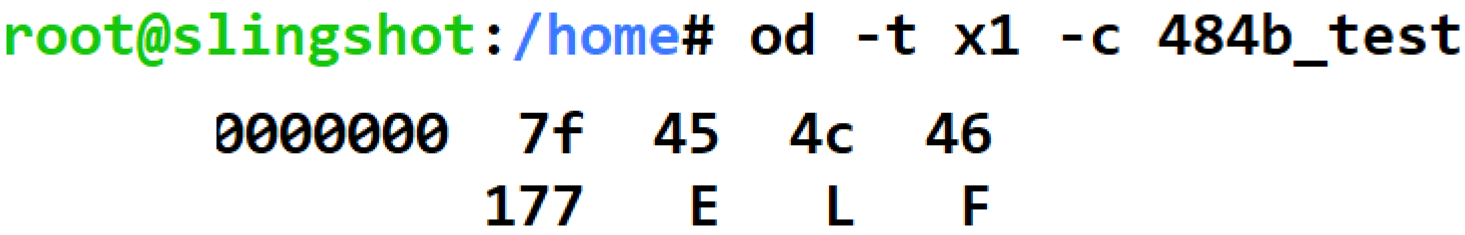


```
ELF Header:
  Magic:   7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00
```

Padding Bytes. These bytes are unused and are always set to 0



```
root@slingshot:/home# hexdump -C 484b_test
00000000  7f 45 4c 46  |.ELF
```



```
root@slingshot:/home# od -t x1 -c 484b_test

        0000000   7f   45   4c   46
                 177    E    L    F
```

ELF Header Inspecting…

- Class:
  - x64 - > (=02)
  - x32 -> (=01)
- Data:
  - LSB -> (=01)
  - MSB -> (=02)
- Version:
  - Current Version -> (=01)
  - Invalid Version -> (=02)

ELF Header Inspecting…

- OS/ ABI : An Application Binary Interface (ABI) is the interface between two binary program modules that work together. An ABI is a contract between pieces of binary code defining the mechanisms by which functions are invoked and how parameters are passed between the caller and callee.
- ABI Version: Show which version of ABI used.

ELF Header Inspecting…

- Type:
  - Relocation File -> (=01)
  - Executable File -> (=02)
  - Shared Object File -> (=03)
  - Core File -> (=04)
- Machine: denotes the architecture that the binary is intended to run on.

ELF Header Inspecting…

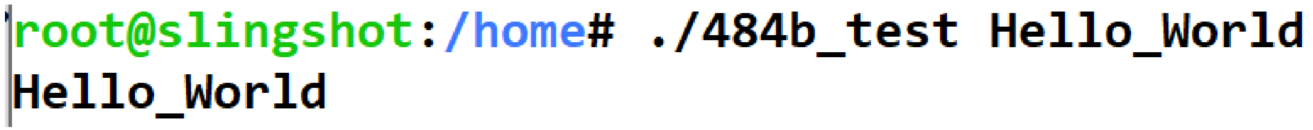
- Entry Point Address: where does the program start?
- Start of Program Header: Identifies the start of the program headers with bytes into the ELF-file.
- Start of Section Header: Identifies the start of the section headers with bytes into the ELF-file.
- Size of Program Header: Identifies the size of the program headers that is in the ELF-file.

ELF Header Inspecting…

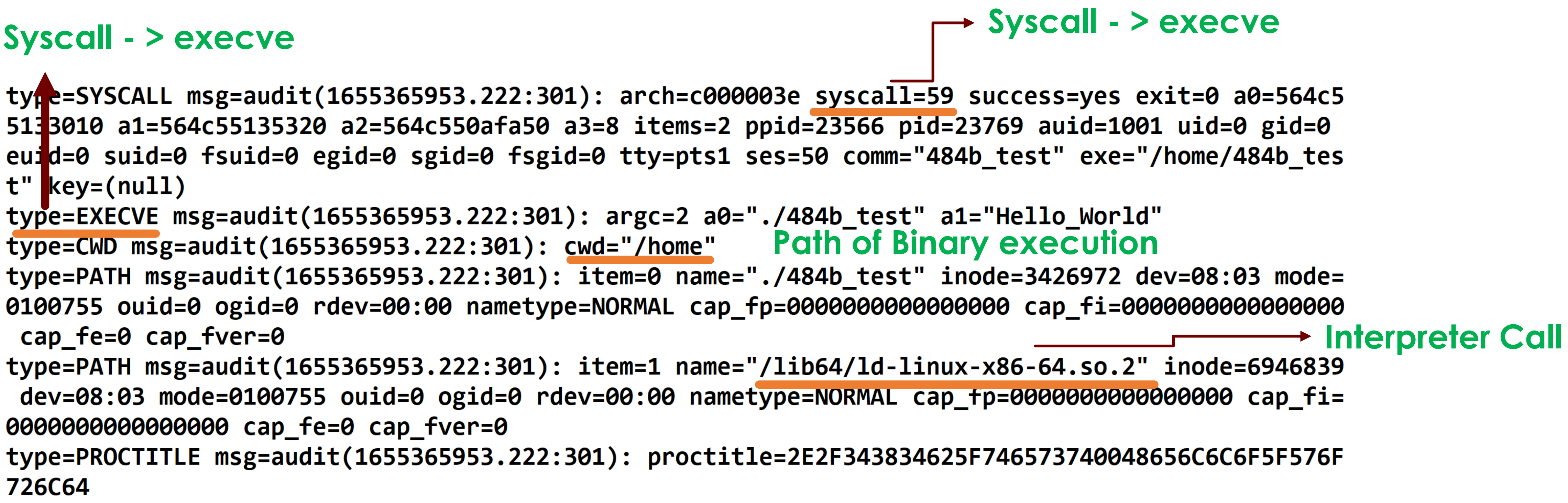
- Size of section headers: Identifies the size of the section headers that is in the ELF-file.
- Number of program headers: Identifies how many program headers there is in the ELF-file.
- Number of section headers: Identifies how many section headers there is in the ELF-file.(2)

Run The Program

Run the program and auditd log:



```
root@slingshot:/home# ./484b_test Hello_World
Hello_World
```



Syscall - > execve

Syscall - > execve

Path of Binary execution

Interpreter Call

```
type=SYSCALL msg=audit(1655365953.222:301): arch=c000003e syscall=59 success=yes exit=0 a0=564c5
5133010 a1=564c55135320 a2=564c550afa50 a3=8 items=2 ppid=23566 pid=23769 auid=1001 uid=0 gid=0
euid=0 suid=0 fsuid=0 egid=0 sgid=0 fsgid=0 tty=pts1 ses=50 comm="484b_test" exe="/home/484b_tes
t" key=(null)
type=EXECVE msg=audit(1655365953.222:301): argc=2 a0="./484b_test" a1="Hello_World"
type=CWD msg=audit(1655365953.222:301): cwd="/home"
type=PATH msg=audit(1655365953.222:301): item=0 name="./484b_test" inode=3426972 dev=08:03 mode=
0100755 ouid=0 ogid=0 rdev=00:00 nametype=NORMAL cap_fp=0000000000000000 cap_fi=0000000000000000
 cap_fe=0 cap_fver=0
type=PATH msg=audit(1655365953.222:301): item=1 name="/lib64/ld-linux-x86-64.so.2" inode=6946839
 dev=08:03 mode=0100755 ouid=0 ogid=0 rdev=00:00 nametype=NORMAL cap_fp=0000000000000000 cap_fi=
0000000000000000 cap_fe=0 cap_fver=0
type=PROCTITLE msg=audit(1655365953.222:301): proctitle=2E2F343834625F746573740048656C6C6F5F576F
726C64
```

Type of ELF Files

- Binary executable (ET_EXEC)
  - Runnable program, must have Segments
- Object files (or relocatable objects (.o), ET_REL)
  - Links with other object files, must have sections.
- Shared Library (.so, ET_DYN)
  - Links with other object files/executables.
  - Has both segments and sections.
- Core Dump(ET_CORE)
  - Generated when program receives SIGABRT.
  - Has no sections, has segments(PT_LOAD/ PT_Notes)

I'll discuss and analysis all type of elf files in next parts.

Define Segment and Section

Sections comprise all information needed for linking a target object file in order to build a working executable. In the other word, **Sections** represent the smallest indivisible units that can be processed within an ELF file. sections perspective of a linker.

Segments, which are commonly known as Program Headers, break down the structure of an ELF binary into suitable chunks to prepare the executable to be loaded into memory.(borrow from Intezer web site)

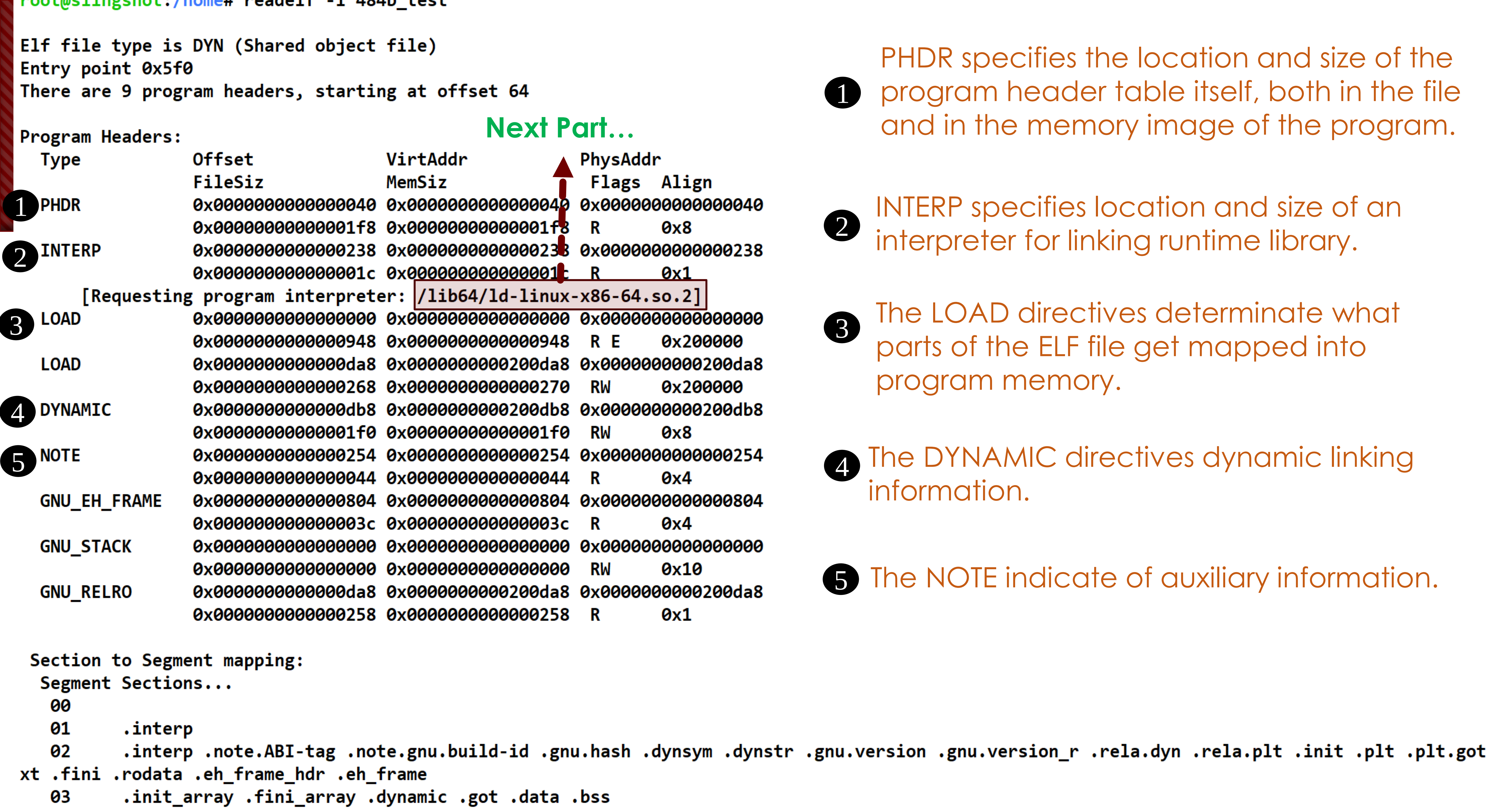
Segments are a collection of sections that represent the smallest individual units that can be mapped to a memory image by the runtime linker.

Sections hold the bulk of object file information for the linking view:

instructions, data, symbol table, relocation information, and so on.

Program Header Table

- A program header table is an array of program headers that defines the memory layout of a program at runtime.
- The program header shows the segments used at run-time, and tells the system how to create a process image. An ELF-file can consist of zero or more segments. The kernel can access the segments and map them into a virtual address space by using mmap system calls. (6)



```
root@slingshot:/home# readelf -l 484b_test

Elf file type is DYN (Shared object file)
Entry point 0x5f0
There are 9 program headers, starting at offset 64

Program Headers:
  Type           Offset             VirtAddr           PhysAddr
                 FileSiz            MemSiz              Flags  Align
1 PHDR           0x0000000000000040 0x0000000000000040 0x0000000000000040
                 0x00000000000001f8 0x00000000000001f8  R      0x8
2 INTERP         0x0000000000000238 0x0000000000000238 0x0000000000000238
                 0x000000000000001c 0x000000000000001c  R      0x1
      [Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]
3 LOAD           0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x0000000000000948 0x0000000000000948  R E    0x200000
  LOAD           0x0000000000000da8 0x0000000000200da8 0x0000000000200da8
                 0x0000000000000268 0x0000000000000270  RW     0x200000
4 DYNAMIC        0x0000000000000db8 0x0000000000200db8 0x0000000000200db8
                 0x00000000000001f0 0x00000000000001f0  RW     0x8
5 NOTE           0x0000000000000254 0x0000000000000254 0x0000000000000254
                 0x0000000000000044 0x0000000000000044  R      0x4
  GNU_EH_FRAME   0x0000000000000804 0x0000000000000804 0x0000000000000804
                 0x000000000000003c 0x000000000000003c  R      0x4
  GNU_STACK      0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x0000000000000000 0x0000000000000000  RW     0x10
  GNU_RELRO      0x0000000000000da8 0x0000000000200da8 0x0000000000200da8
                 0x0000000000000258 0x0000000000000258  R      0x1

 Section to Segment mapping:
  Segment Sections...
   00     
   01     .interp 
   02     .interp .note.ABI-tag .note.gnu.build-id .gnu.hash .dynsym .dynstr .gnu.version .gnu.version_r .rela.dyn .rela.plt .init .plt .plt.got
xt .fini .rodata .eh_frame_hdr .eh_frame 
   03     .init_array .fini_array .dynamic .got .data .bss 
```

Next Part…

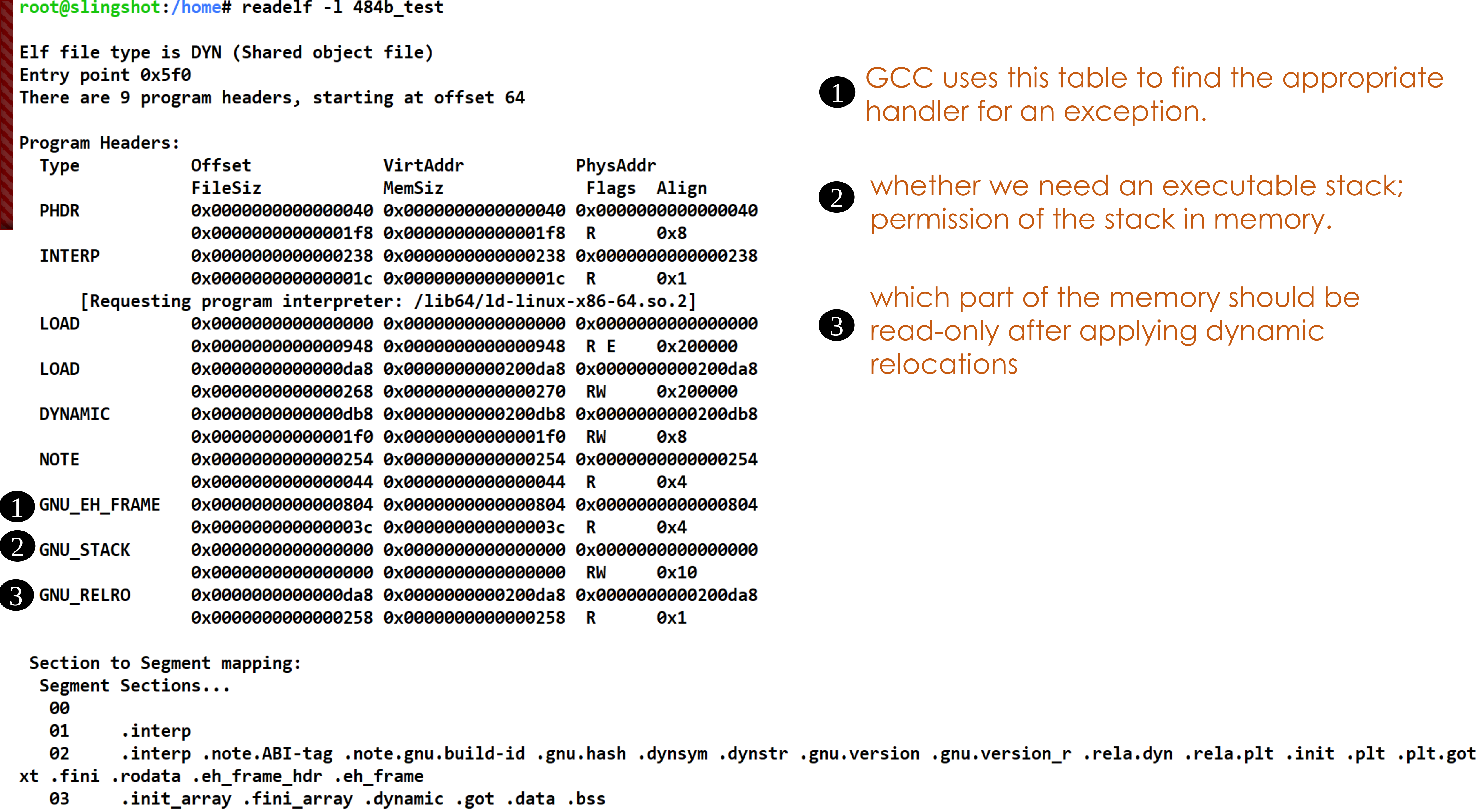
1 PHDR specifies the location and size of the program header table itself, both in the file and in the memory image of the program.

2 INTERP specifies location and size of an interpreter for linking runtime library.

3 The LOAD directives determinate what parts of the ELF file get mapped into program memory.

4 The DYNAMIC directives dynamic linking information.

5 The NOTE indicate of auxiliary information.



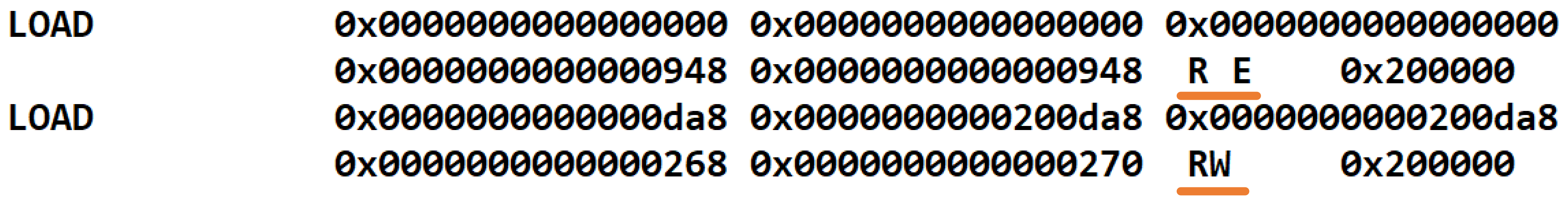
```
root@slingshot:/home# readelf -l 484b_test

Elf file type is DYN (Shared object file)
Entry point 0x5f0
There are 9 program headers, starting at offset 64

Program Headers:
  Type           Offset             VirtAddr           PhysAddr
                 FileSiz            MemSiz              Flags  Align
  PHDR           0x0000000000000040 0x0000000000000040 0x0000000000000040
                 0x00000000000001f8 0x00000000000001f8  R      0x8
  INTERP         0x0000000000000238 0x0000000000000238 0x0000000000000238
                 0x000000000000001c 0x000000000000001c  R      0x1
      [Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]
  LOAD           0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x0000000000000948 0x0000000000000948  R E    0x200000
  LOAD           0x0000000000000da8 0x0000000000200da8 0x0000000000200da8
                 0x0000000000000268 0x0000000000000270  RW     0x200000
  DYNAMIC        0x0000000000000db8 0x0000000000200db8 0x0000000000200db8
                 0x00000000000001f0 0x00000000000001f0  RW     0x8
  NOTE           0x0000000000000254 0x0000000000000254 0x0000000000000254
                 0x0000000000000044 0x0000000000000044  R      0x4
❶ GNU_EH_FRAME   0x0000000000000804 0x0000000000000804 0x0000000000000804
                 0x000000000000003c 0x000000000000003c  R      0x4
❷ GNU_STACK      0x0000000000000000 0x0000000000000000 0x0000000000000000
                 0x0000000000000000 0x0000000000000000  RW     0x10
❸ GNU_RELRO      0x0000000000000da8 0x0000000000200da8 0x0000000000200da8
                 0x0000000000000258 0x0000000000000258  R      0x1

 Section to Segment mapping:
  Segment Sections...
   00
   01     .interp
   02     .interp .note.ABI-tag .note.gnu.build-id .gnu.hash .dynsym .dynstr .gnu.version .gnu.version_r .rela.dyn .rela.plt .init .plt .plt.got
xt .fini .rodata .eh_frame_hdr .eh_frame
   03     .init_array .fini_array .dynamic .got .data .bss
```

❶ GCC uses this table to find the appropriate handler for an exception.

❷ whether we need an executable stack; permission of the stack in memory.

❸ which part of the memory should be read-only after applying dynamic relocations

PHT Inspecting...



```
LOAD           0x0000000000000000 0x0000000000000000 0x0000000000000000
               0x0000000000000948 0x0000000000000948  R E    0x200000
LOAD           0x0000000000000da8 0x0000000000200da8 0x0000000000200da8
               0x0000000000000268 0x0000000000000270  RW     0x200000
```

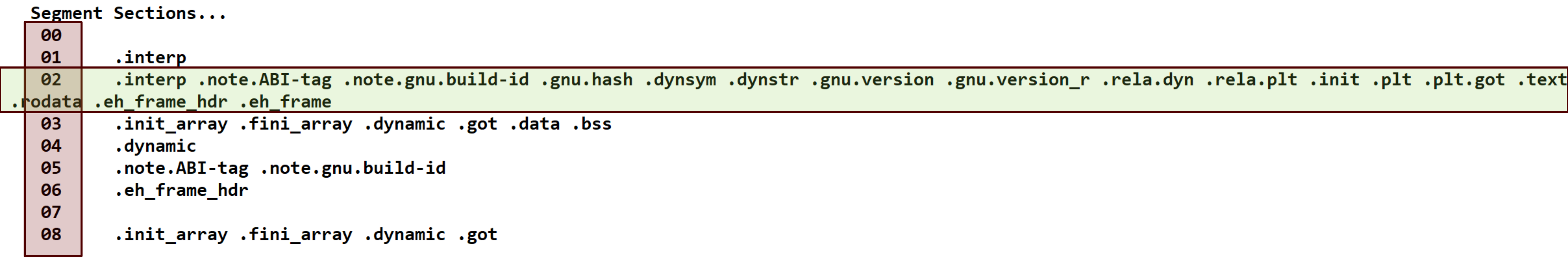
❑ **Load Segment appear twice. Why?**

First LOAD has read and execute permission. Therefore, this segment running *text* segment. Because only text segment contain read-only instruction with read-only data section (go to next page for more detailed) .

Second LOAD has read and write permission. So this is a *data* segment. Notice that this segment can not executable.

PHT Inspecting...

- All segments contains sections.



```
 Segment Sections...
  00
  01     .interp
  02     .interp .note.ABI-tag .note.gnu.build-id .gnu.hash .dynsym .dynstr .gnu.version .gnu.version_r .rela.dyn .rela.plt .init .plt .plt.got .text
.rodata .eh_frame_hdr .eh_frame
  03     .init_array .fini_array .dynamic .got .data .bss
  04     .dynamic
  05     .note.ABI-tag .note.gnu.build-id
  06     .eh_frame_hdr
  07
  08     .init_array .fini_array .dynamic .got
```

Index of Segments. In other word, The first number is the index of a program header in program header table, and the remaining text is the list of all sections within a segment.

Look at the number 2 index, this section belonging to First LOAD segment. So, first LOAD segment contains the number 2 index sections.

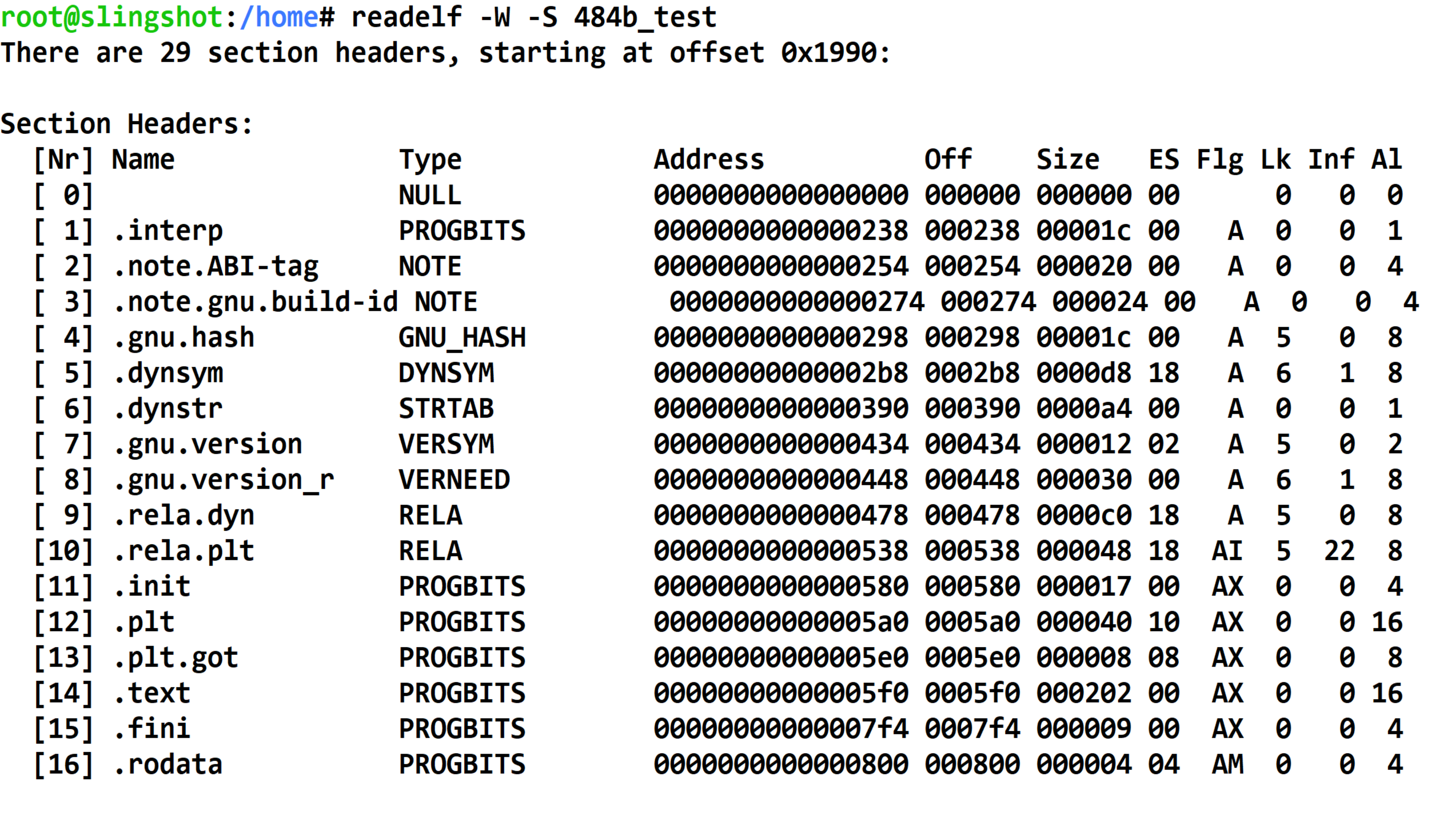
Section Header Table

- The section headers define all the sections within an ELF-file. In the section header the data is linked and relocated. The section header table describes zero or more sections that are followed by data which are referred to by entries from the program header table, or section header table.(6)

Some Sections…

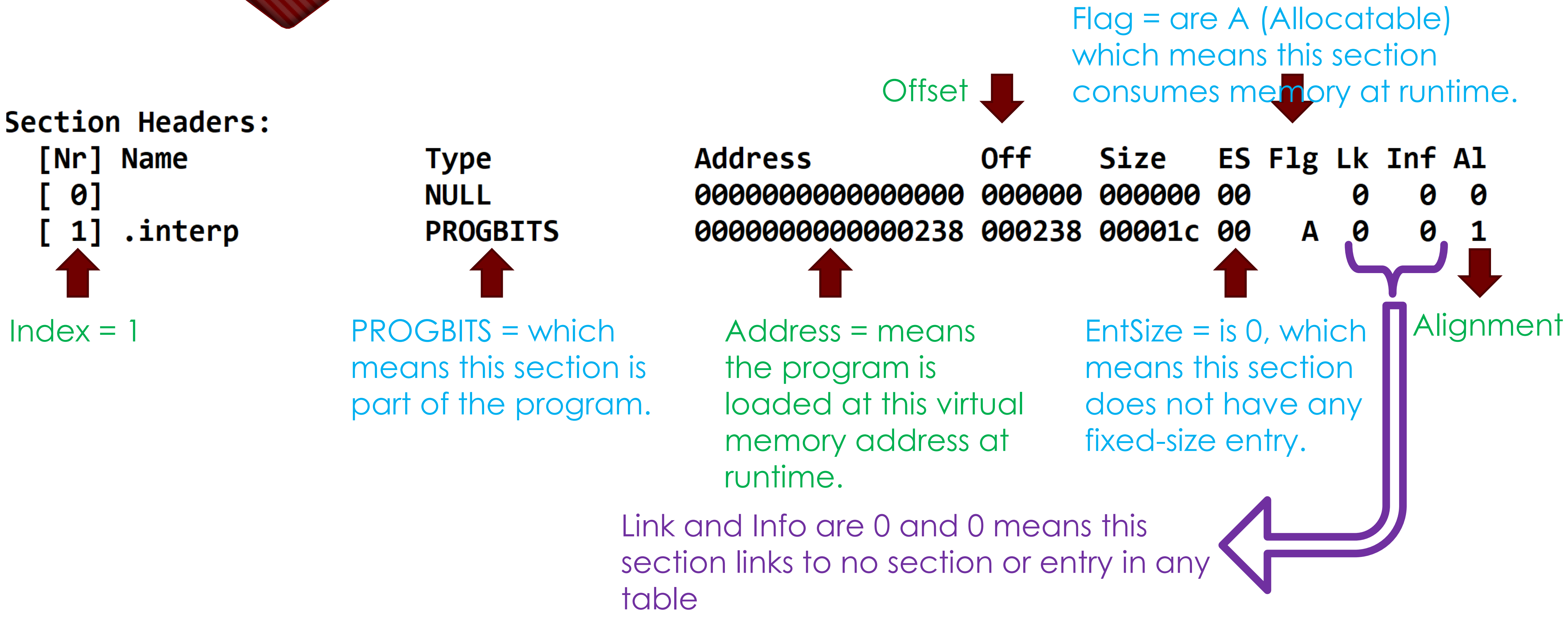
Sections:

- .text -> contains executable code, which will be packed into a segment with read and execute access rights. Which is only loaded once, as the contents will not change.
- .rodata -> Initialized data with read access rights only
- .data -> Initialized data with read/write access rights
- .bss -> initialized data with read/write access rights(6)



```
root@slingshot:/home# readelf -W -S 484b_test
There are 29 section headers, starting at offset 0x1990:

Section Headers:
  [Nr] Name              Type            Address          Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL            0000000000000000 000000 000000 00      0   0  0
  [ 1] .interp           PROGBITS        0000000000000238 000238 00001c 00   A  0   0  1
  [ 2] .note.ABI-tag     NOTE            0000000000000254 000254 000020 00   A  0   0  4
  [ 3] .note.gnu.build-id NOTE            0000000000000274 000274 000024 00   A  0   0  4
  [ 4] .gnu.hash         GNU_HASH        0000000000000298 000298 00001c 00   A  5   0  8
  [ 5] .dynsym           DYNSYM          00000000000002b8 0002b8 0000d8 18   A  6   1  8
  [ 6] .dynstr           STRTAB          0000000000000390 000390 0000a4 00   A  0   0  1
  [ 7] .gnu.version      VERSYM          0000000000000434 000434 000012 02   A  5   0  2
  [ 8] .gnu.version_r    VERNEED         0000000000000448 000448 000030 00   A  6   1  8
  [ 9] .rela.dyn         RELA            0000000000000478 000478 0000c0 18   A  5   0  8
  [10] .rela.plt         RELA            0000000000000538 000538 000048 18  AI  5  22  8
  [11] .init             PROGBITS        0000000000000580 000580 000017 00  AX  0   0  4
  [12] .plt              PROGBITS        00000000000005a0 0005a0 000040 10  AX  0   0 16
  [13] .plt.got          PROGBITS        00000000000005e0 0005e0 000008 08  AX  0   0  8
  [14] .text             PROGBITS        00000000000005f0 0005f0 000202 00  AX  0   0 16
  [15] .fini             PROGBITS        00000000000007f4 0007f4 000009 00  AX  0   0  4
  [16] .rodata           PROGBITS        0000000000000800 000800 000004 04  AM  0   0  4
```

SHT Inspecting ...



```
Section Headers:
  [Nr] Name              Type             Address           Off    Size   ES Flg Lk Inf Al
  [ 0]                   NULL             0000000000000000 000000 000000 00      0   0  0
  [ 1] .interp           PROGBITS         0000000000000238 000238 00001c 00   A  0   0  1
```

Offset

Flag = are A (Allocatable) which means this section consumes memory at runtime.

Index = 1

PROGBITS = which means this section is part of the program.

Address = means the program is loaded at this virtual memory address at runtime.

EntSize = is 0, which means this section does not have any fixed-size entry.

Alignment

Link and Info are 0 and 0 means this section links to no section or entry in any table

Reference

1 - Ubuntu linux -> /usr/include/elf.h

2 - Espen, Amar & Abdi, “Automated dynamic malware analysis of ELF-files”

3 - https://www.linuxjournal.com/article/6463

4 - https://refspecs.linuxfoundation.org/elf/elf.pdf

5 - https://web.stanford.edu/~ouster/cs111-spring21/all_lectures/

6 - A. Dennis, "Practical binary analysis : build your own Linux tools for binary", No Starch Press, 2019.

7 - https://en.wikipedia.org/wiki/Executable_and_Linkable_Format

To be Continued …