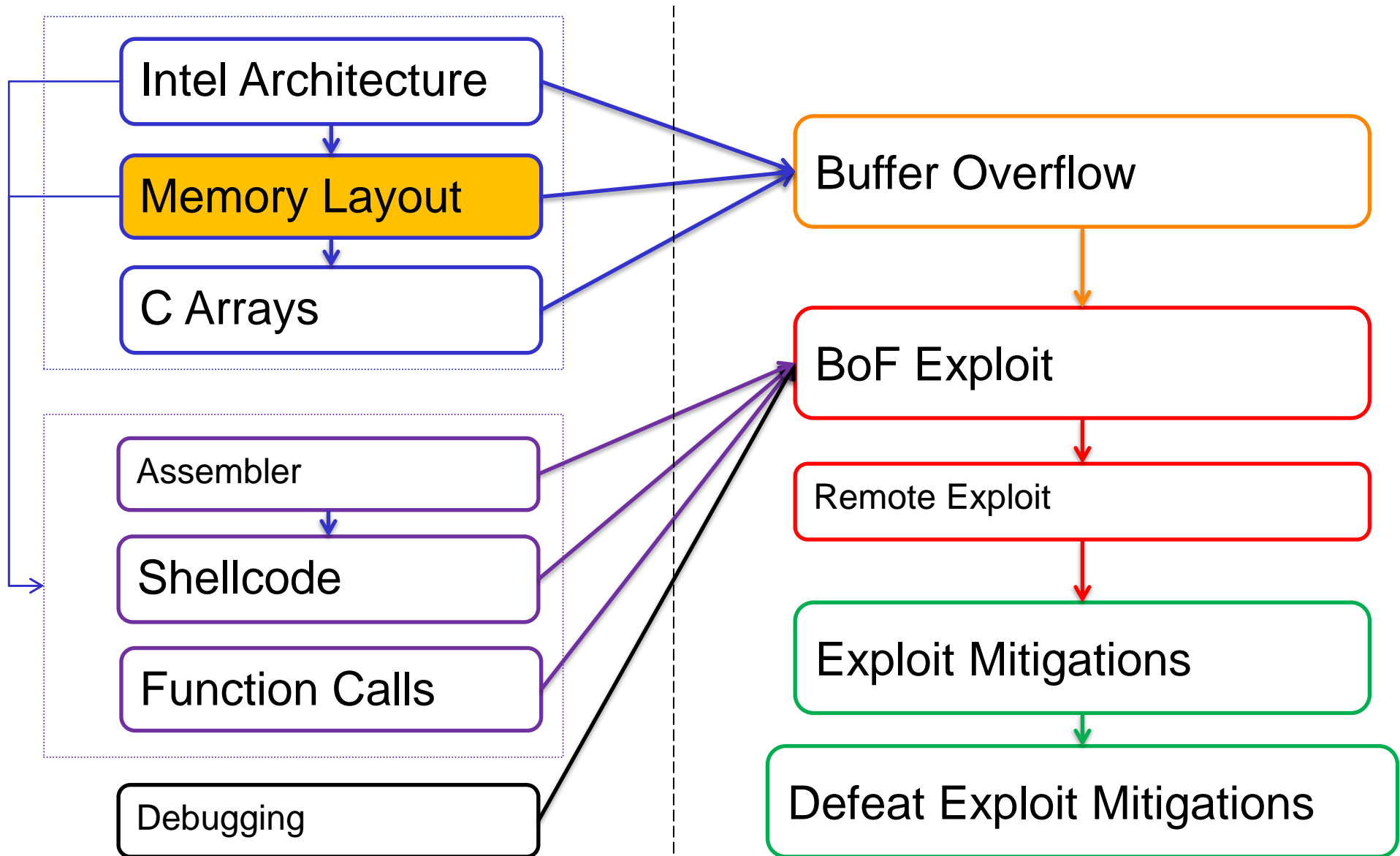


---

# Memory Layout

Linux Userspace Process Memory Layout

# Content

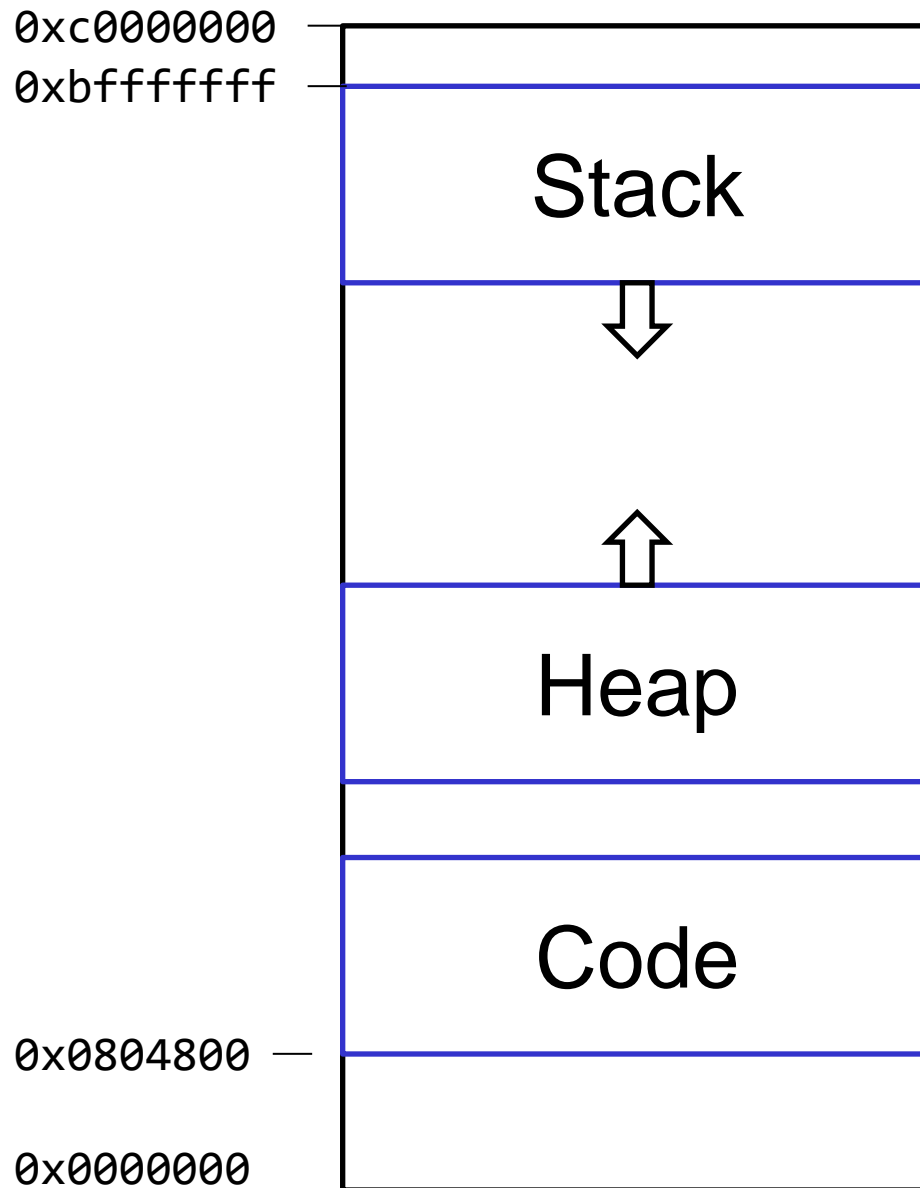


---

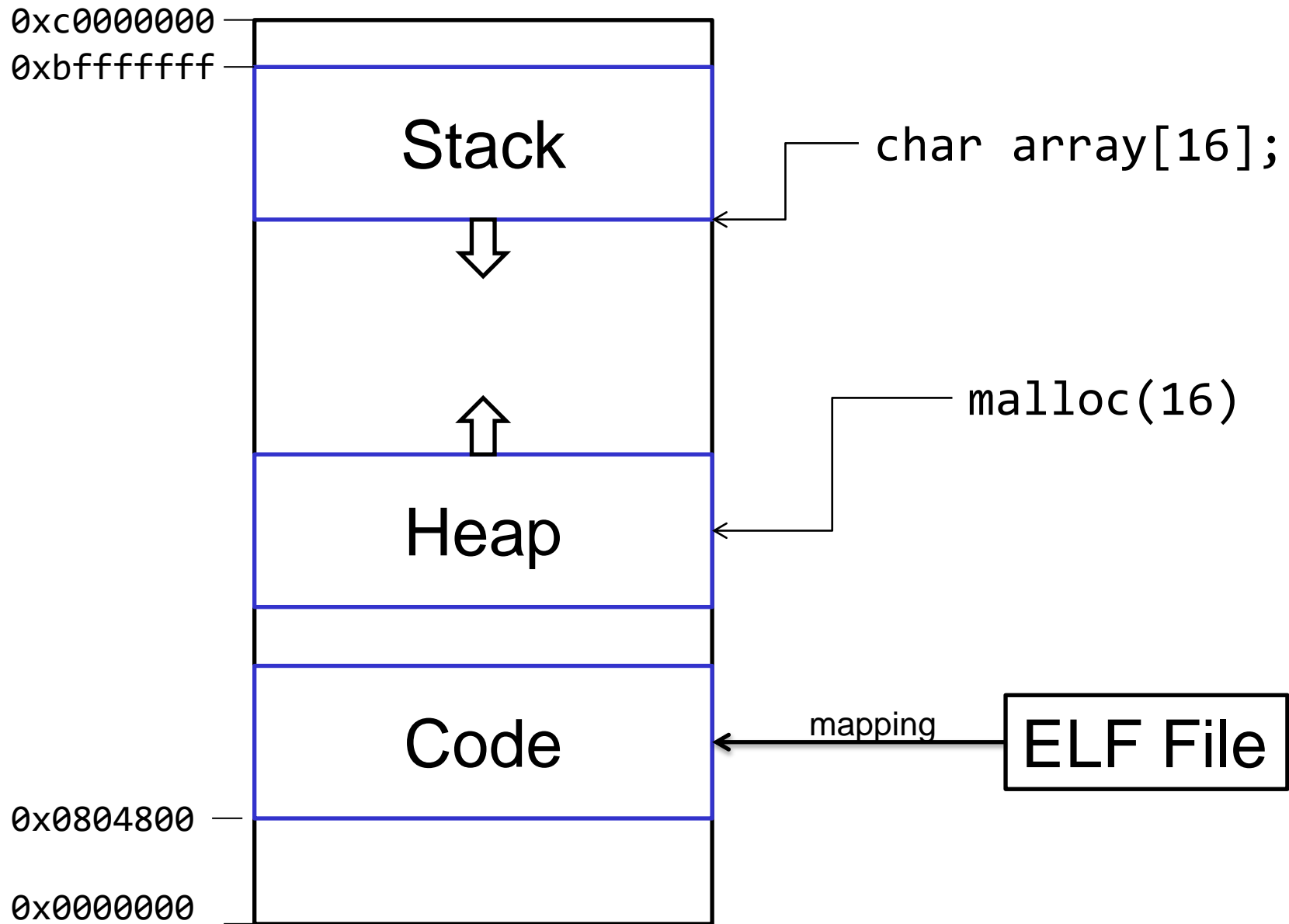
# Userspace Memory Layout

In 32 bit

## x32 Memory Layout

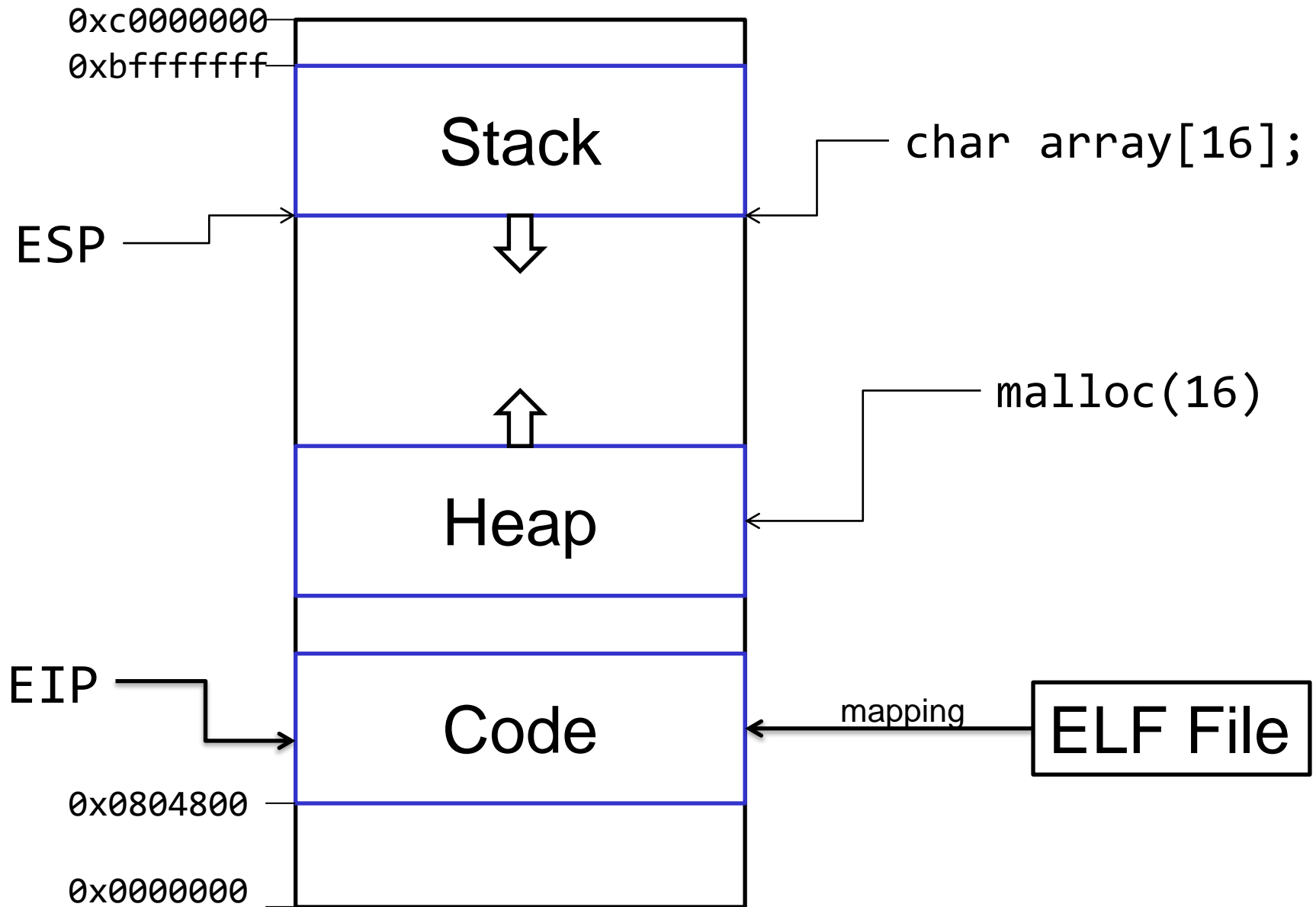


## x32 Memory Layout





## 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:

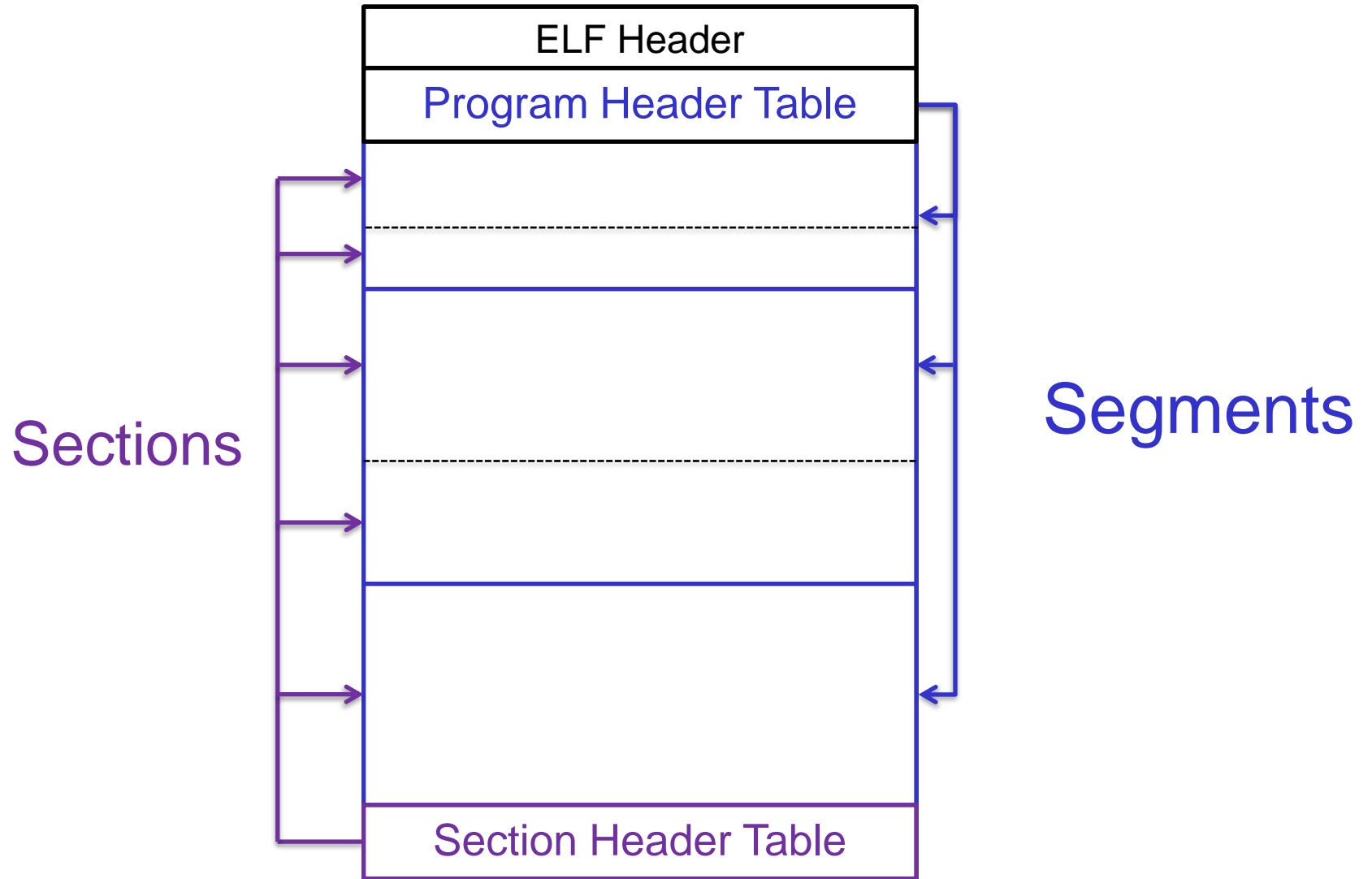
- ✦ ET\_EXEC: Executable File
- ✦ ET\_REL: Relocatable File
- ✦ ET\_DYN: Shared Object File

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



```
$ 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: Uninitialized 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
	0x00000000000000b24	R E 200000
(03) LOAD	0x00000000000000b28	0x0000000000600b28
	0x00000000000000270	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

ELF Header
Program Header Table
.plt
.text
.init
.got
.data
.bss
Section Header Table

---

## 02 Executable Segment

r-X

---

---

## 03 Data Segment

rW-

---

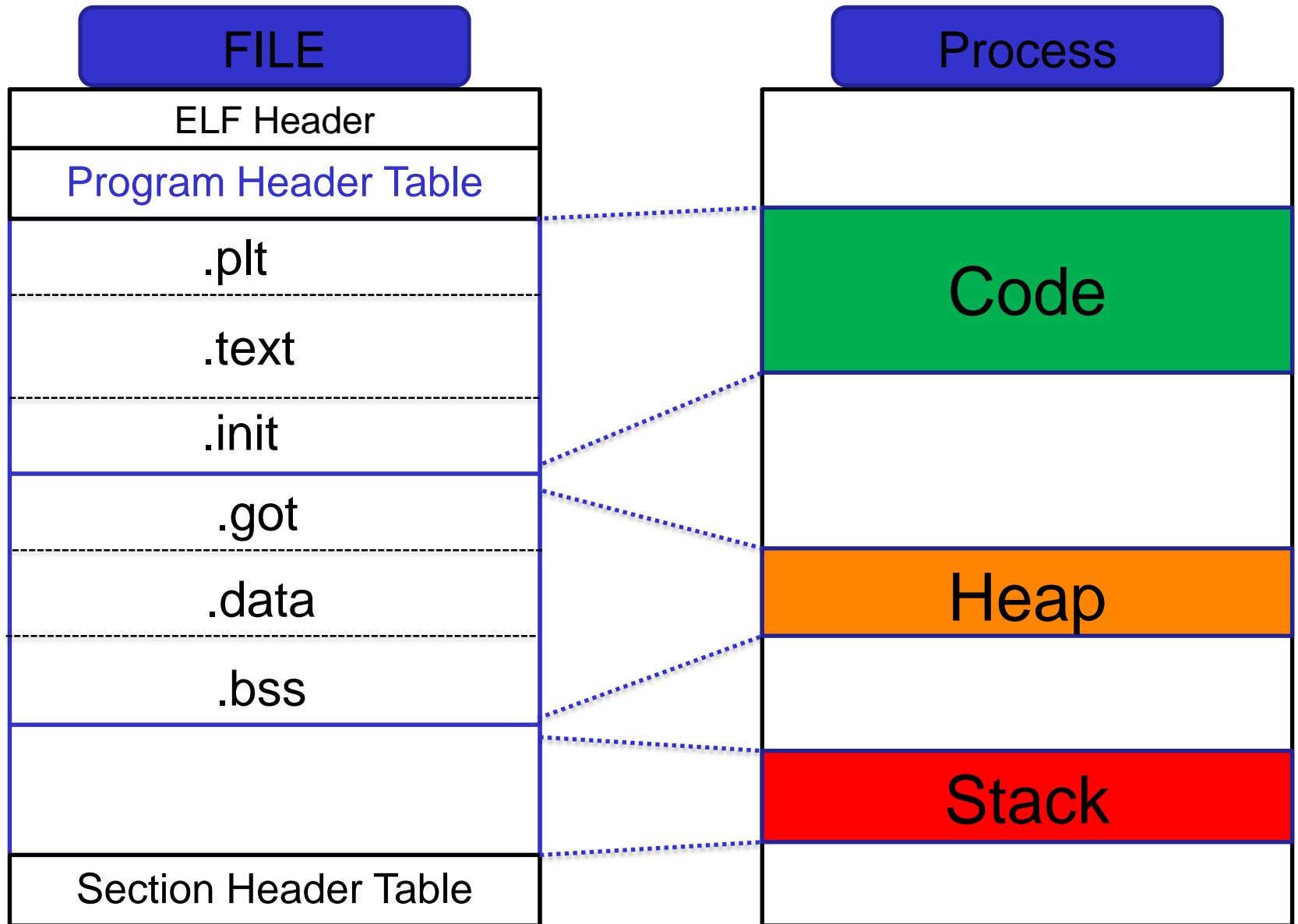
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## 07 Stack

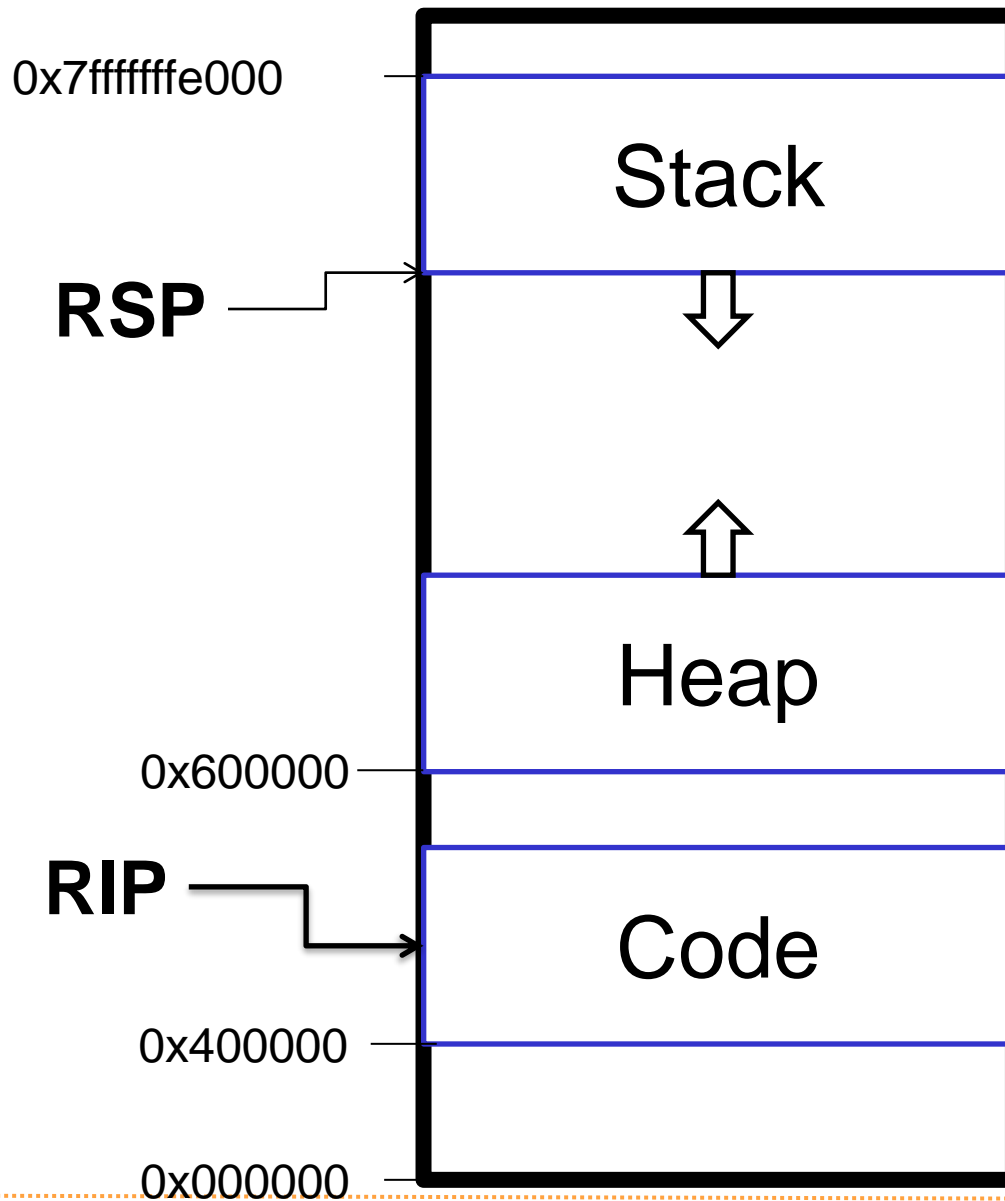
rw-

---





# 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 : **0x7fffffffefe990**

(2) **LOAD** **0x000000000000400000**

**R E** 200000

(3) **LOAD** **0x000000000000600b28**

**RW** 200000

(7) **GNU\_STACK** **0x00000000000000000000**

**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
...
7fffffffde000-7fffffffffff000 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 or more sections





## 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>

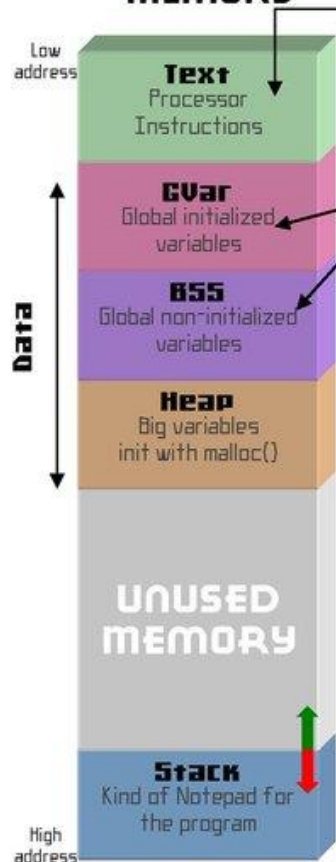
- ✦ Challenge 0: Introduction to memory layout – basic
- ✦ Challenge 1: Introduction to memory layout - advanced

# memory Segmentation Cheat Sheet

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



## MEMORY



SP/ESP/RSP End Stack Pointer  
Last element address

//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

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

## STACK

Low  
address

High  
address

UNUSED  
MEMORY

Buffer [10]

Intern [1]

SFP [4]  
Saved Frame Pointer

Return  
address [4]

Nb [4]

Global1 [4]

Global2 [1]

Rest of the  
Stack

## 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

### 64 BITS REGISTER

63..32 31..16 15..8 7..0

AH AL

AX

EAX

RAX [x64 only]

## 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 read/write to memory

X86

CS : Code

DS : Data

SS : Stack

ES : Extra data #1

FS : Extra data #2

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.

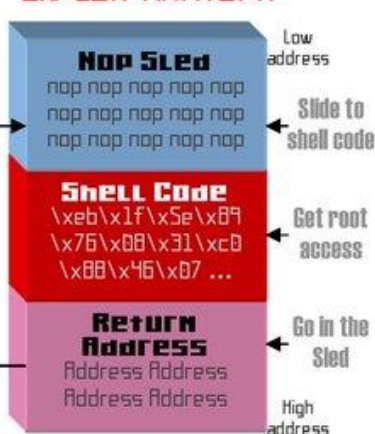
### [Stack based]

Smart overwrite of return address

### EXAMPLE

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

## EXPLOIT ANATOMY



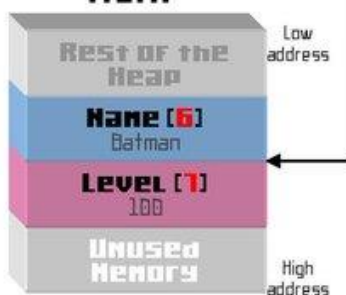
### [Heap based]

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**, to overwrite  
level variable and get max stats!

## HEAP



## 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 ...