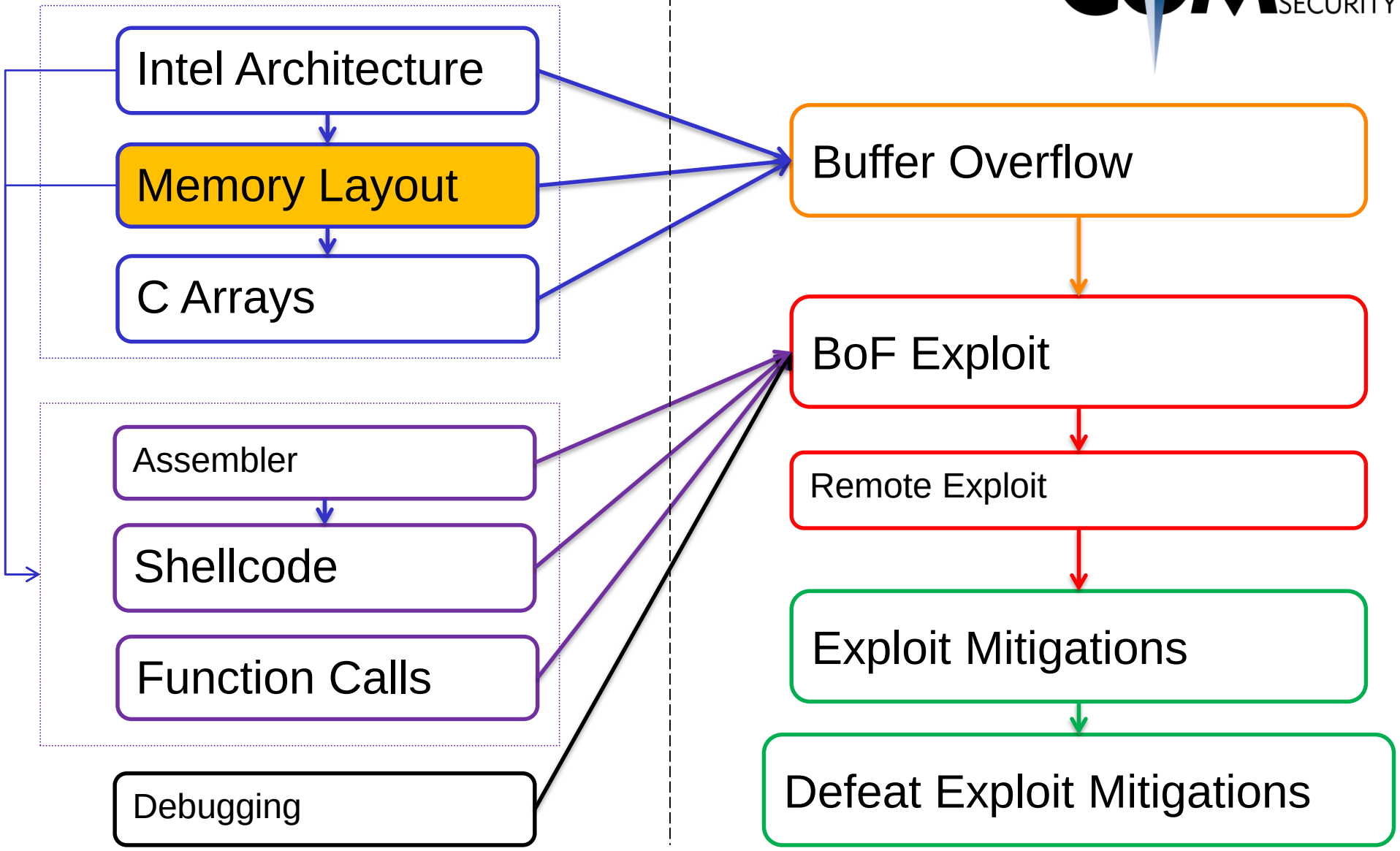
Memory Layout

Linux Userspace Process Memory Layout

Compass Security Schweiz AG
Werkstrasse 20
Postfach 2038
CH-8645 Jona

Tel +41 55 214 41 60
Fax +41 55 214 41 61
team@csnc.ch
www.csnc.ch

Content


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

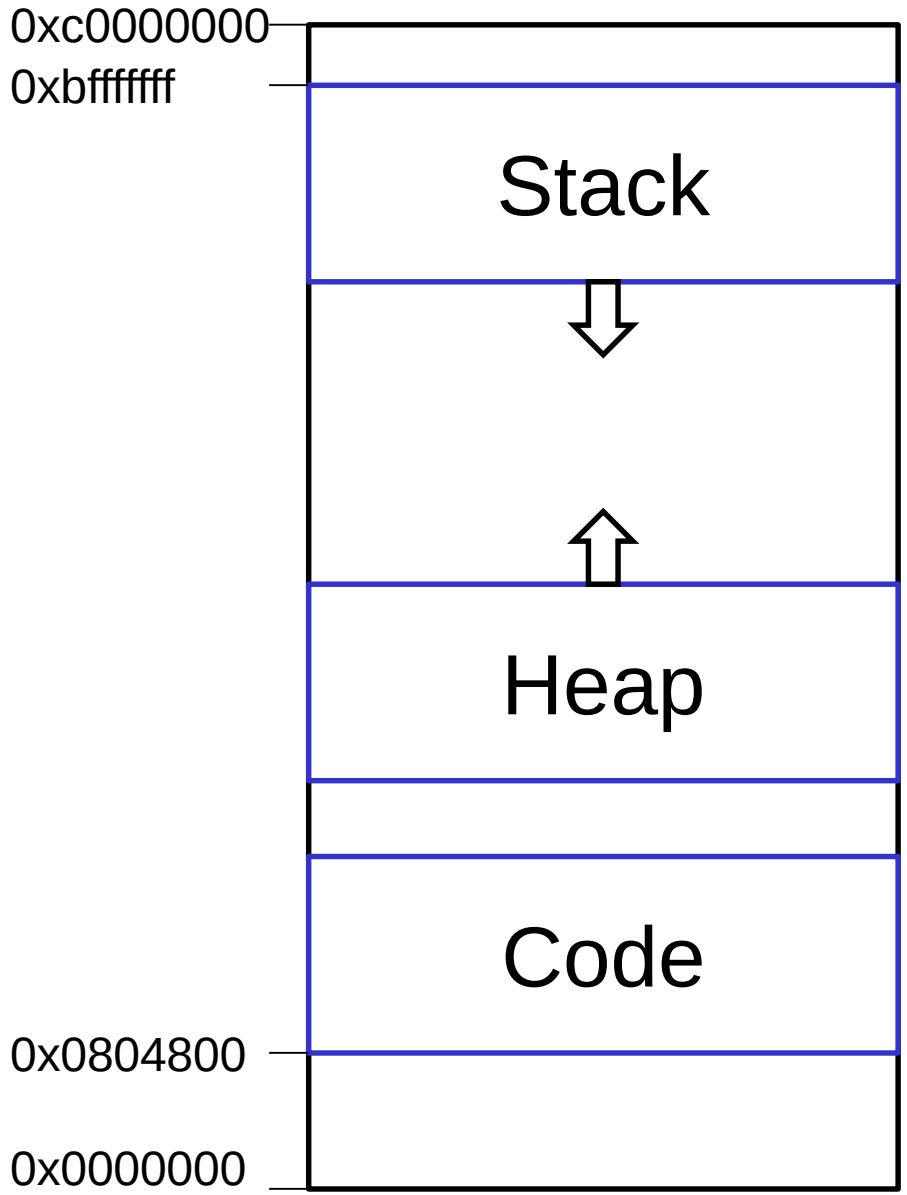
Userspace Memory Layout

In x32

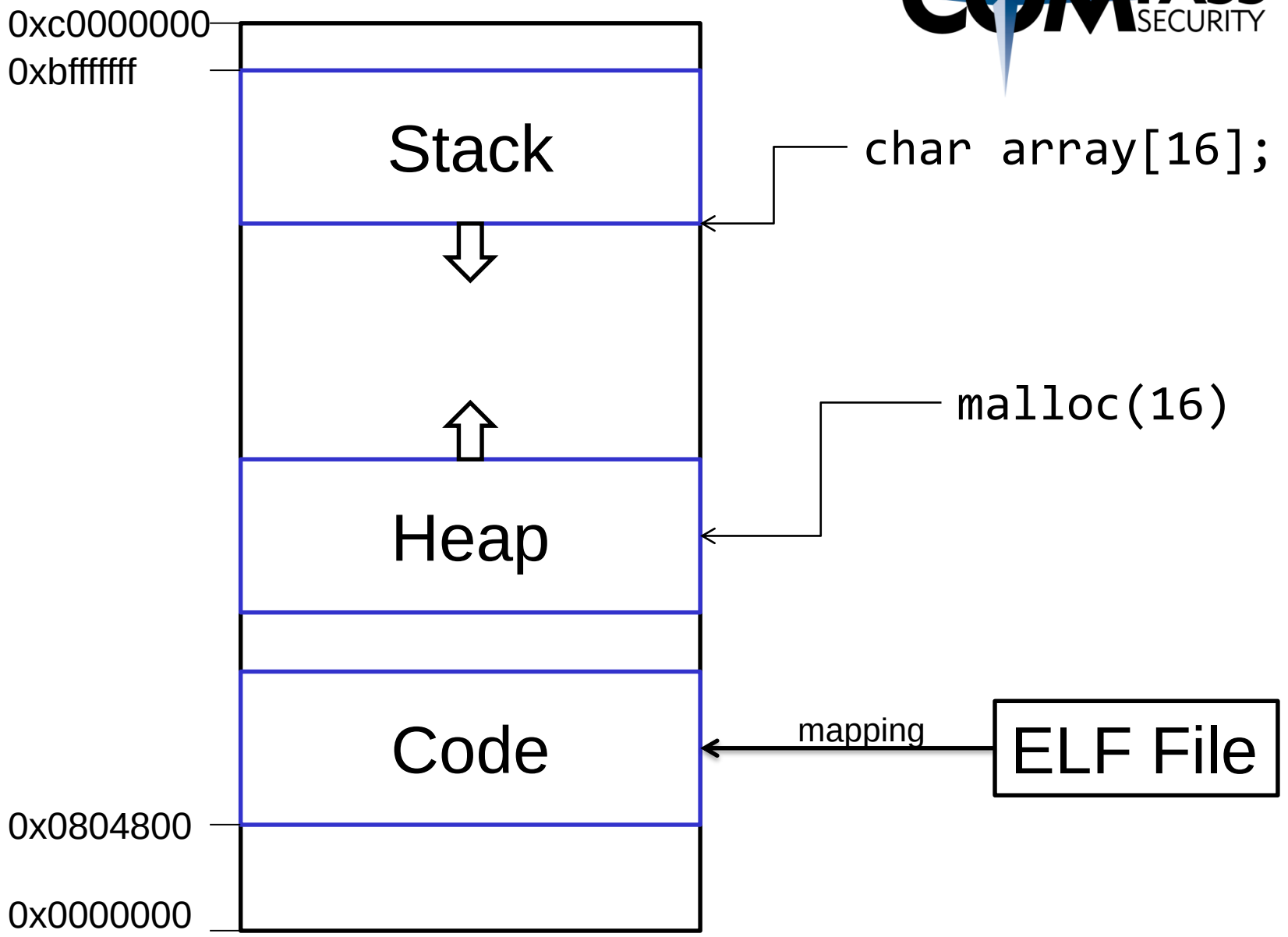
Compass Security Schweiz AG
Werkstrasse 20
Postfach 2038
CH-8645 Jona

Tel +41 55 214 41 60
Fax +41 55 214 41 61
team@csnc.ch
www.csnc.ch

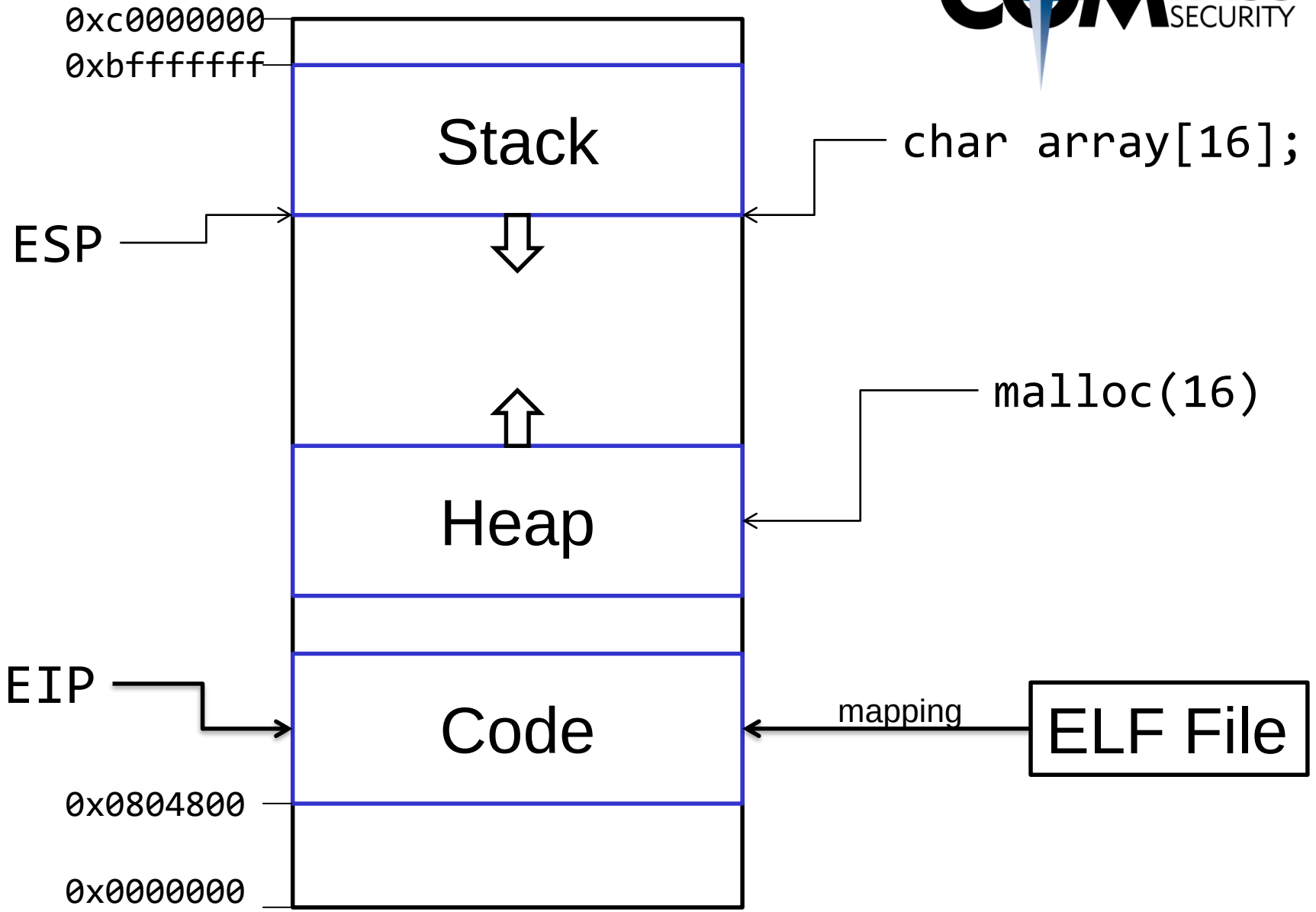
x32 Memory Layout



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

x32 Memory Layout

Memory regions:

Code

- Compiled program code

ELF Format

How do programs on disk look like

Compass Security Schweiz AG
Werkstrasse 20
Postfach 2038
CH-8645 Jona

Tel +41 55 214 41 60
Fax +41 55 214 41 61
team@csnc.ch
www.csnc.ch

ELF Format

Programs are stored in ELF files

ELF: Executable and Linkable Format

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

ELF types:

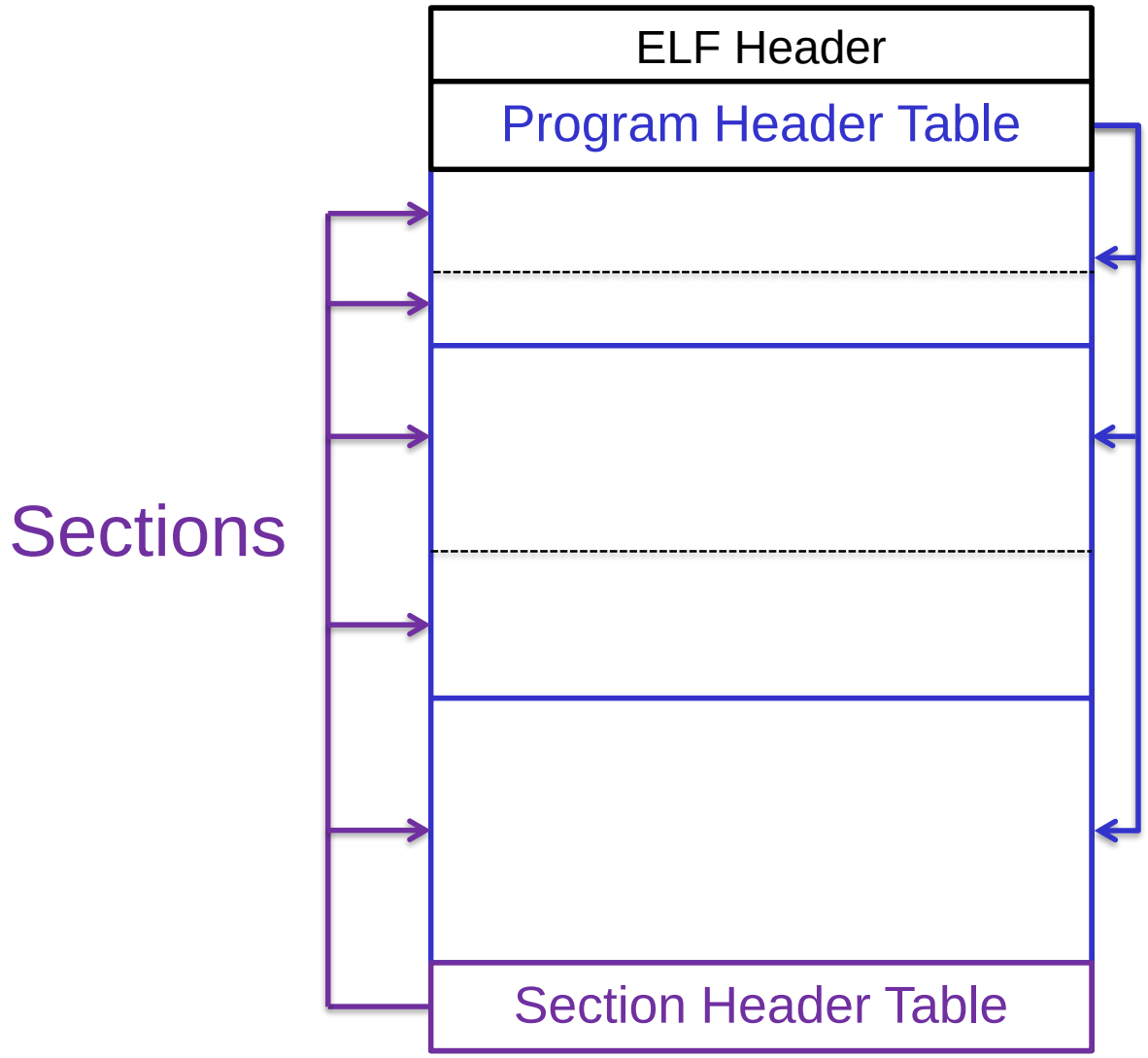
- ET_EXEC: Executable File
- ET_REL: Relocatable File
- ET_DYN: Shared Object File

ELF “views”:

- Sections
- Segments

$ readelf –l <binary>

ELF Format


ELF Header
Program Header Table
Section Header Table
Sections
Segments

ELF Format

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
LOAD	0x00000000	0x0000400000	**0x0000000000400000**
	0x00000b24	0x0000000b24	**R E** 200000
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
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
```

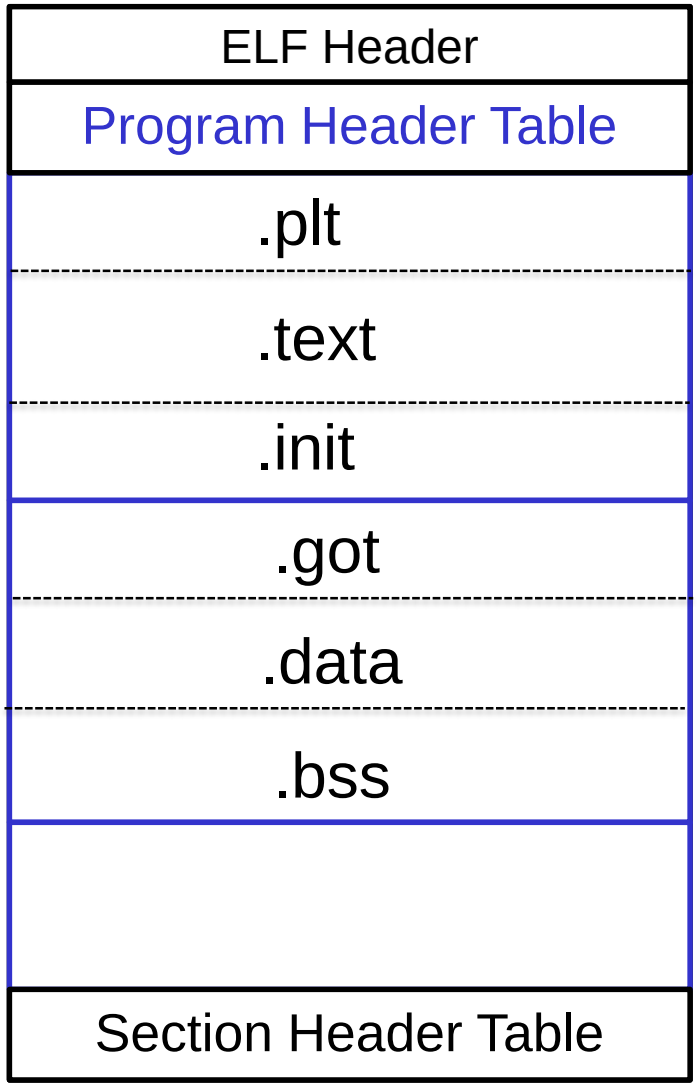
```
02      .init .plt .text .fini .rodata
03      .got .got.plt .data .bss
07
```

ELF Loader

Compass Security Schweiz AG
Werkstrasse 20
Postfach 2038
CH-8645 Jona

Tel +41 55 214 41 60
Fax +41 55 214 41 61
team@csnc.ch
www.csnc.ch

ELF Format



02 Executable Segment

r-x

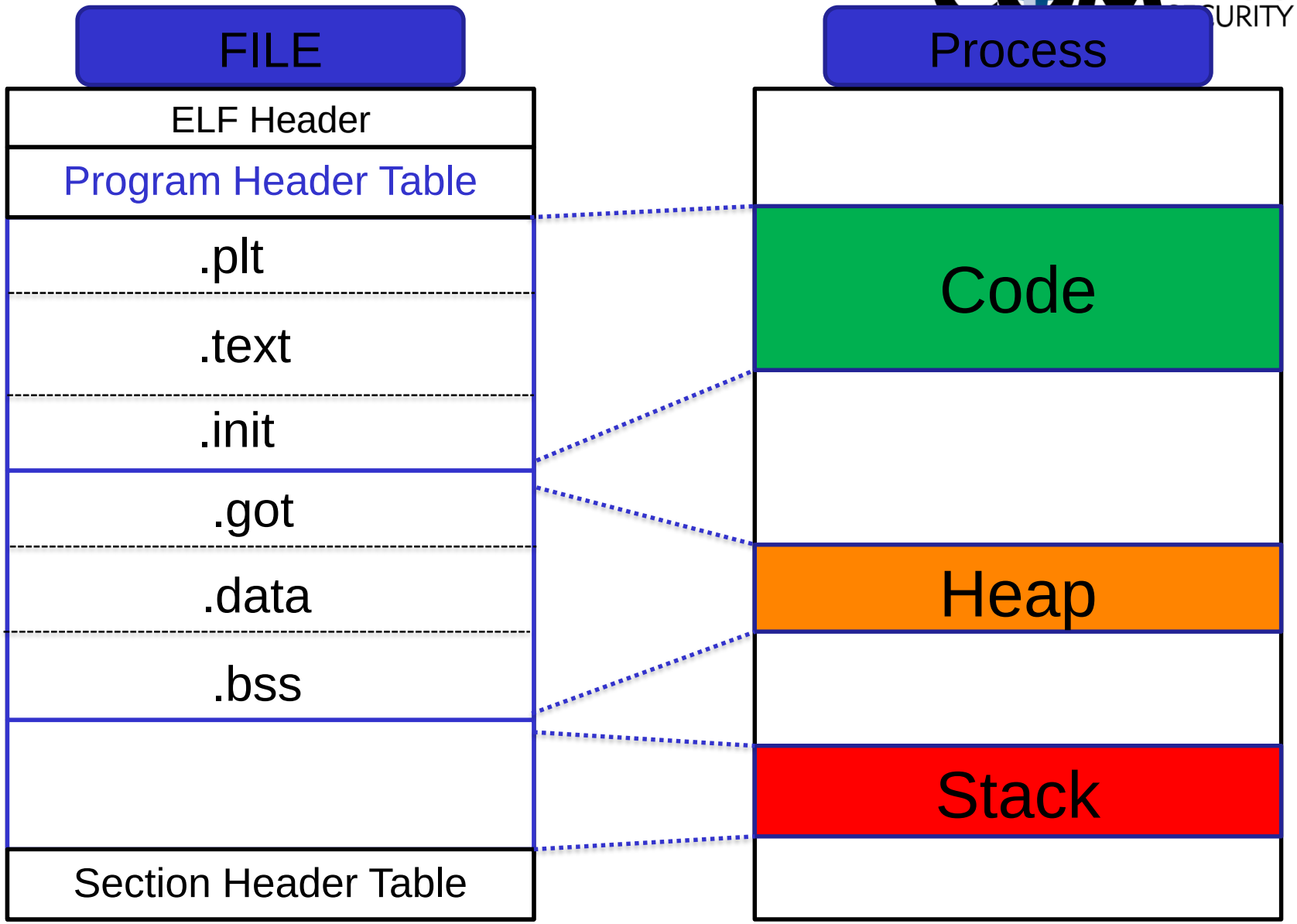
03 Data Segment

rw-

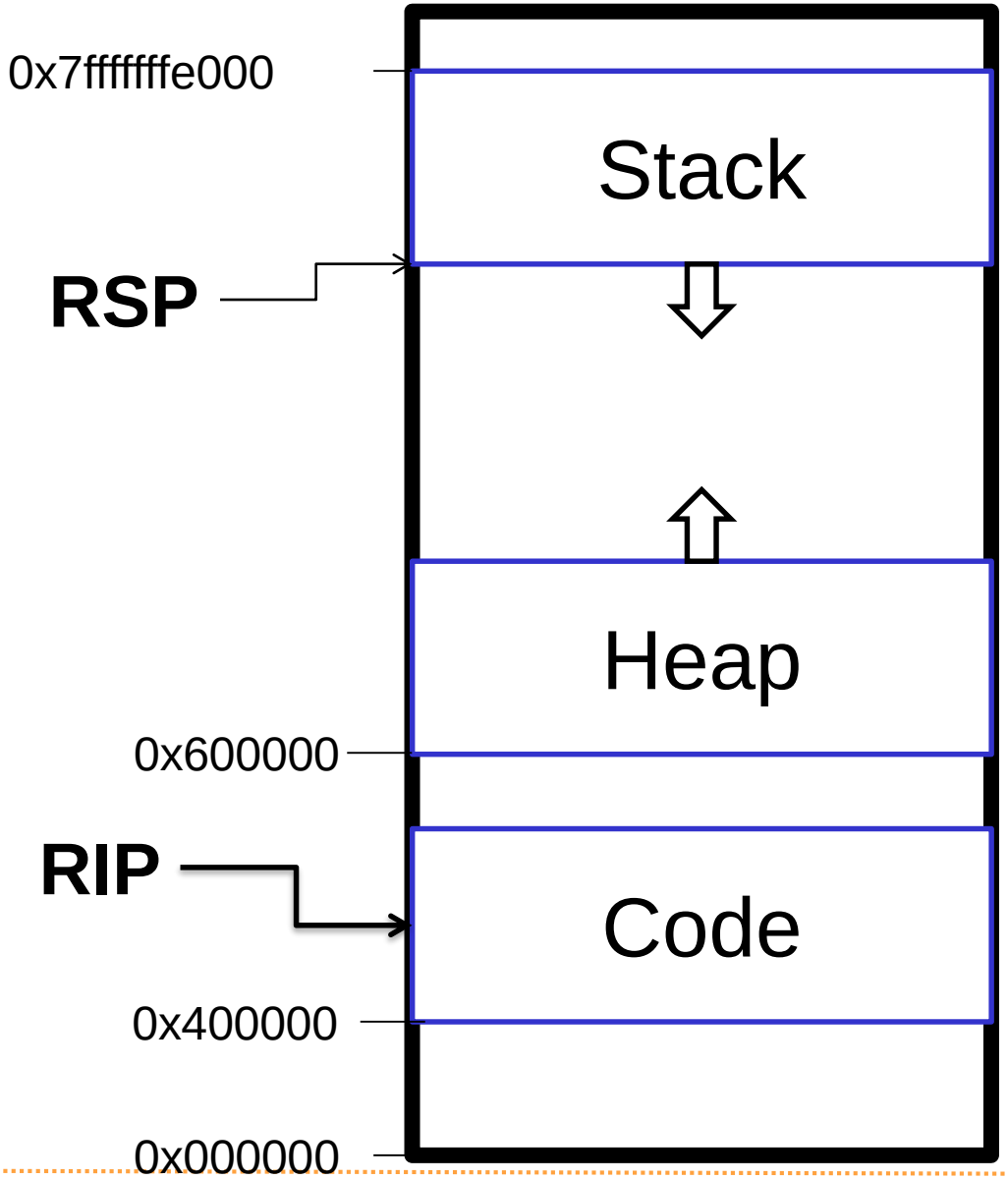
07 Stack

rw-

ELF Format


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

x64 Memory Layout



Lets do an example

some static and dynamic binary analysis

Compass Security Schweiz AG
Werkstrasse 20
Postfach 2038
CH-8645 Jona

Tel +41 55 214 41 60
Fax +41 55 214 41 61
team@csnc.ch
www.csnc.ch

ELF Format

```
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);
}
```

```
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
…
7ffffffde000-7fffffffe000 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
- 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

Challenges

Challenges:

https://exploit.courses

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