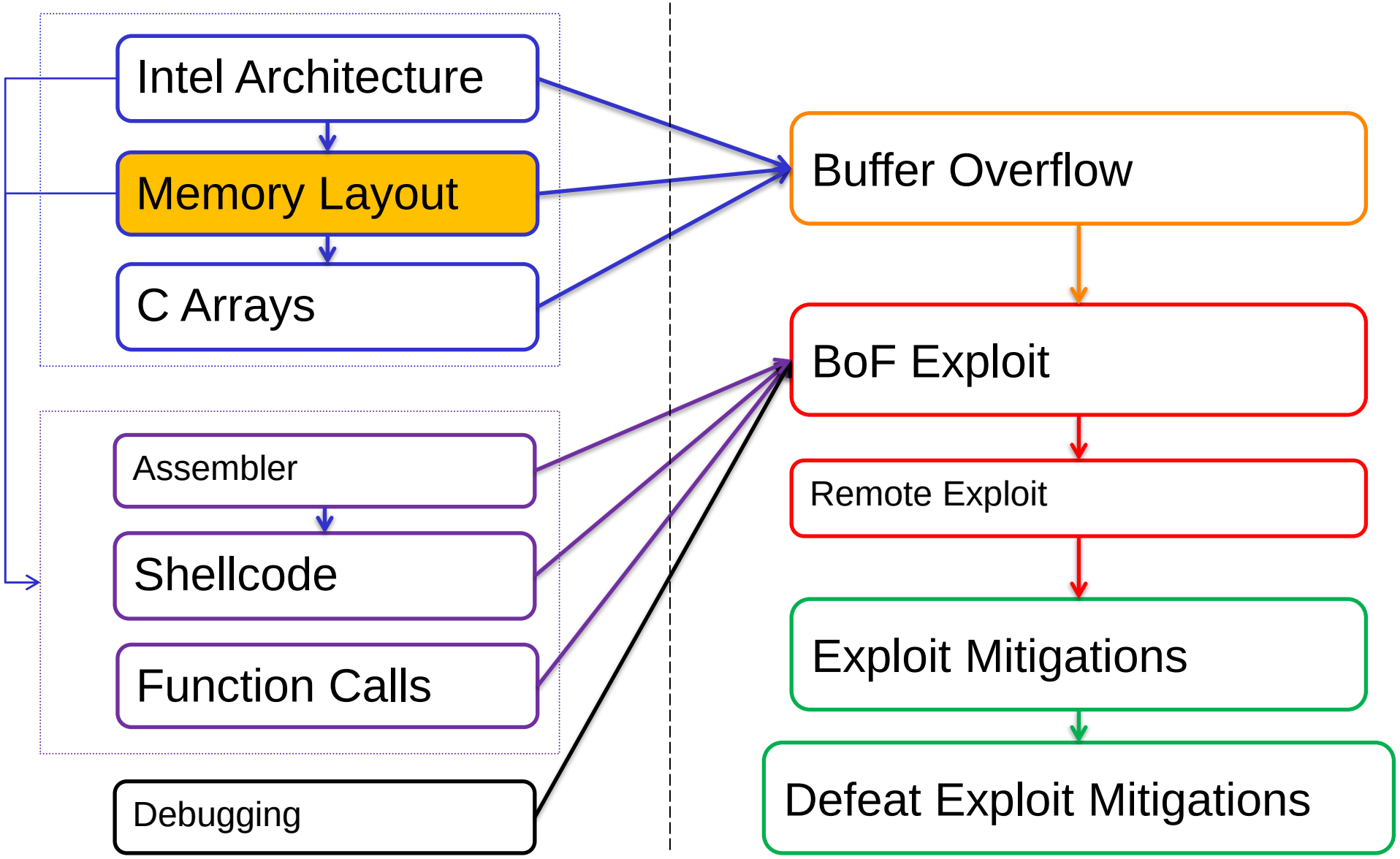
Memory Layout

Linux Userspace Process Memory Layout

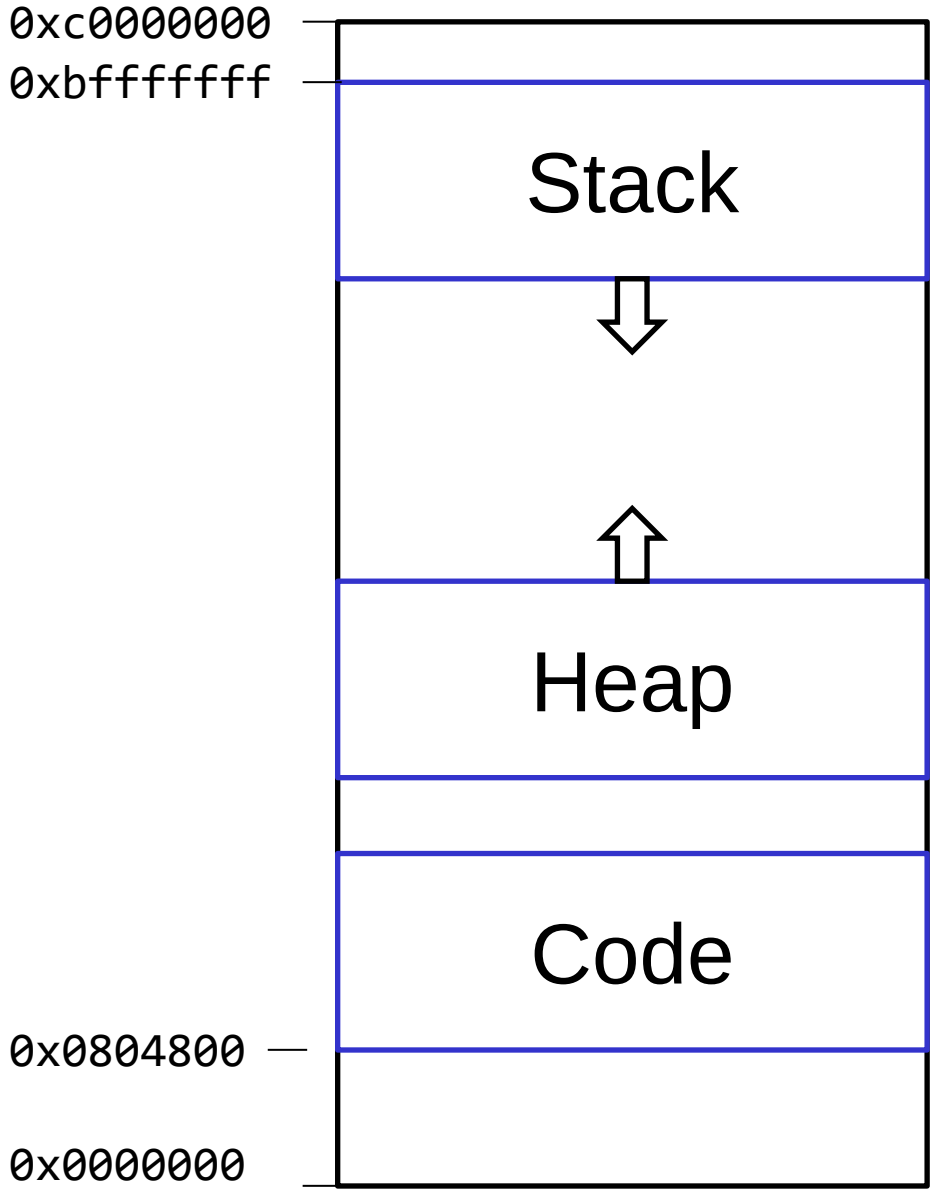
Content


Intel Architecture
Memory Layout
C Arrays
Assembler
Shellcode
Function Calls
Debugging
Buffer Overflow
BoF Exploit
Remote Exploit
Exploit Mitigations
Defeat Exploit Mitigations

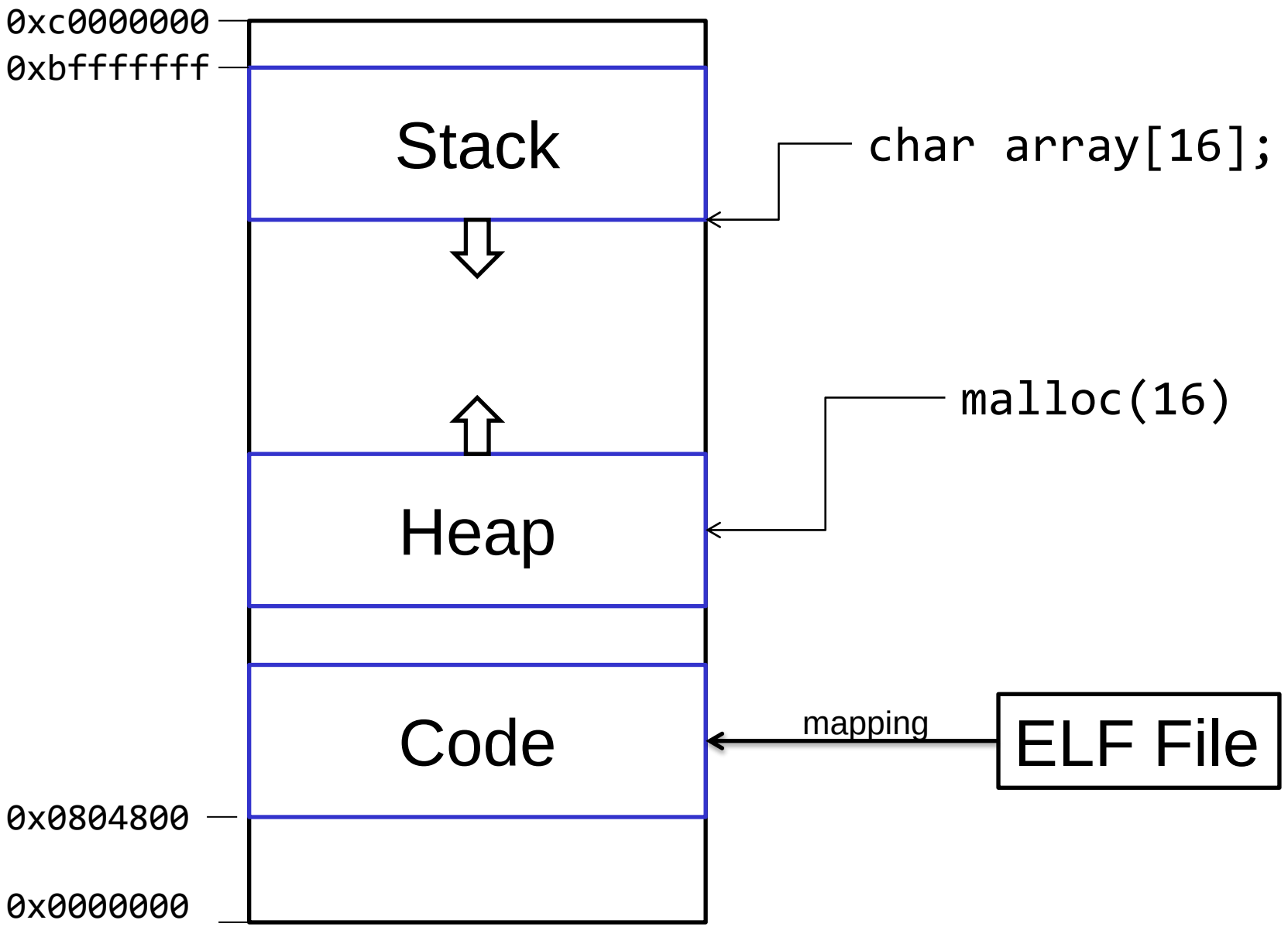
Userspace Memory Layout

In 32 bit

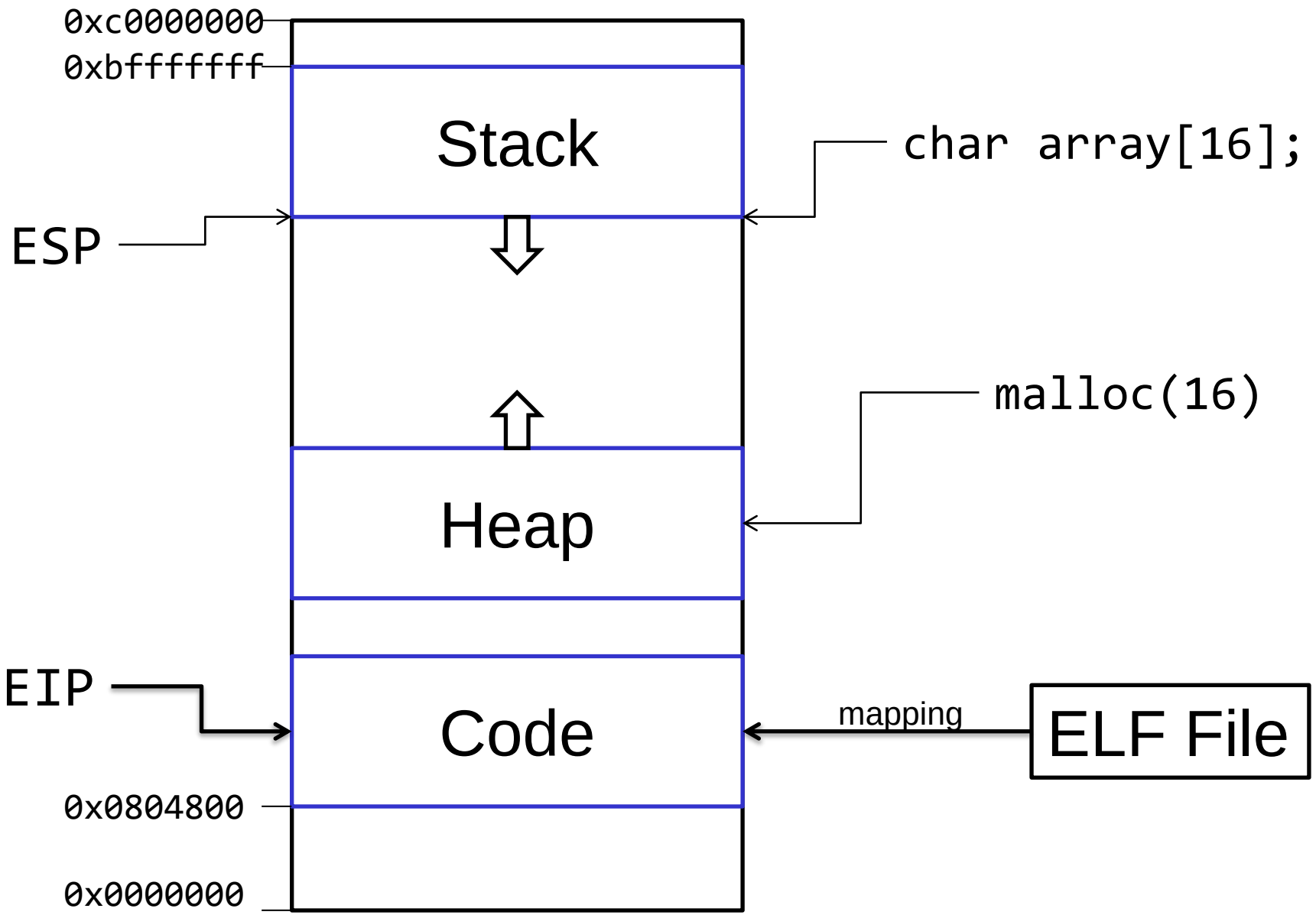
x32 Memory Layout



x32 Memory Layout



x32 Memory Layout



x32 Memory Layout

Memory regions:

Stack

- There's one contiguous memory region containing the stack for the process
- LIFO – Last in, First Out
- Contains function **local variables**
- Also contains: **Saved Instruction Pointer (SIP)**
- Current function adds data to the top (bottom) of the stack

Heap

- There's one contiguous memory region containing the heap
- Memory allocator returns specific pieces of the memory region
- For **malloc()**
- Also contains: heap management data

Code

- Compiled program code

ELF Format

How do programs on disk look like

ELF Format

Programs (e.g. Firefox) are stored in ELF files

ELF: Executable and Linkable Format

- Previously: “a.out” (Linux 1.2)
- Like COFF, PE (EXE), COM, …

ELF types:

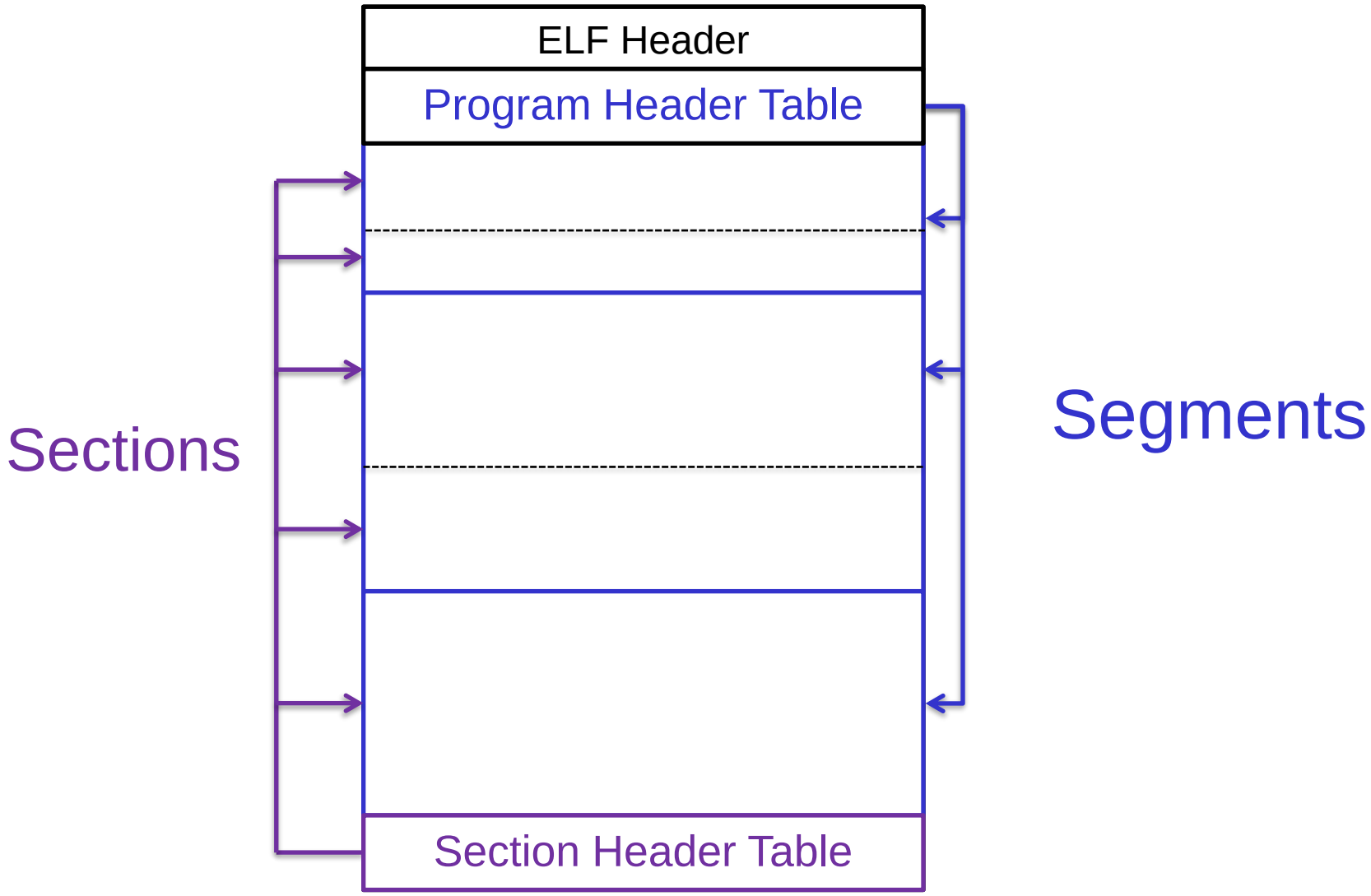
- ET_EXEC: Executable File
- ET_REL: Relocatable File
- ET_DYN: Shared Object File

ELF “views”:

- Sections
- Segments

$ readelf –l <binary>

ELF Format - Sections and Segments



ELF Format - Segment View

Program Headers:

	Type	Offset	VirtAddr	PhysAddr
		FileSiz	MemSiz	Flags Align
	PHDR	0x00000040	0x0000400040	0x0000000000400040
		0x000001c0	0x00000001c0	R E 8
	INTERP	0x00000200	0x0000400200	0x0000000000400200
		0x0000001c	0x000000001c	R 1
02	**LOAD**	0x00000000	0x0000400000	**0x0000000000400000**
		0x00000b24	0x0000000b24	**R E** 200000
03	**LOAD**	0x00000b28	0x0000600b28	**0x0000000000600b28**
		0x00000270	0x0000000278	**RW** 200000
	DYNAMIC	0x00000b40	0x0000600b40	0x0000000000600b40
		0x000001e0	0x00000001e0	RW 8
	NOTE	0x0000021c	0x000040021c	0x000000000040021c
		0x00000044	0x0000000044	R 4
	GNU_EH_FRAME	0x000009ac	0x00004009ac	0x00000000004009ac
		0x00000044	0x0000000044	R 4
07	**GNU_STACK**	0x00000000	0x0000000000	0x0000000000000000
		0x00000000	0x0000000000	**RW** 10

ELF Format

```
$ readelf -l challenge0

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 .text .fini .rodata
          .eh_frame_hdr .eh_frame
   03     .init_array .fini_array .jcr .dynamic .got .got.plt
          .data .bss
   04     .dynamic
   05     .note.ABI-tag .note.gnu.build-id
   06     .eh_frame_hdr
   07
```

Sections:

- .text: Executable instructions
- .bss: Unitialized data (usually the heap)
- .data: initialized data
- .rodata: Read-Only data
- .got: Global Offset Table
- .plt: Procedure Linkage Table
- .init/.fini: Initialization instructions (“glibc”)

ELF Format

```
Program Headers:
  Type           Offset             PhysAddr
                 FileSiz            Flags  Align
(02) LOAD        0x0000000000000000 0x0000000000400000
                 0x0000000000000b24 R E    200000
(03) LOAD        0x0000000000000b28 0x0000000000600b28
                 0x0000000000000270 RW     200000
(07)  GNU_STACK  0x0000000000000000 0x0000000000000000
                 0x0000000000000000 RW     10
```

02 .init .plt .text .fini .rodata

03 .got .got.plt .data .bss

07

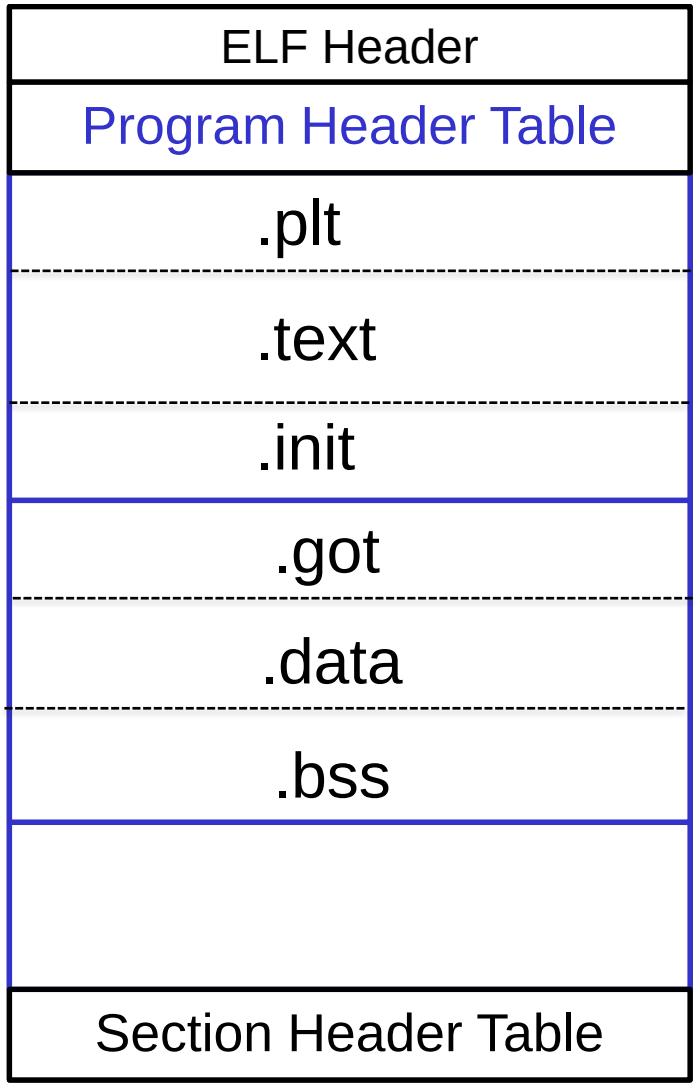
Executable Code R/E

Heap Data R/W

Stack Data R/W

ELF Loader

ELF Format



02 Executable Segment

r-x

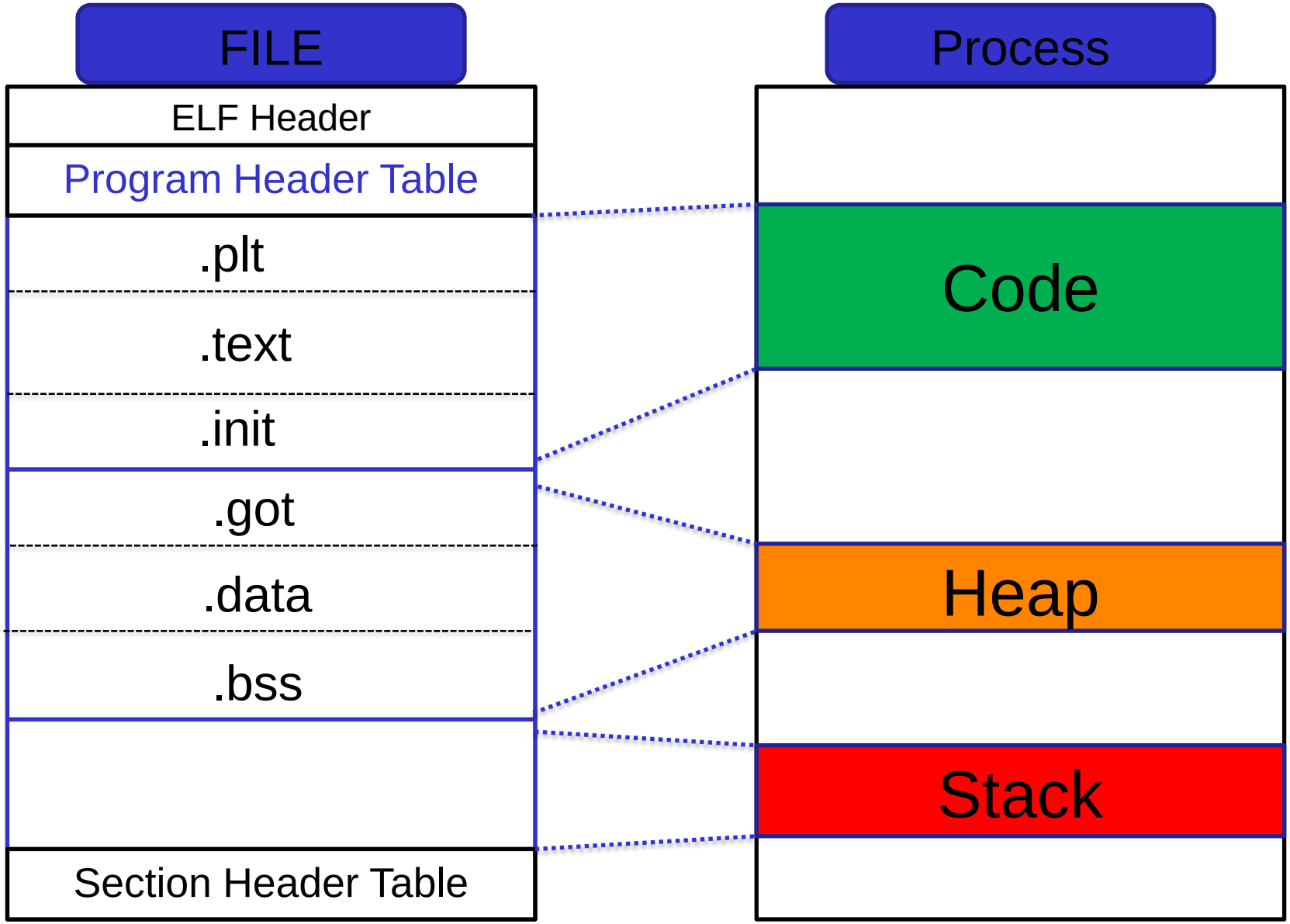
03 Data Segment

rw-

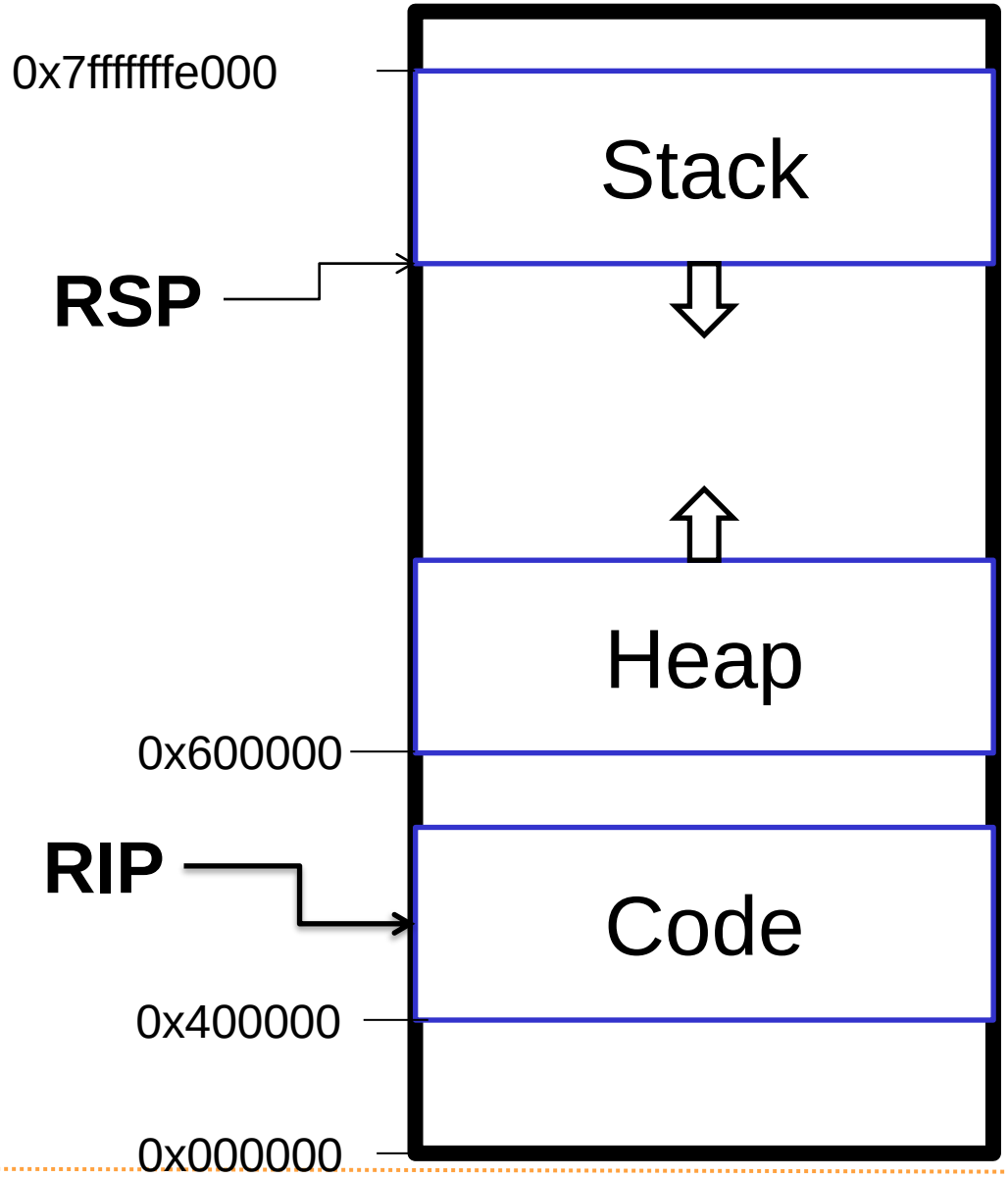
07 Stack

rw-

ELF Format


FILE
Process
ELF Header
Program Header Table
.plt
.text
.init
.got
.data
.bss
Section Header Table
Code
Heap
Stack

x64 Memory Layout



Stack, Heap, Code from ELF File By Example

some static and dynamic binary analysis

ELF Format - Example C code

```
char *globalVar = "Global";

void main(void) {
        char stackVar[16];
        char *heapVar = (char *) malloc(4);

        printf("Global var: %p\n", globalVar);
        printf("Heap var  : %p\n", heapVar);
        printf("Stack var : %p\n", stackVar);
}
```

ELF Format - ELF Analysis

```
Global var: 0x400654
Heap var  : 0x601010
Stack var : 0x7fffffffe990


(2)   LOAD            0x0000000000400000
                      R E    200000
(3)   LOAD            0x0000000000600b28
                      RW     200000
(7)   GNU_STACK       0x0000000000000000
                      RW     10
```

ELF Format

See it at runtime

```
# cat /proc/self/maps
00400000-0040c000 r-xp 00000000 08:01 391694     /bin/cat
0060b000-0060c000 r--p 0000b000 08:01 391694     /bin/cat
0060c000-0060d000 rw-p 0000c000 08:01 391694     /bin/cat
…
7ffffffde000-7ffffffff000 rw-p 00000000 00:00 0 [stack]
```

ELF Format

Show Code section, and disassemble:

```
$ objdump -d ./challenge1
./challenge1:     file format elf64-x86-64
Disassembly of section .init:
0000000000400588 <_init>:
…
000000000040077f <handleData>:
  40077f:   55                    push   %rbp
  400780:   48 89 e5              mov    %rsp,%rbp
  400783:   48 83 ec 30           sub    $0x30,%rsp
  400787:   48 89 7d d8           mov    %rdi,-0x28(%rbp)
  40078b:   48 89 75 d0           mov    %rsi,-0x30(%rbp)
```

ELF Format

The process of creating a process from an ELF file is called:

- “Linking and Loading”

Sections:

- Are for compiler (gcc), to link several object files together (.o)

Segments:

- Are for the loader, to create the process
- Each segment consists of one ore more sections

ELF Format

Recap:

- Program Code is stored in ELF Files
- ELF Files contain segments
- Segments are copied 1:1 in the memory to create a process (of that program)
- A process has generally three important segments:
  - Code segment (the actual compiled code)
  - Heap (global allocations with malloc())
  - Stack (local variables of functions)

Challenges

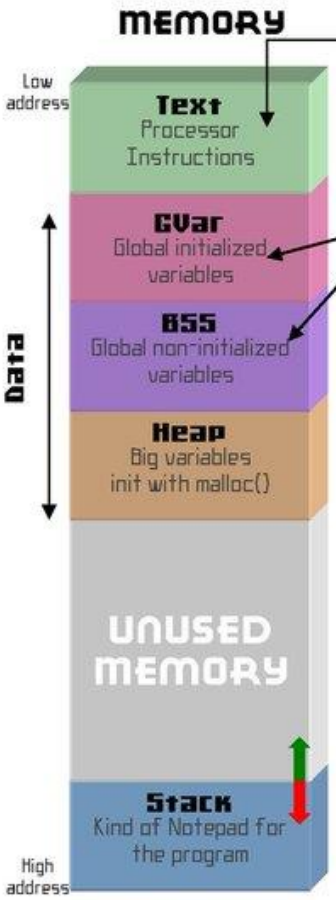
Challenges:

https://exploit.courses

- Challenge 0: Introduction to memory layout – basic
- Challenge 1: Introduction to memory layout - advanced
- (Challenge 4: Introduction to hex numbers, code and GDB)

Memory Segmentation Cheat Sheet

0x0ff.info production, inspired by bases-hacking.org

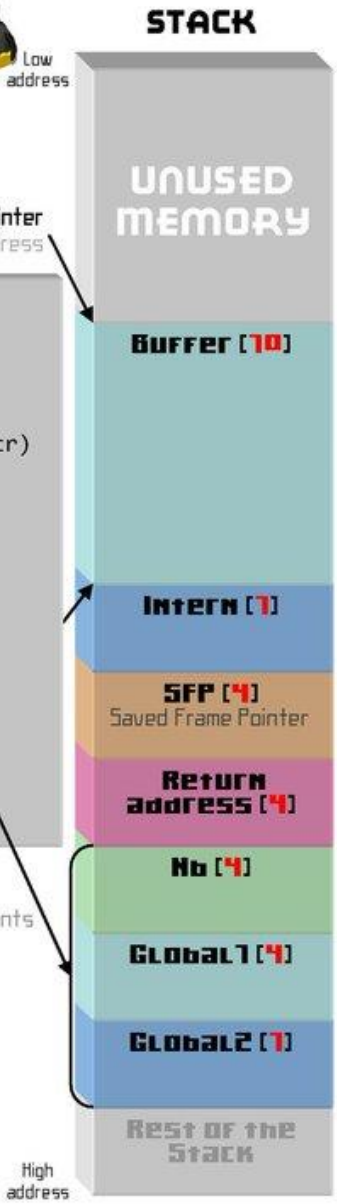



```c
//exemple.c

int global1 = 1;
char global2;

void func(int nb1,int nb2,char str)
{
   char intern;
   char buffer[10];
}

int main() {
   int nb; //in the stack
   nb = 24;

   func(nb, global1, global2);

   return 0;
}
```

PUSHING
Insert data
POPPING
Remove data

SP/ESP/RSP End Stack Pointer
Last element address

EBP/FP/LBP
Pointer on various elements in the stack frame



HOW TO WEAKEN A PROGRAM Training

LINUX

Disable ASLR (random memory address) :

```
# echo 0 > /proc/sys/kernel/randomize_va_space
```

Disable non-executable stack :

```
$ gcc -z execstack ...
```

Disable stack protector :

```
$ gcc -fno-stack-protector ...
```

Force 32-bits compilation mode :

```
$ gcc -m32 ...
```

GLOBAL REGISTERS

Used for general purpose

X86

AL/AH/AX/EAX/RAX
BL/BH/BX/EBX/RBX
CL/CH/CX/ECX/RCX
DL/DH/DX/EDX/RDX

ARM

r0-r12

INDEX POINTERS

Use for Strings operations

X86

SI/ESI/RSI : Source index
DI/EDI/RDI : Destination index

INSTRUCTION POINTER

The current instruction address.

X86

IP/EIP/RIP

ARM

PC

SEGMENT REGISTERS

Use to easily reade/write to memory

X86

CS : Code	ES : Extra data #1
DS : Data	FS : Extra data #2
SS : Stack	GS : Extra data #3

MEMORY ALIGNMENT

Data must be aligned on 4,8,16... Bytes, depending on your system.

EXAMPLE
There is an 3 bytes long empty gap between intern and SFP.

BUFFER OVERFLOW

when input is longer than the allocated memory space.

[Stack based]

Smart overwrite of return address

EXAMPLE
Put a 22 bytes long string and overwrite intern Return address.

EXPLOIT ANATOMY

[Heap based]

Smart overwrite of others variables like file name.

EXAMPLE
You have to enter a 6 letters name in the character builder of a game. You enter Batman\x64, to overwrite level variable and get max stats !