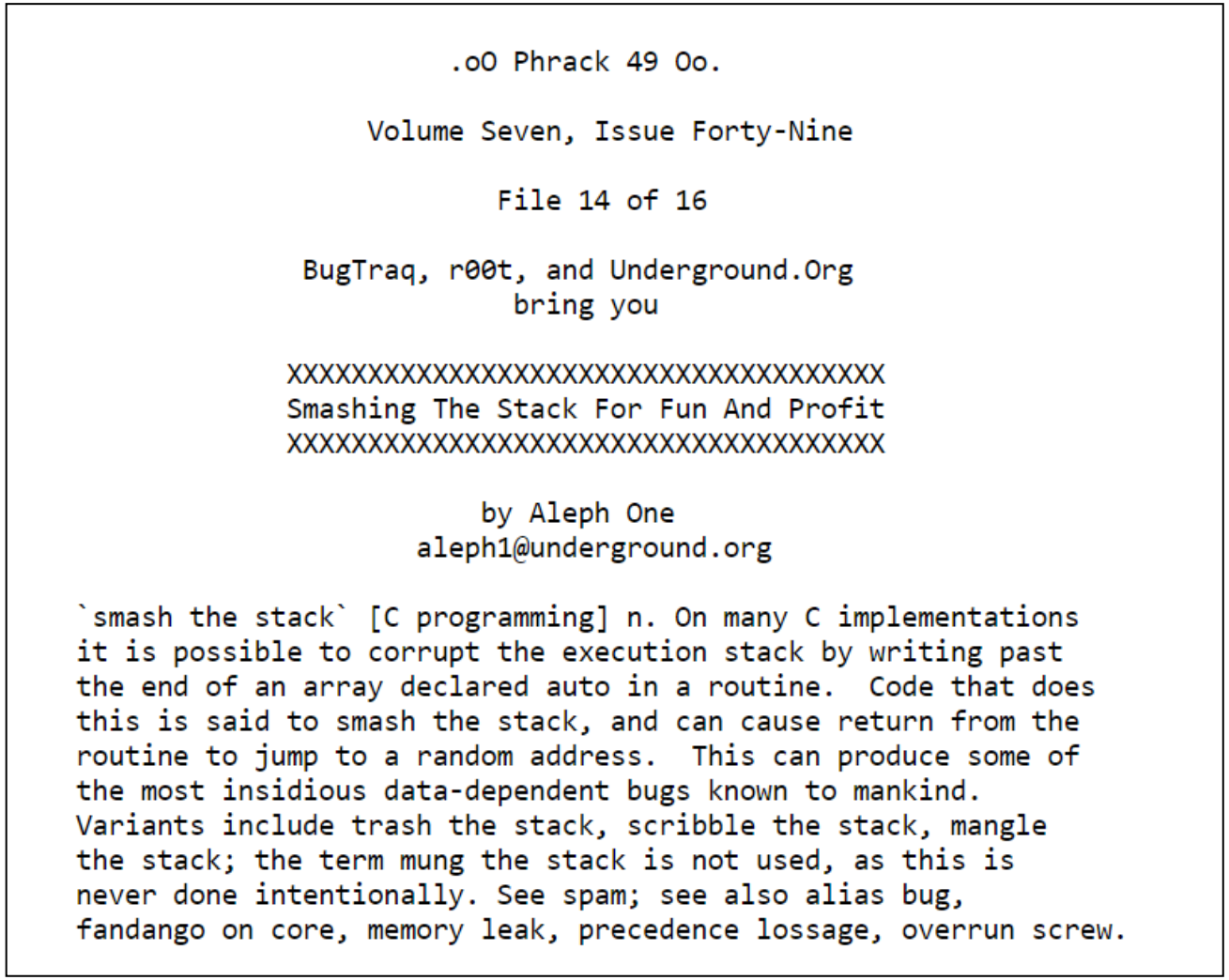
Exploit Mitigations

Exploit Mitigations: Recap

You know how to exploit a buffer overflow.

Like it’s 1996.

Lets take you to 2016



.oO Phrack 49 Oo.

Volume Seven, Issue Forty-Nine

File 14 of 16

BugTraq, r00t, and Underground.Org
bring you

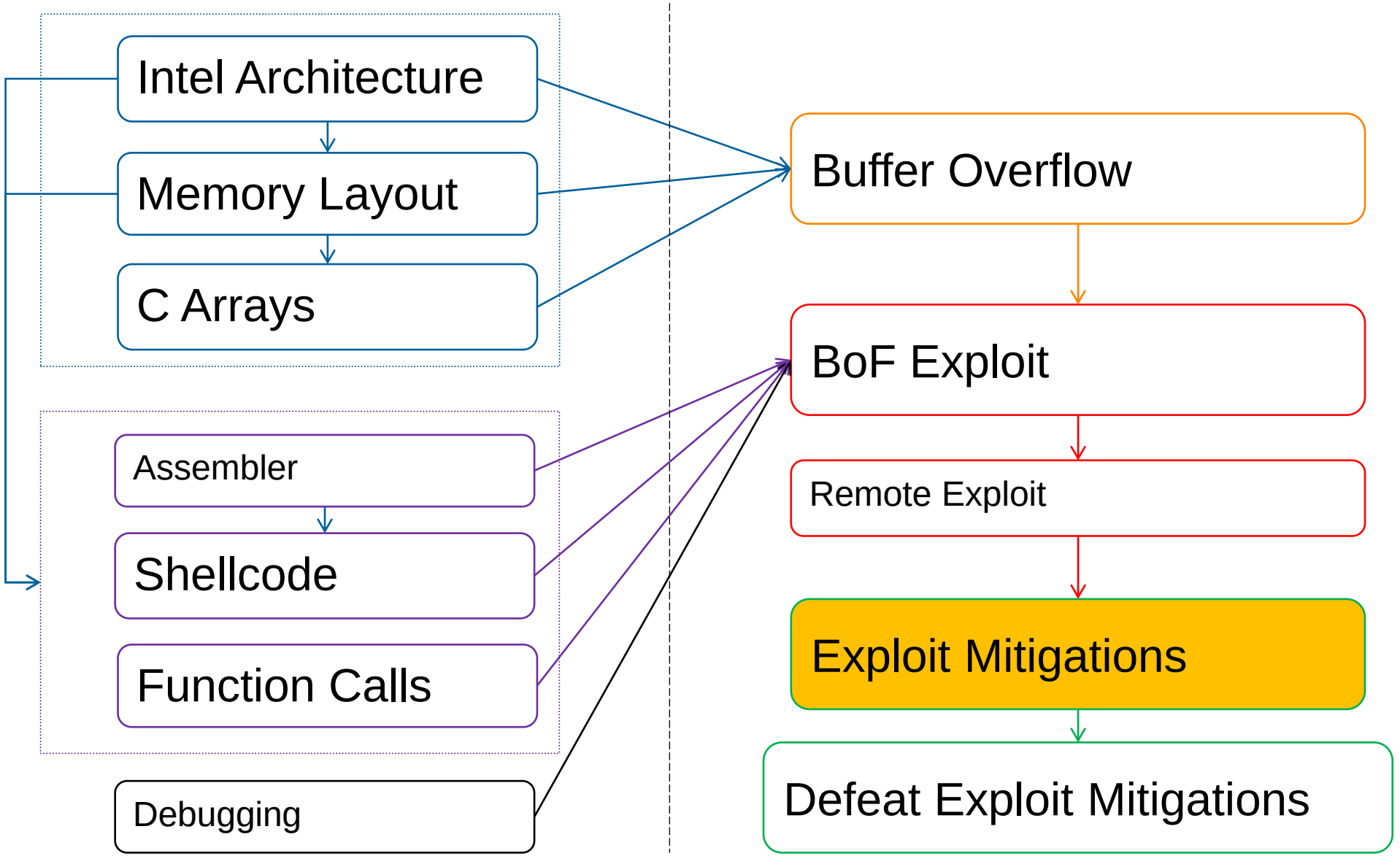
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Smashing The Stack For Fun And Profit
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

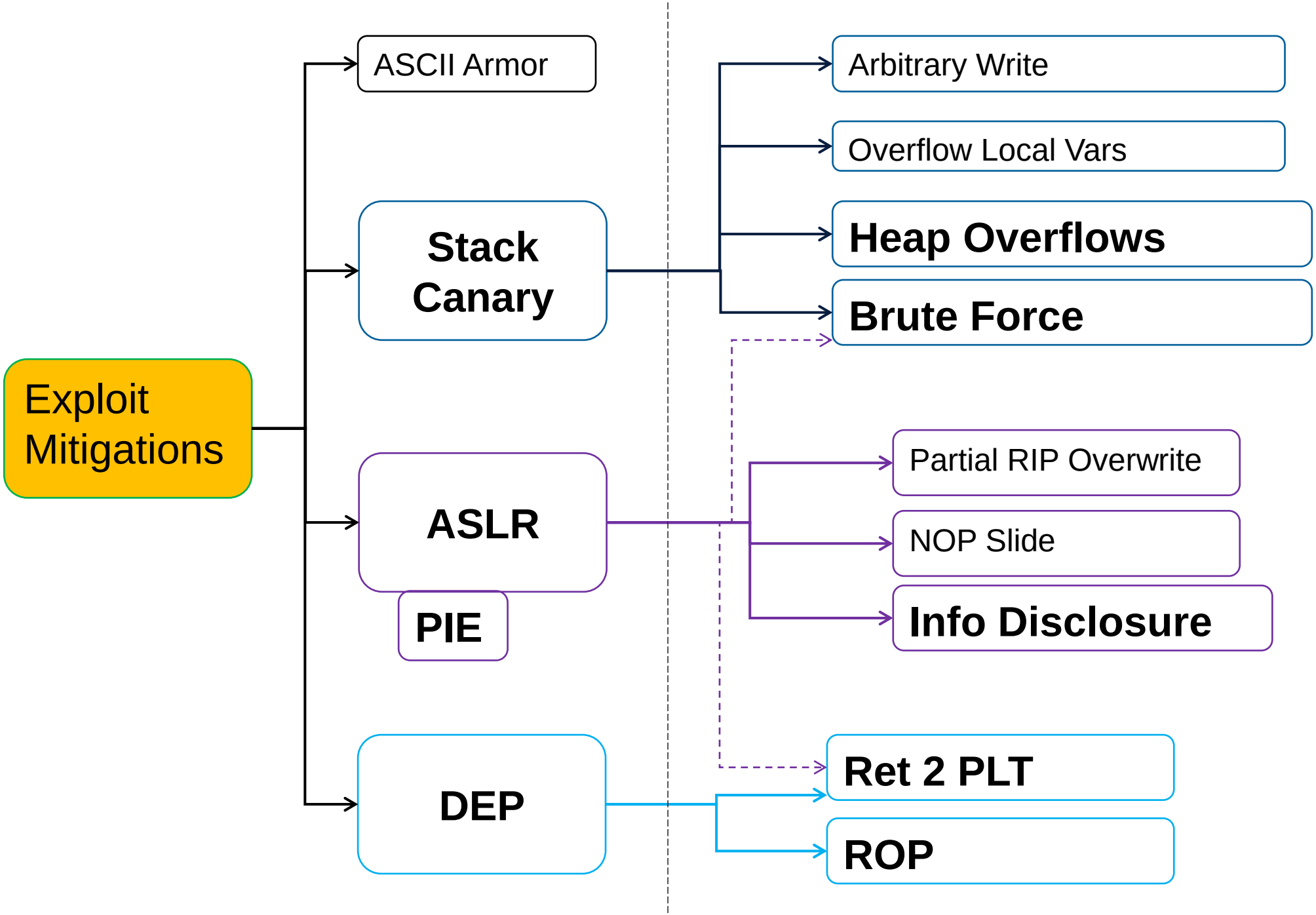
by Aleph One
aleph1@underground.org

`smash the stack` [C programming] n. On many C implementations
it is possible to corrupt the execution stack by writing past
the end of an array declared auto in a routine. Code that does
this is said to smash the stack, and can cause return from the
routine to jump to a random address. This can produce some of
the most insidious data-dependent bugs known to mankind.
Variants include trash the stack, scribble the stack, mangle
the stack; the term mung the stack is not used, as this is
never done intentionally. See spam; see also alias bug,
fandango on core, memory leak, precedence lossage, overrun screw.

Exploit Mitigations: Recap

Content


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


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Exploit Mitigations: Content

DEP (Data Execution Prevention)

Stack Canary

ASLR (Address Space Layout Randomization)

Exploit Mitigations: Security News

OpenBSD

Subject: anti-ROP mechanism in libc
From: Theo de Raadt <deraadt () openbsd ! org>
2016-04-25 13:10:25
26067.1461589825 () cvs ! openbsd ! org
[Download message RAW]

This change randomizes the order of symbols in libc.so at boot time.

This is done by saving all the independent .so sub-files into an ar archive, and then relinking them into a new libc.so in random order, at each boot. The cost is less than a second on the systems I am using.

Grsecurity/PAX

RAP is here. Public demo in 4.5 test patch and commercially available today!

April 28, 2016

Today's release of grsecurity® for the Linux 4.5 kernel marks an important milestone in the project's history. It is the first kernel to contain RAP, a defense mechanism against code reuse attacks. RAP was announced to the

Linux Kernel 4.6

Currently on i386 and on X86_64 when emulating X86_32 in legacy mode, only the stack and the executable are randomized but not other mmapped files (libraries, vDSO, etc.). This patch enables randomization for the libraries, vDSO and mmap requests on i386 and in X86_32 in legacy mode.

Exploit Mitigations

Best Exploit Mitigation:

(Security relevant-) Bugs should not exist at all

Write secure code!

- Use **secure libraries**
- Perform **Static Analysis** of the source code
- Perform **Dynamic Analysis** of programs
- Perform **fuzzing** of input vectors
- Have a secure development lifecycle (**SDL**)
- Manual source code **reviews**
- …

Developers, developers, developers

Not the focus of this lessons

Practical Exploit Mitigations

Our focus: “Sysadmin/user view”

What can WE do to improve security on our systems?

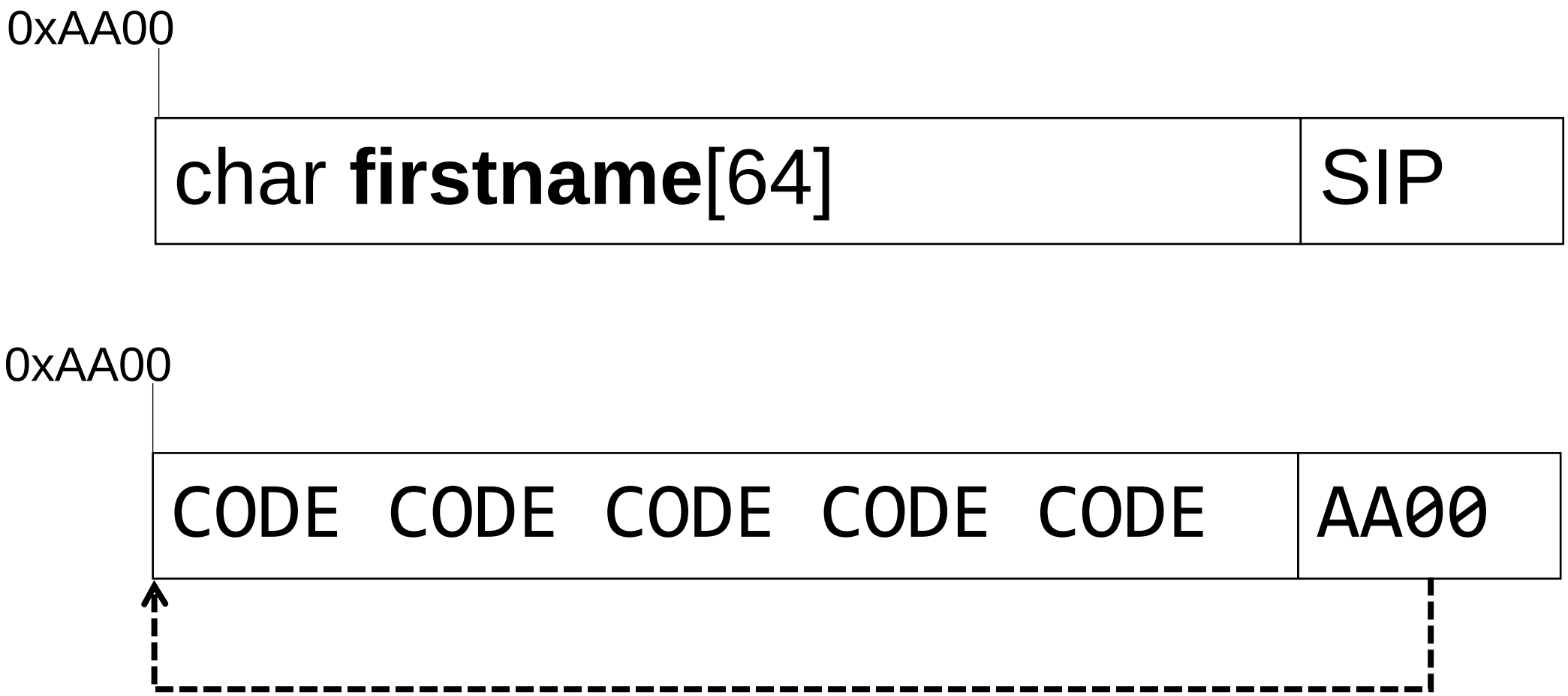
- Without fixing other people’s code

Two things:

- Compile Time Protection
- Runtime Protection

Practical Exploit Mitigations

Buffer Overflow Exploit



Exploit Mitigations: Recap

What is required to create an exploit?

- Executable Shellcode
  - Aka “Hacker instructions”
- The distance from buffer to SIP
  - Offset for the overflow
- The Address of shellcode
  - in memory of the target process

Buffer Overflow Exploit

```
shellcode = "\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\x50\x53\x89\xe1\xb0\x0b\xcd\x80"

buf_size = 64
offset = ??

ret_addr = "\x??\x??\x??\x??"

# fill up to 64 bytes
exploit = "\x90" * (buf_size - len(shellcode))
exploit += shellcode

# garbage between buffer and RET
exploit += "A" * (offset - len(exploit))

# add ret
exploit += ret_addr

# print to stdout
sys.stdout.write(exploit)
```

Practical Exploit Mitigations

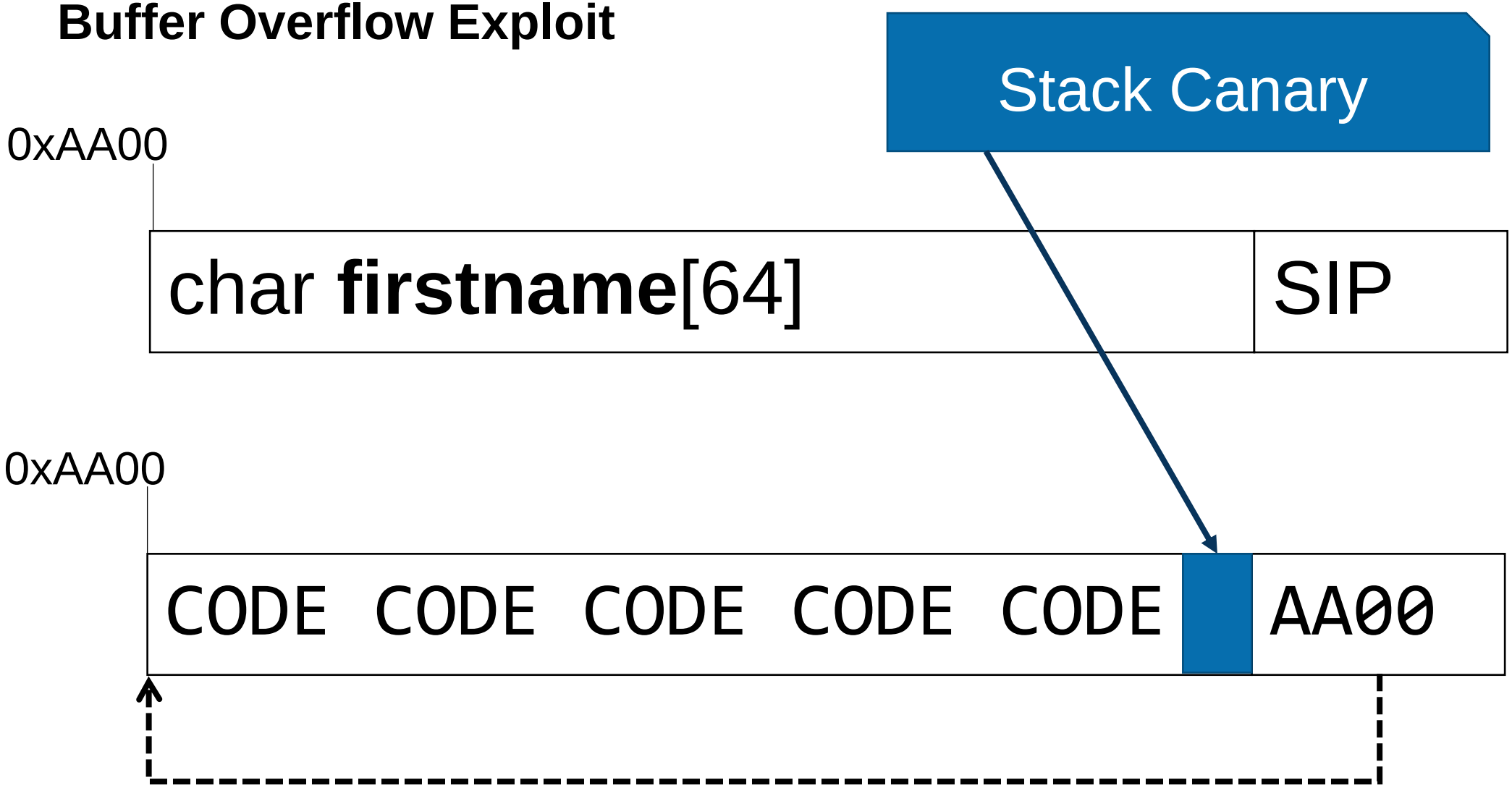
Compile Time:

- Stack canaries
- PIE

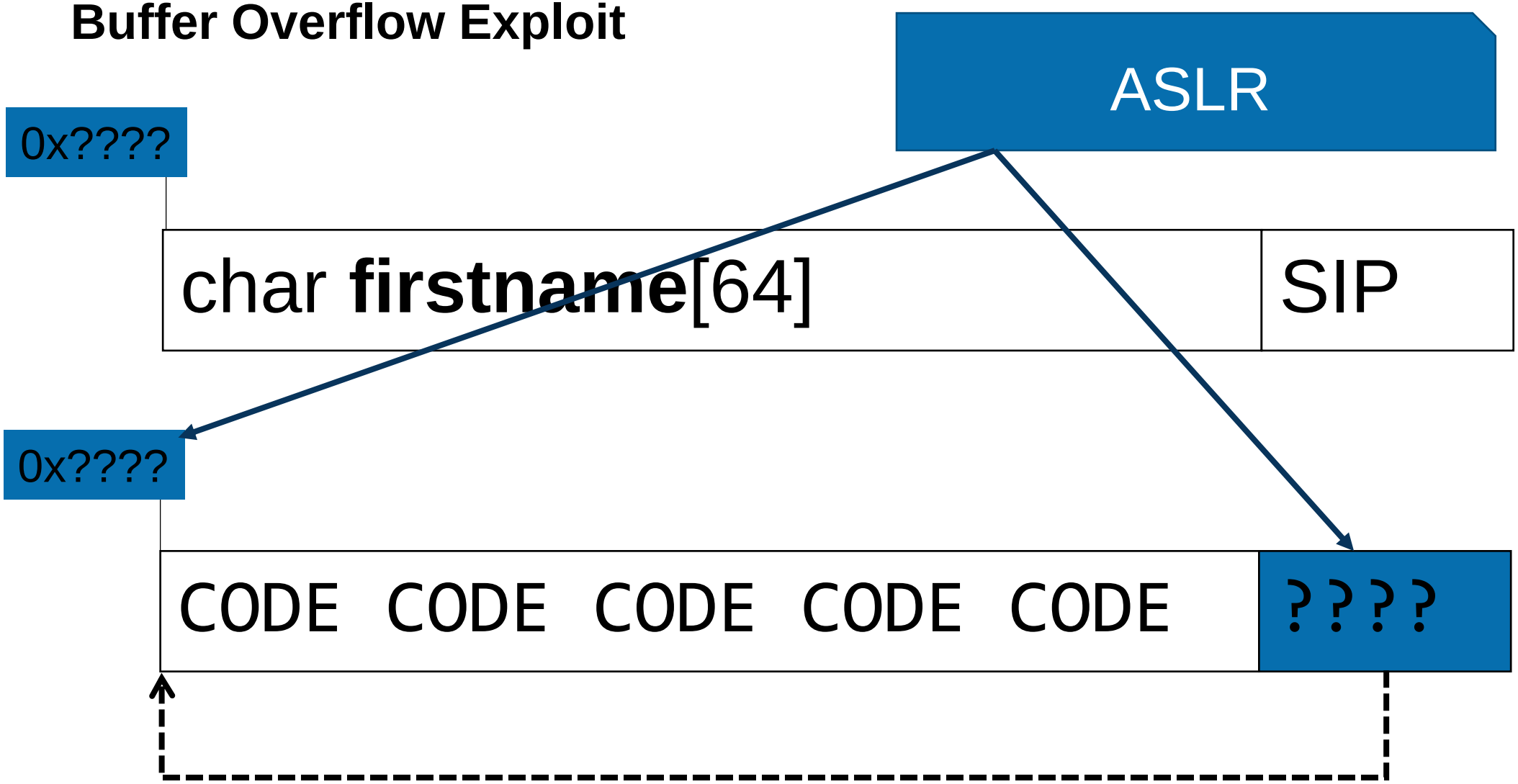
Runtime:

- ASLR
- DEP
- ASCII Armor

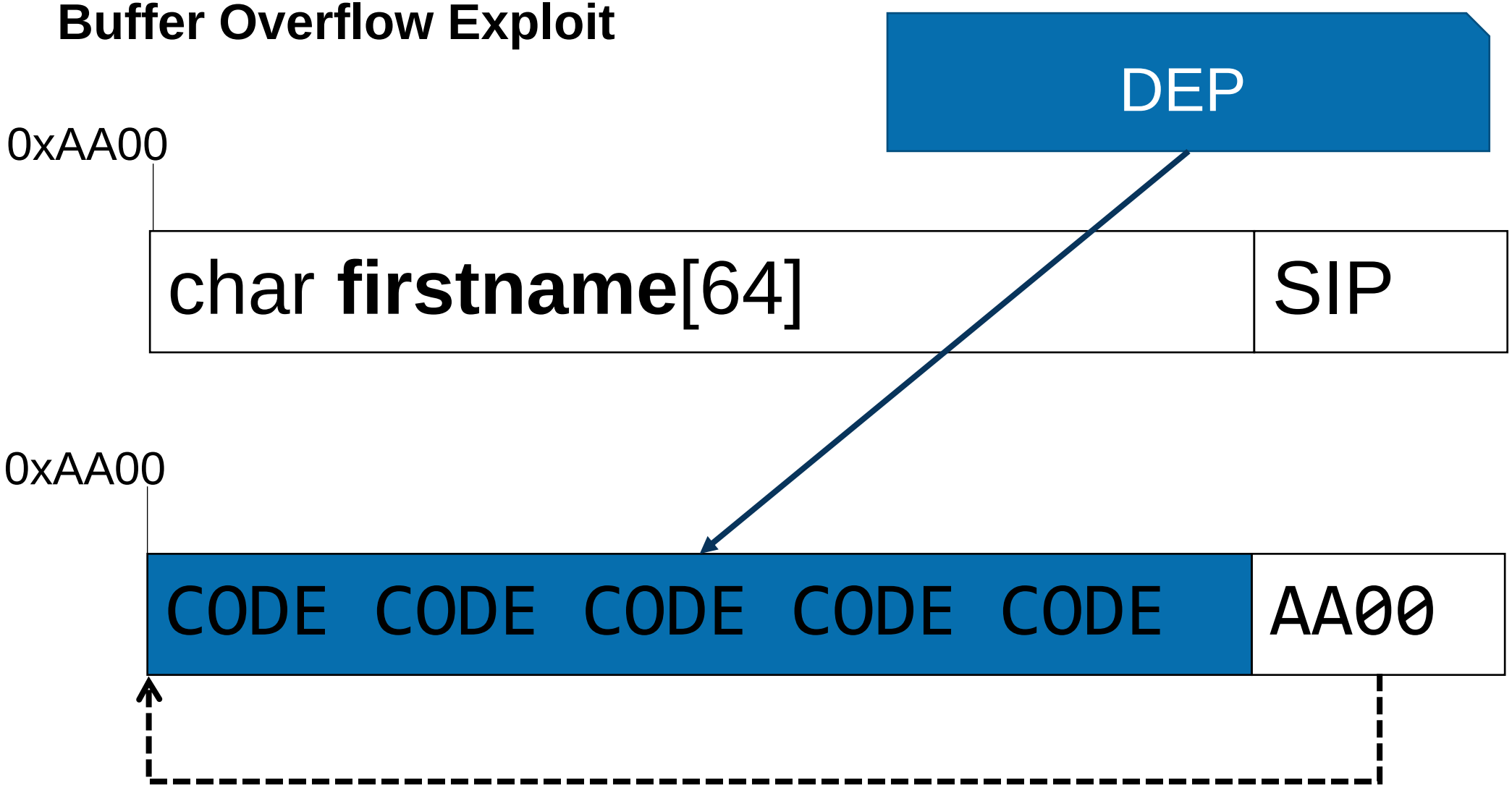
Buffer Overflow Exploit



Buffer Overflow Exploit

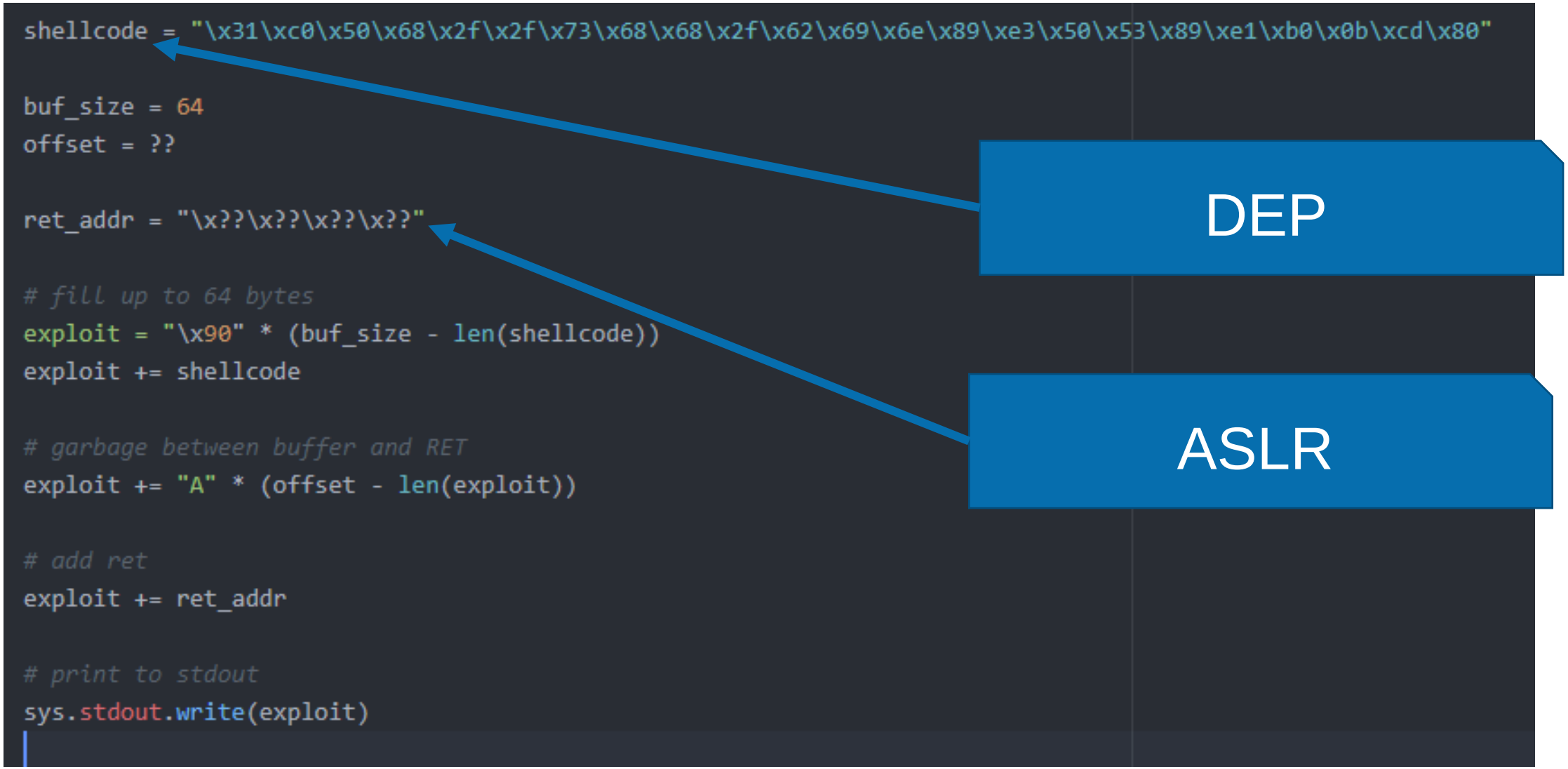


Buffer Overflow Exploit

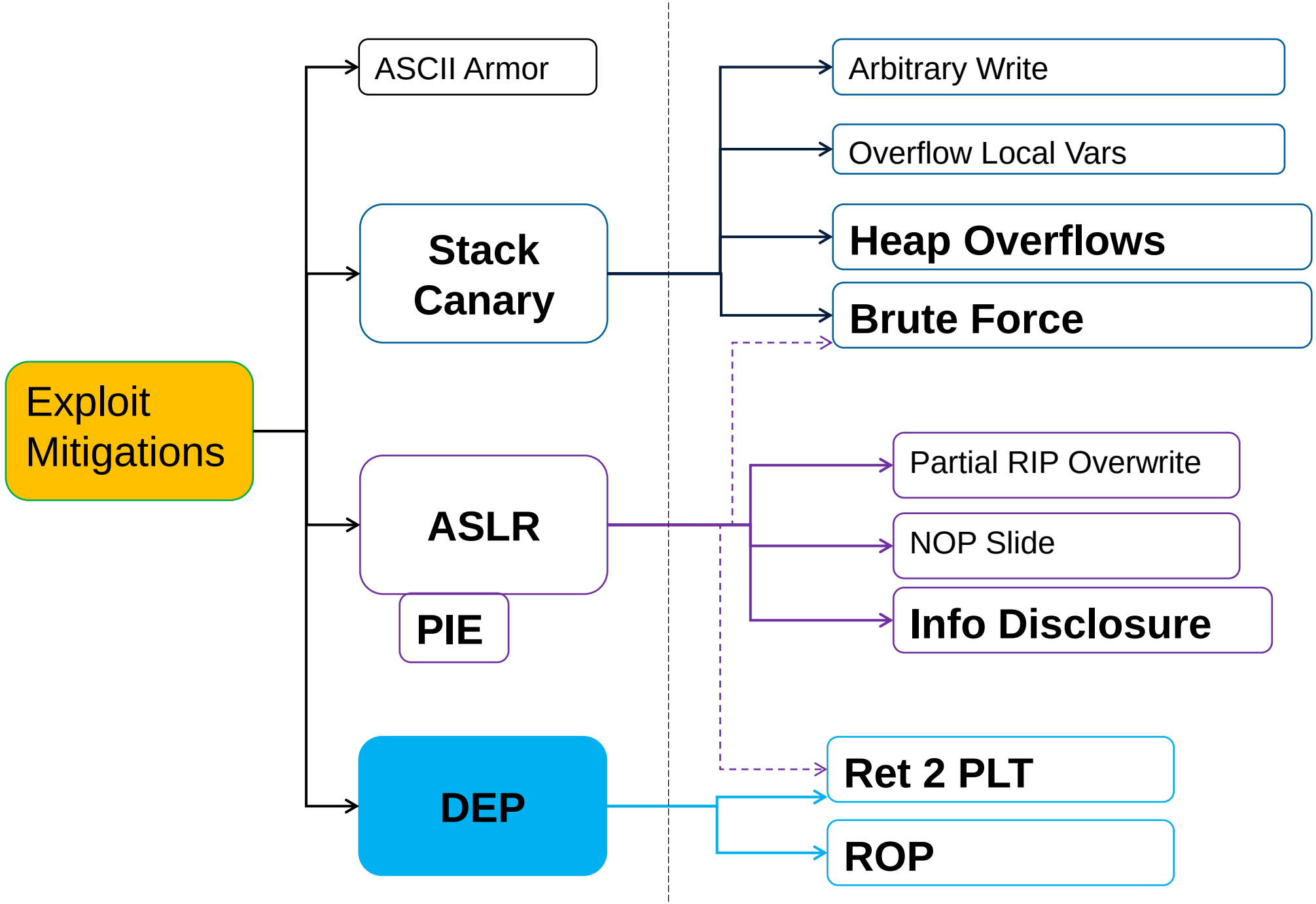


Buffer Overflow Exploit

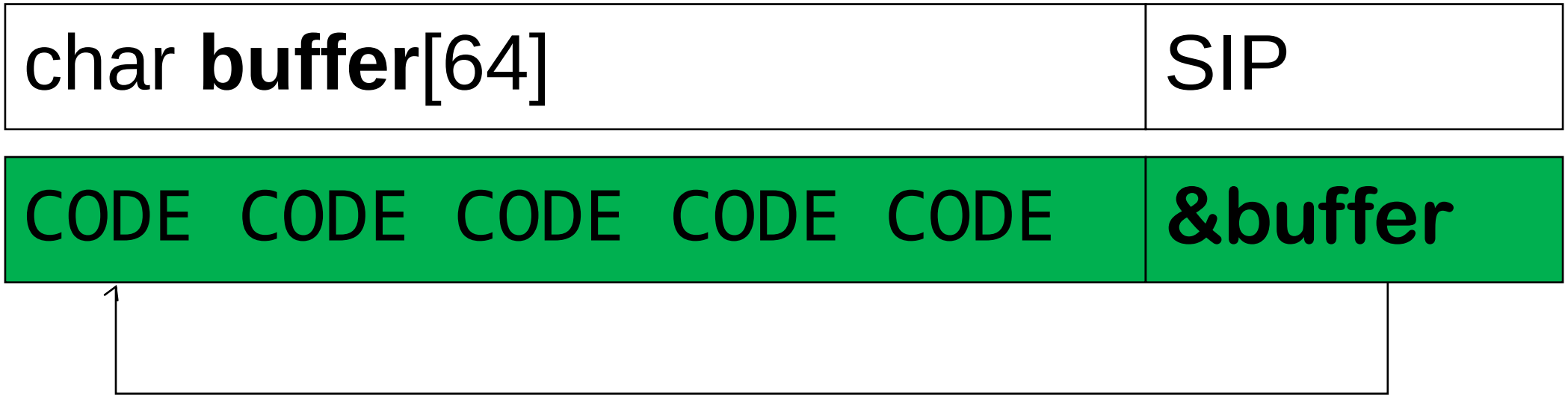
```
shellcode = "\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f\x62\x69\x6e\x89\xe3\x50\x53\x89\xe1\xb0\x0b\xcd\x80"

buf_size = 64
offset = ??

ret_addr = "\x??\x??\x??\x??"

# fill up to 64 bytes
exploit = "\x90" * (buf_size - len(shellcode))
exploit += shellcode

# garbage between buffer and RET
exploit += "A" * (offset - len(exploit))

# add ret
exploit += ret_addr

# print to stdout
sys.stdout.write(exploit)
```



Exploit Mitigation: DEP


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Exploit Mitigations: Recap



DEP: Make stack not executable

DEP

DEP – **D**ata **E**xecution **P**revention

- Aka: No-Exec Stack
- Aka: W^X (Write XOR eXecute)(OpenBSD)
- Aka: NX (Non-Execute) Bit

32 bit (x86)

- Since 386
- “saved” Xecute bit (only R/W are available)

AMD64 (x86-64)

- introduced NX bit in HW
- Or kernel patches like PaX
- For 32 bit, need PAE (Physical Address Extension, 32->36bit)

Linux

- Support in 2004, Kernel 2.6.8, default active

DEP

Memory regions

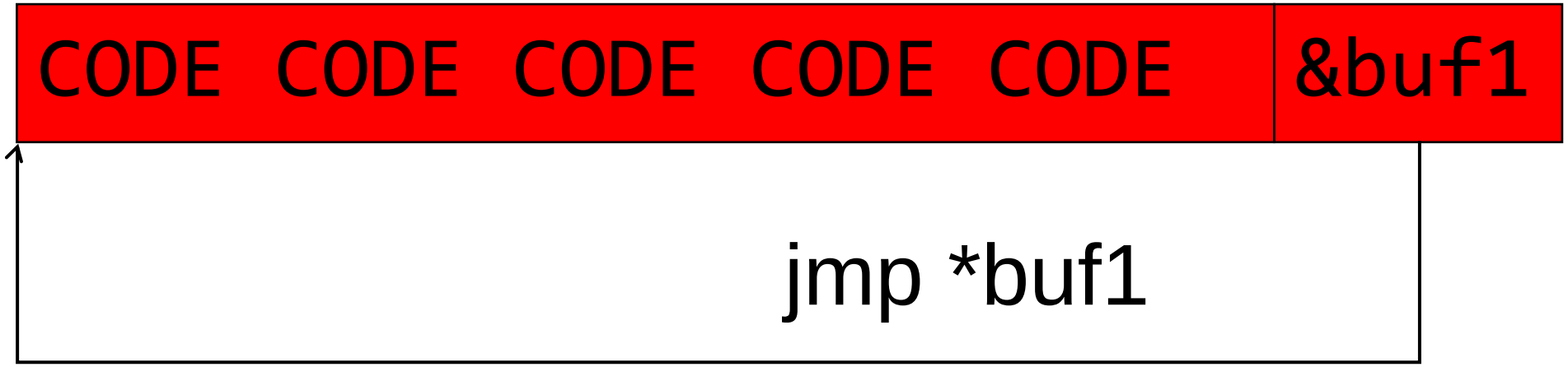
- Are mapped with permissions
- Like files
  - R Read
  - W Write
  - X eXecute

- DEP removes X bit from memory which do not contain code
  - Stack
  - Heap
  - (Possibly others)

Anti-Exploitation: No-Exec Stack

Without DEP:

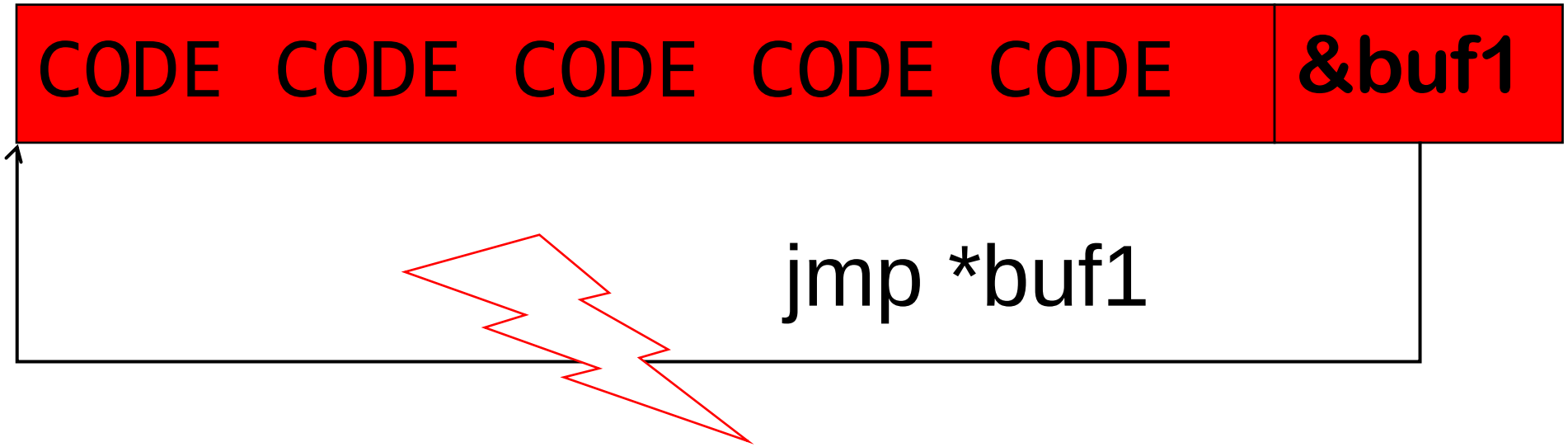
Permissions: rw**x**



Anti-Exploitation: No-Exec Stack

With DEP:

Permissions: rw-



"Segmentation Fault"

DEP Example

```
(gdb) r
Program received signal SIGSEGV, Segmentation fault.
0xbffff4ec in ?? ()

(gdb) info proc mappings
Mapped address spaces:
[…]
 0xbffdf000 0xc0000000    0x21000        0x0 [stack]

(gdb) i r eip
eip            0xbffff4ec       0xbffff4ec
```

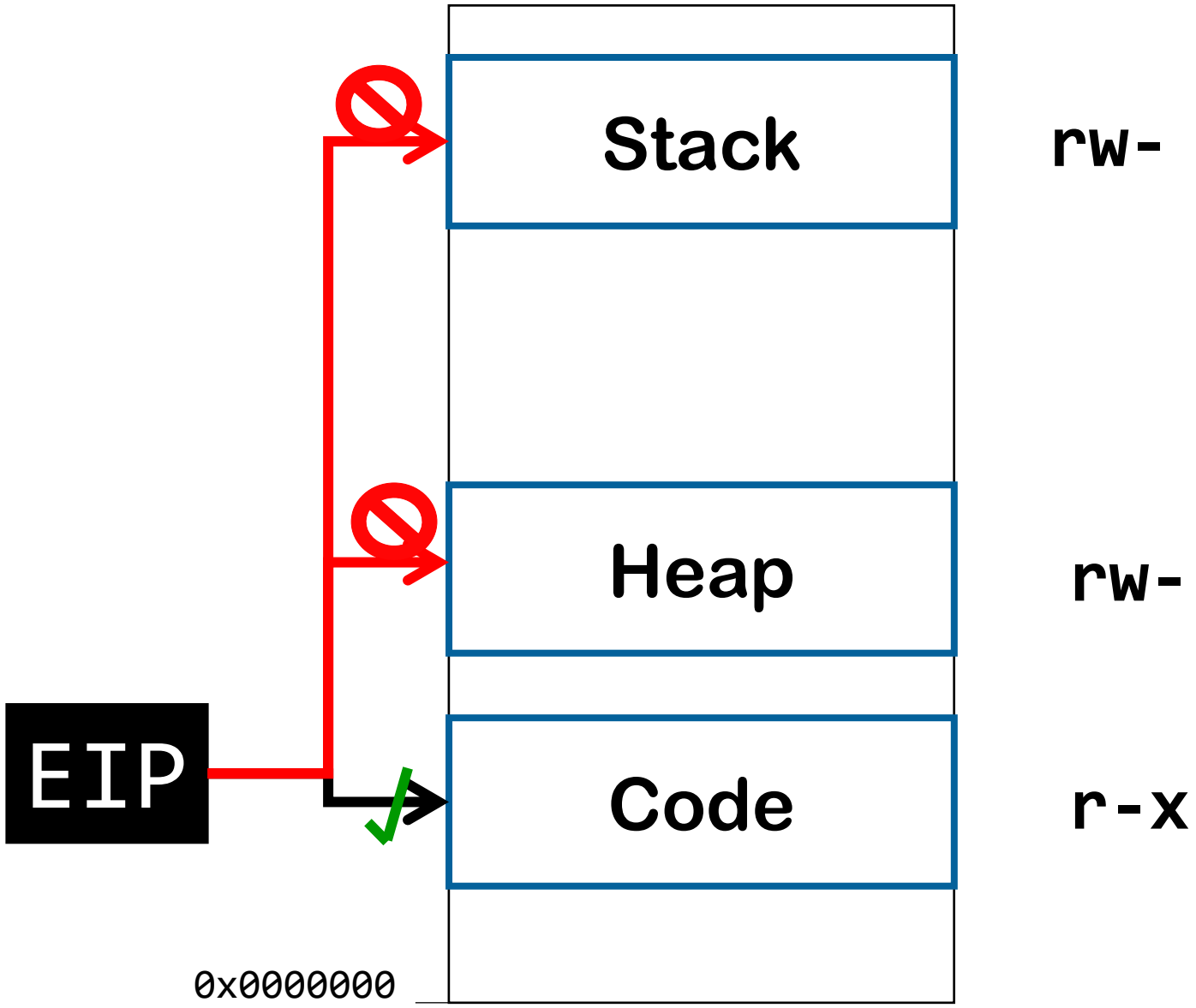
Anti-Exploitation: No-Exec Stack

```
$ gcc system.c -o system && readelf -l system


Program Headers:
  Type           Offset   VirtAddr   MemSiz  Flg Align
  PHDR           0x000034 0x08048034 0x00120 R E 0x4
  INTERP         0x000154 0x08048154 0x00013 R   0x1
  LOAD           0x000000 0x08048000 0x005d0 R E 0x1000
  LOAD           0x000f14 0x08049f14 0x00108 RW  0x1000
  DYNAMIC        0x000f28 0x08049f28 0x000c8 RW  0x4
  NOTE           0x000168 0x08048168 0x00044 R   0x4
  GNU_EH_FRAME   0x0004d8 0x080484d8 0x00034 R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000 RW  0x4
  GNU_RELRO      0x000f14 0x08049f14 0x000ec R   0x1
```

Anti-Exploitation: No-Exec Stack

```
$ gcc system.c -z execstack -o system
$ readelf -l system

Program Headers:
  Type           Offset   VirtAddr   MemSiz  Flg Align
  PHDR           0x000034 0x08048034 0x00120 R E 0x4
  INTERP         0x000154 0x08048154 0x00013 R   0x1
  LOAD           0x000000 0x08048000 0x005d0 R E 0x1000
  LOAD           0x000f14 0x08049f14 0x00108 RW  0x1000
  DYNAMIC        0x000f28 0x08049f28 0x000c8 RW  0x4
  NOTE           0x000168 0x08048168 0x00044 R   0x4
  GNU_EH_FRAME   0x0004d8 0x080484d8 0x00034 R   0x4
  GNU_STACK      0x000000 0x00000000 0x00000 RWE 0x4
  GNU_RELRO      0x000f14 0x08049f14 0x000ec R   0x1
```

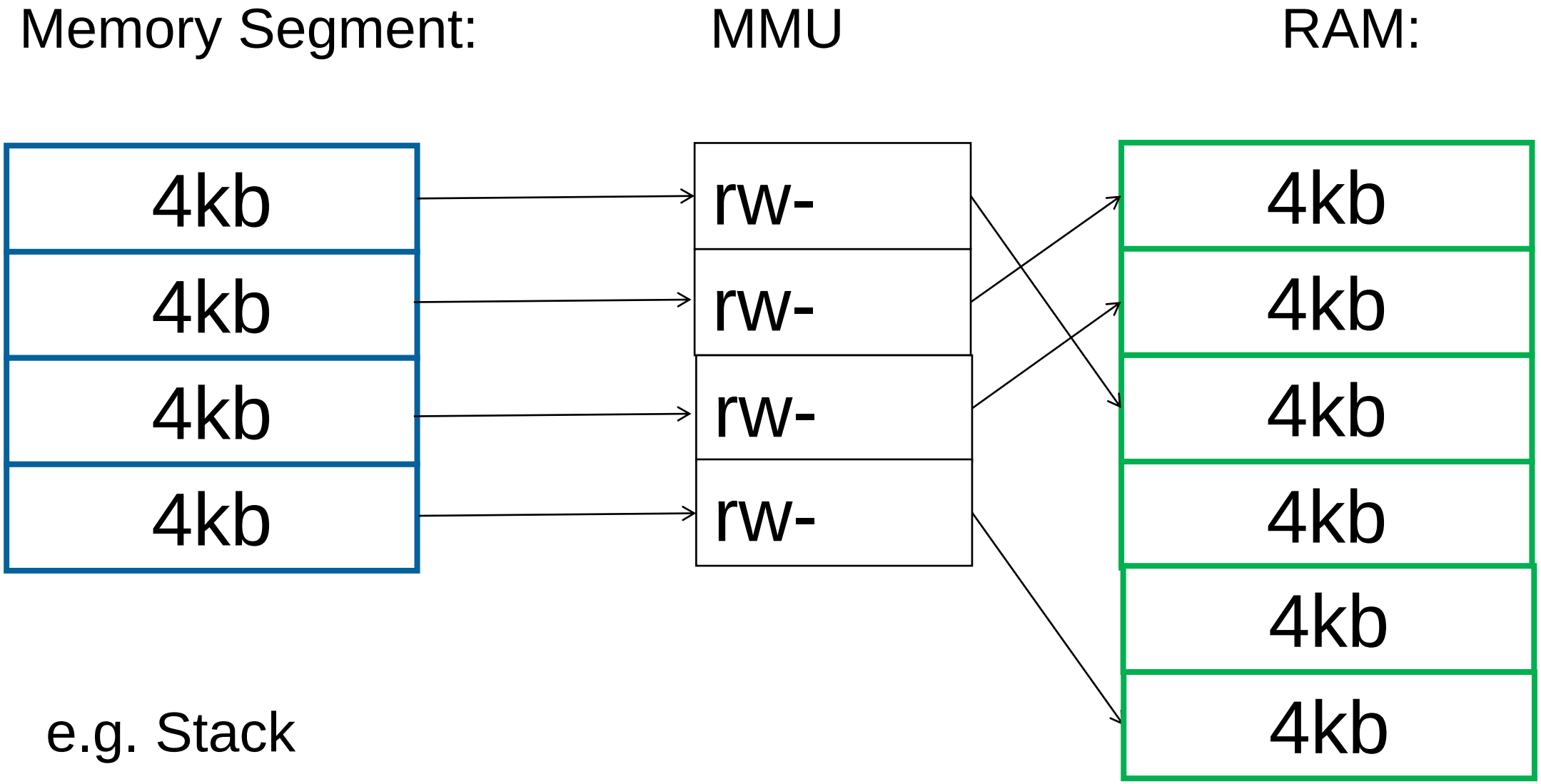
Anti-Exploitation: No-Exec Stack



Anti-Exploitation: No-Exec Stack

<Demo>

MMU


Memory Segment:
MMU
RAM:
4kb
4kb
4kb
4kb
rw-
rw-
rw-
rw-
4kb
4kb
4kb
4kb
4kb
4kb
e.g. Stack

Anti-Exploitation: No-Exec Stack

GCC compiles automatically with no-exec stack

Recap! DEP

Exploit Mitigation – DEP

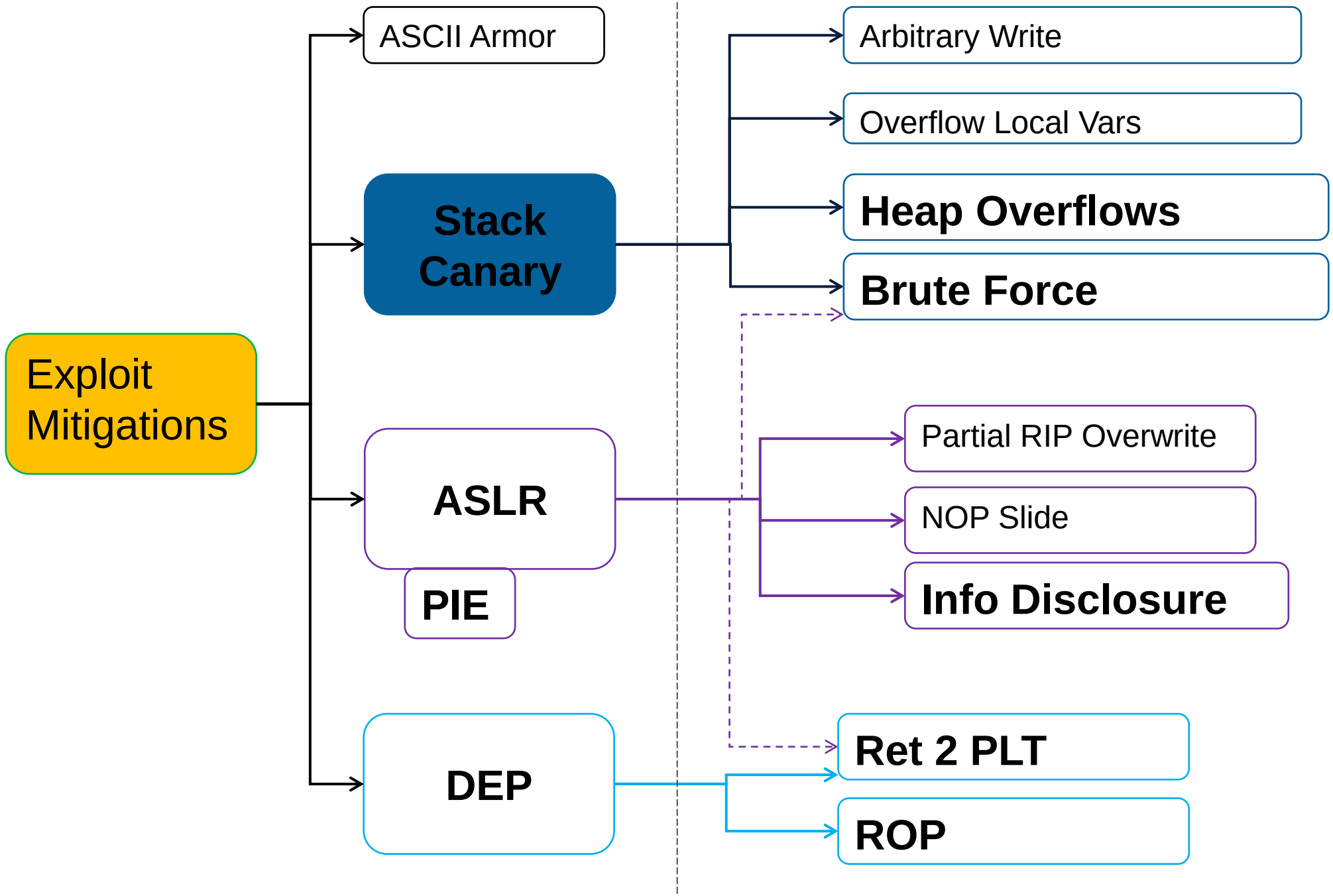
- Makes it impossible for an attacker to execute his own shellcode
- Code segment: eXecute (no write)
- Heap, Stack: Write (no execute)

Recap! DEP

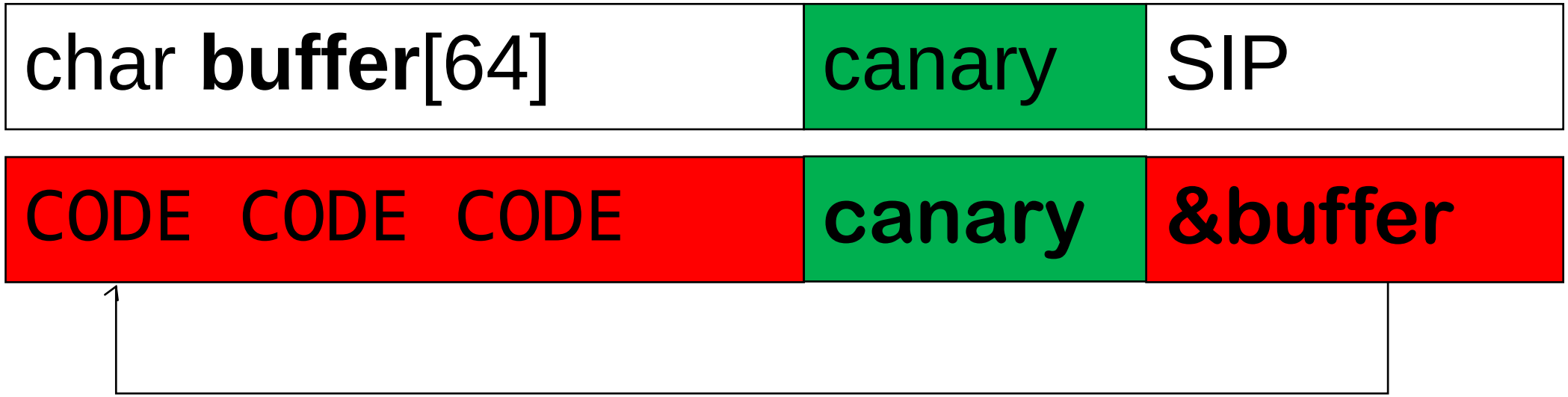
Exploit Mitigation – DEP

- No-no: Write AND Execute
- Sometimes necessary
- Interpreted Languages
  - E.g. Java
  - Or JavaScript
  - Ähem *Browser* ähem

Exploit Mitigation – Stack Protector


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Exploit Mitigations: Recap



Exploit Mitigation – Stack Protector

Aka:

- SSP: Stack Smashing Protector
- Stack Cookie
- Stack Canary

Exploit Mitigation – Stack Protector

Secret value in front of control data

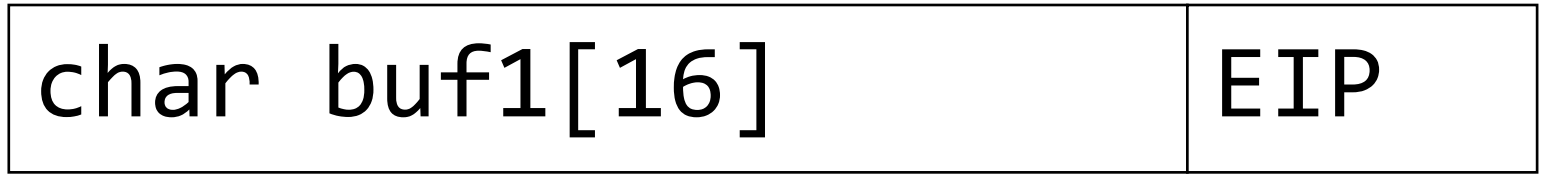
A value unknown to the attacker

Checked before performing a “ret”

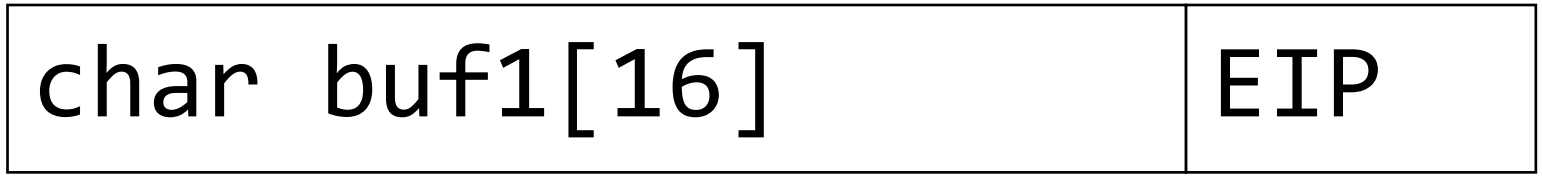
- When returning from a function; “return;”
- Before using SIP

```
if (secret_on_stack == global_secret) {
        return;
} else {
        crash();
}
```

Exploit Mitigation – Stack Protector



Exploit Mitigation – Stack Protector



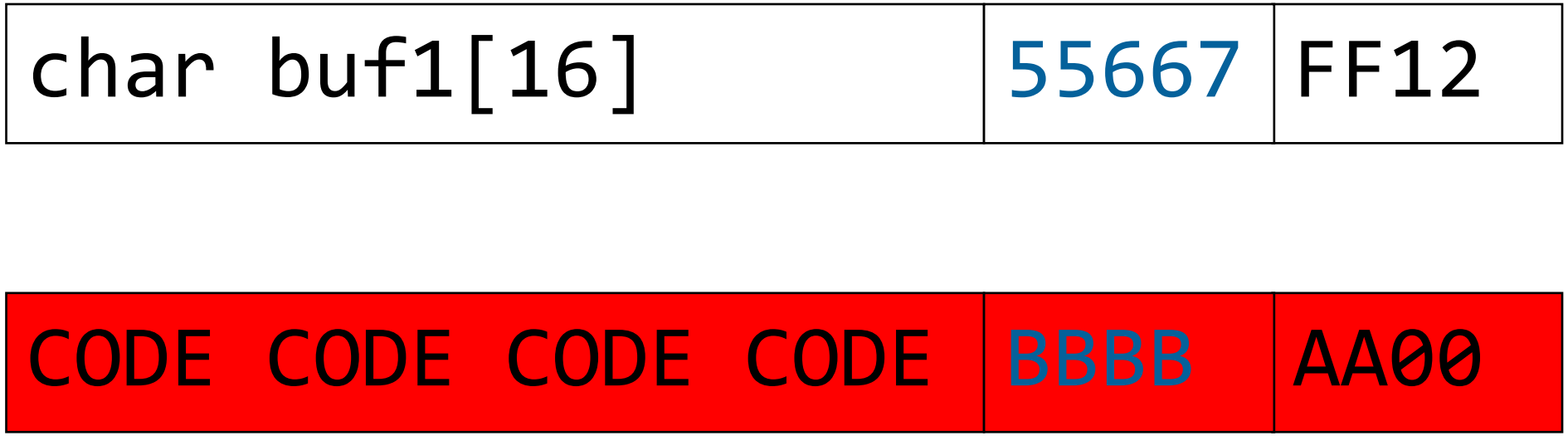
Exploit Mitigation – Stack Protector

char buf1[16]	secret	EIP

char buf1[16]	55667	FF12

CODE CODE CODE CODE	BBBB	AA00

Exploit Mitigation – Stack Protector



Exploit Mitigation – Stack Protector

Stack Protector

- GCC patch
  - First: StackGuard in 1997
  - Then: ProPolice in 2001, by IBM
- Finally: Re-implement ProPolice in 2005 by RedHat
  - introduced in GCC 4.1
  - -fstack-protector
- Update: Better implementation by Google in 2012
  - -fstack-protector-strong
- Enabled since like forever by default
  - most distributions
  - most packages

Exploit Mitigation – Stack Protector

When does the stack protector change?

- On execve()
  - (replace current process with a ELF file from disk)
- NOT on fork()
  - (copy current process)

Exploit Mitigation – Stack Protector

Stack canary properties:

- Not predictable
- Be located in a non-accessible location
- Cannot be brute-forced
- Should contain at least one termination character

Exploit Mitigation – Stack Protector

```
gdb-peda$ disas handleData
Dump of assembler code for function handleData:
[...]
   0x080488b5 <+136>:   call   0x8048650 <puts@plt>
   0x080488ba <+141>:   add    esp,0x10
   0x080488bd <+144>:   nop
   0x080488be <+145>:   mov    eax,DWORD PTR [ebp-0xc]
   0x080488c1 <+148>:   xor    eax,DWORD PTR gs:0x14
   0x080488c8 <+155>:   je     0x80488cf <handleData+162>
   0x080488ca <+157>:   call   0x8048600 <__stack_chk_fail@plt>
   0x080488cf <+162>:   leave
   0x080488d0 <+163>:   ret
```

Exploit Mitigation – Stack Protector Check

Stack protector in ASM, static analysis:

```
// get stack canary from current frame
mov    -0xc(%ebp),%eax

// compare hat with reference value
xor    %gs:0x14,%eax

// skip next instruction if ok
je     0x804846e <bla+58>

// was not ok - crash/exit program
call   0x8048340 <__stack_chk_fail@plt>
```

Exploit Mitigation – Stack Protector Check

Stack protector in ASM, dynamic analysis:

```
=> 0x08048458 <+36>:    call   0x8048350 <strcpy@plt>
   0x0804845d <+41>:    mov    -0xc(%ebp),%eax
   0x08048460 <+44>:    xor    %gs:0x14,%eax
   0x08048467 <+51>:    je     0x804846e <bla+58>
   0x08048469 <+53>:    call   0x8048340 <__stack_chk_fail@plt>
(gdb) x/1x $ebp-0xc
0xbffff5cc:     0x2f140600
(gdb) info auxv
25   AT_RANDOM            Address of 16 random bytes     0xbffff7bb
(gdb) x/1x 0xbffff7bb
0xbffff7bb:     0x2f1406ae
```

Exploit Mitigation – Stack Protector Setup

```
0x0804888c <+0>:     push   ebp                              // Prologue
0x0804888d <+1>:     mov    ebp,esp                          // Prologue
0x0804888f <+3>:     sub    esp,0x38                         // Make some space
0x08048892 <+6>:     mov    eax,DWORD PTR [ebp+0x8]          // Parameter 1
0x08048895 <+9>:     mov    DWORD PTR [ebp-0x2c],eax
0x08048898 <+12>:    mov    eax,DWORD PTR [ebp+0xc]          // Parameter 2
0x0804889b <+15>:    mov    DWORD PTR [ebp-0x30],eax
0x0804889e <+18>:    mov    eax,gs:0x14                      // Stack cookie
0x080488a4 <+24>:    mov    DWORD PTR [ebp-0xc],eax
0x080488a7 <+27>:    xor    eax,eax
```

Stack Smashing Example

```
$ ./strcpy AAAAAAAAAAAAA
*** stack smashing detected ***: ./strcpy terminated
======= Backtrace: =========
/lib/i386-linux-gnu/libc.so.6(__fortify_fail+0x45)[0xb76ff095]
/lib/i386-linux-gnu/libc.so.6(+0x10404a)[0xb76ff04a]
./strcpy[0x804846e]
./strcpy[0x8048489]
/lib/i386-linux-gnu/libc.so.6(__libc_start_main+0xf3)[0xb7614533]
./strcpy[0x80483a1]
======= Memory map: ========
```

Stack Smashing Example

```
(gdb) disas overflow
Dump of assembler code for function overflow:
   0x08048434 <+0>:     push   %ebp
   0x08048435 <+1>:     mov    %esp,%ebp
   0x08048437 <+3>:     sub    $0x38,%esp
[…]
   0x08048458 <+36>:    call   0x8048350 <strcpy@plt>
   0x0804845d <+41>:    mov    -0xc(%ebp),%eax
   0x08048460 <+44>:    xor    %gs:0x14,%eax
   0x08048467 <+51>:    je     0x804846e <overflow+58>
   0x08048469 <+53>:    call   0x8048340
                          <__stack_chk_fail@plt>
   0x0804846e <+58>:    leave
   0x0804846f <+59>:    ret
```

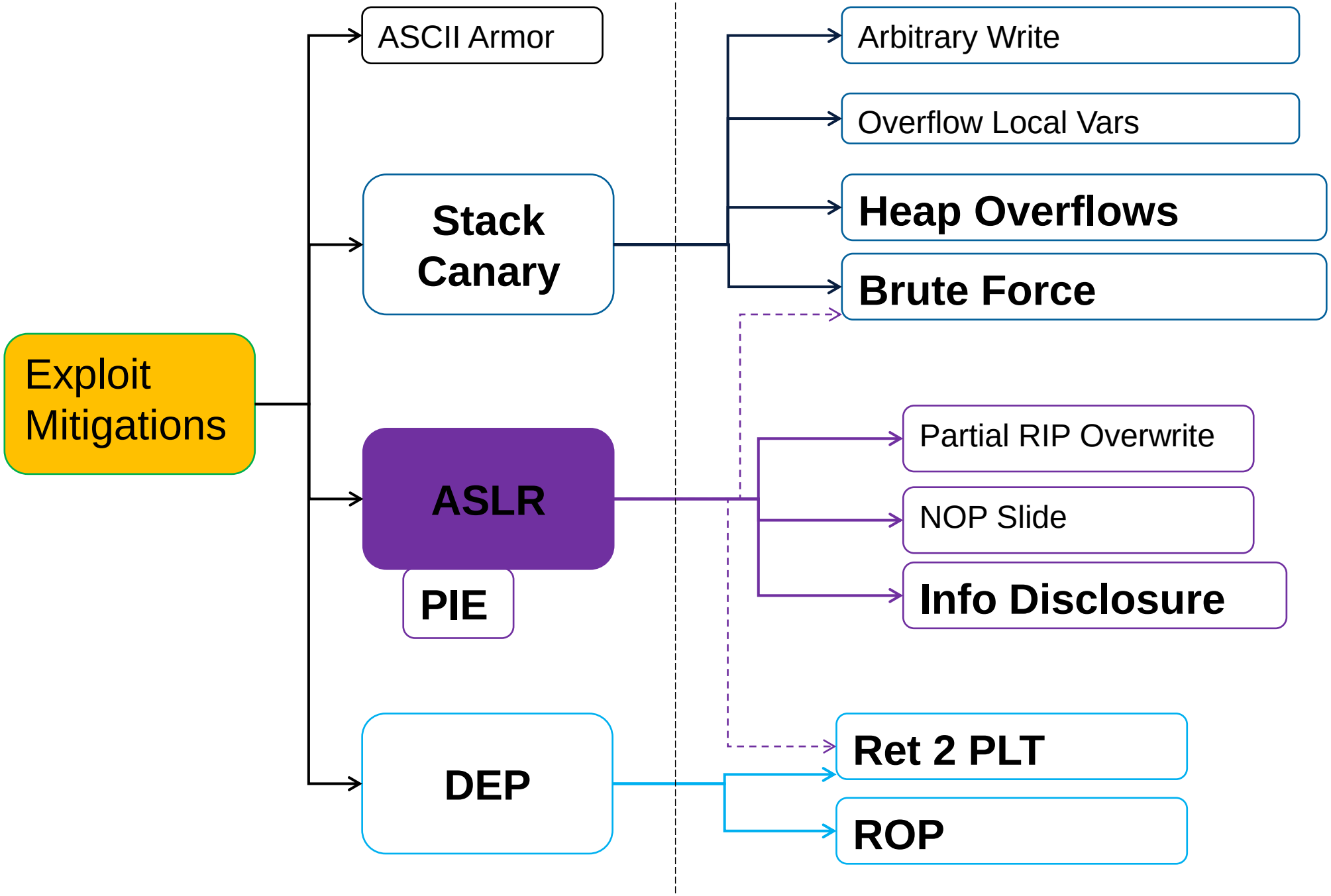
Exploit Mitigation – Stack Protector

Stack Canary

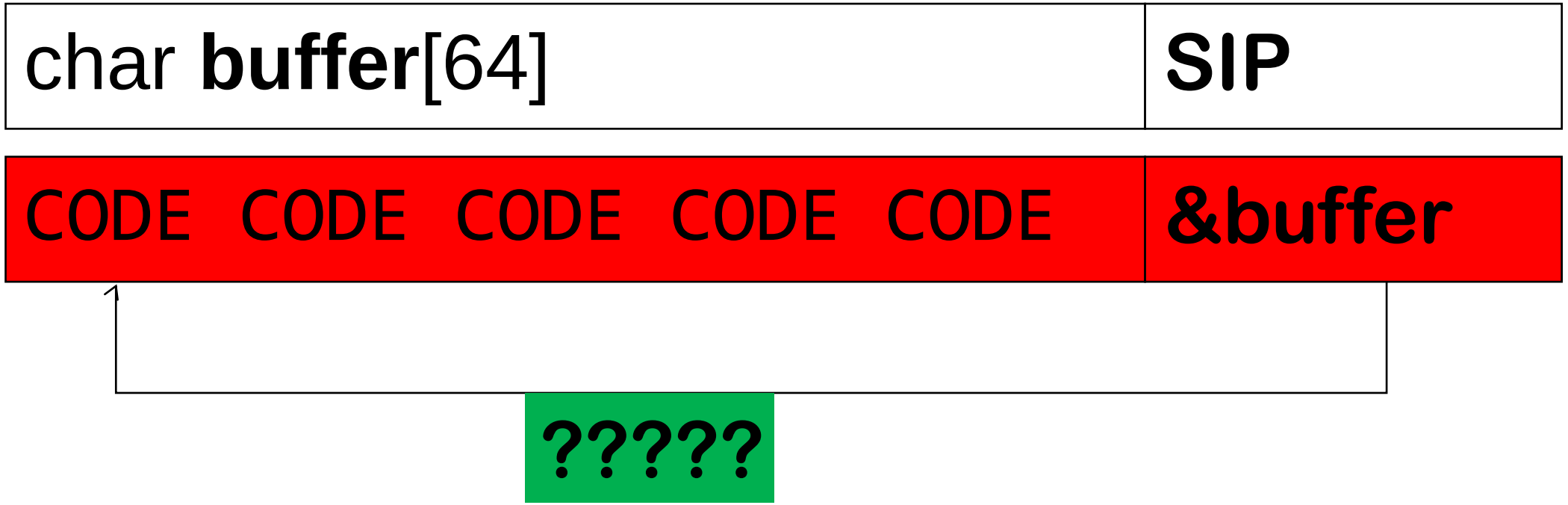
Exploit Mitigation – Stack Protector

Arrival: Canary

Exploit Mitigation: ASLR


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Exploit Mitigations: ASLR

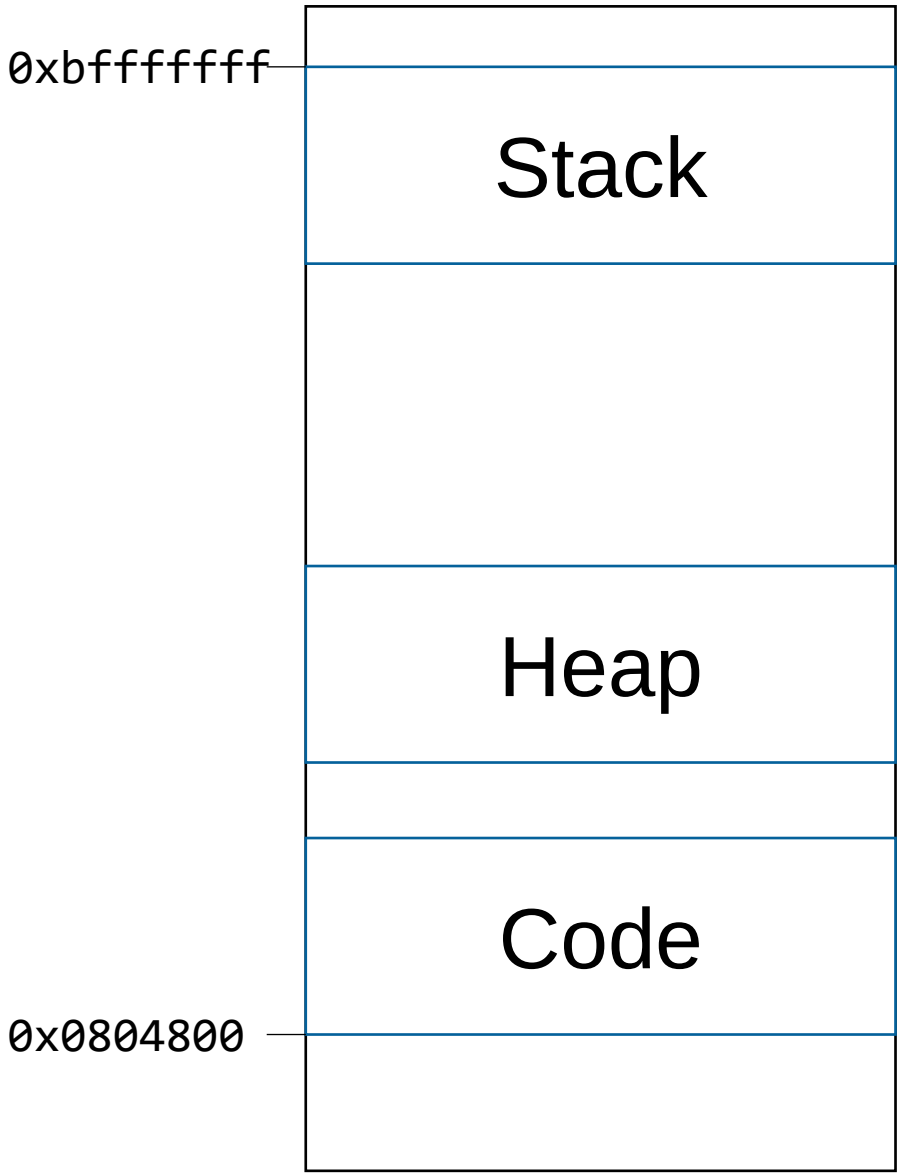


Exploit Mitigation - ASLR

Code execution is surprisingly deterministic

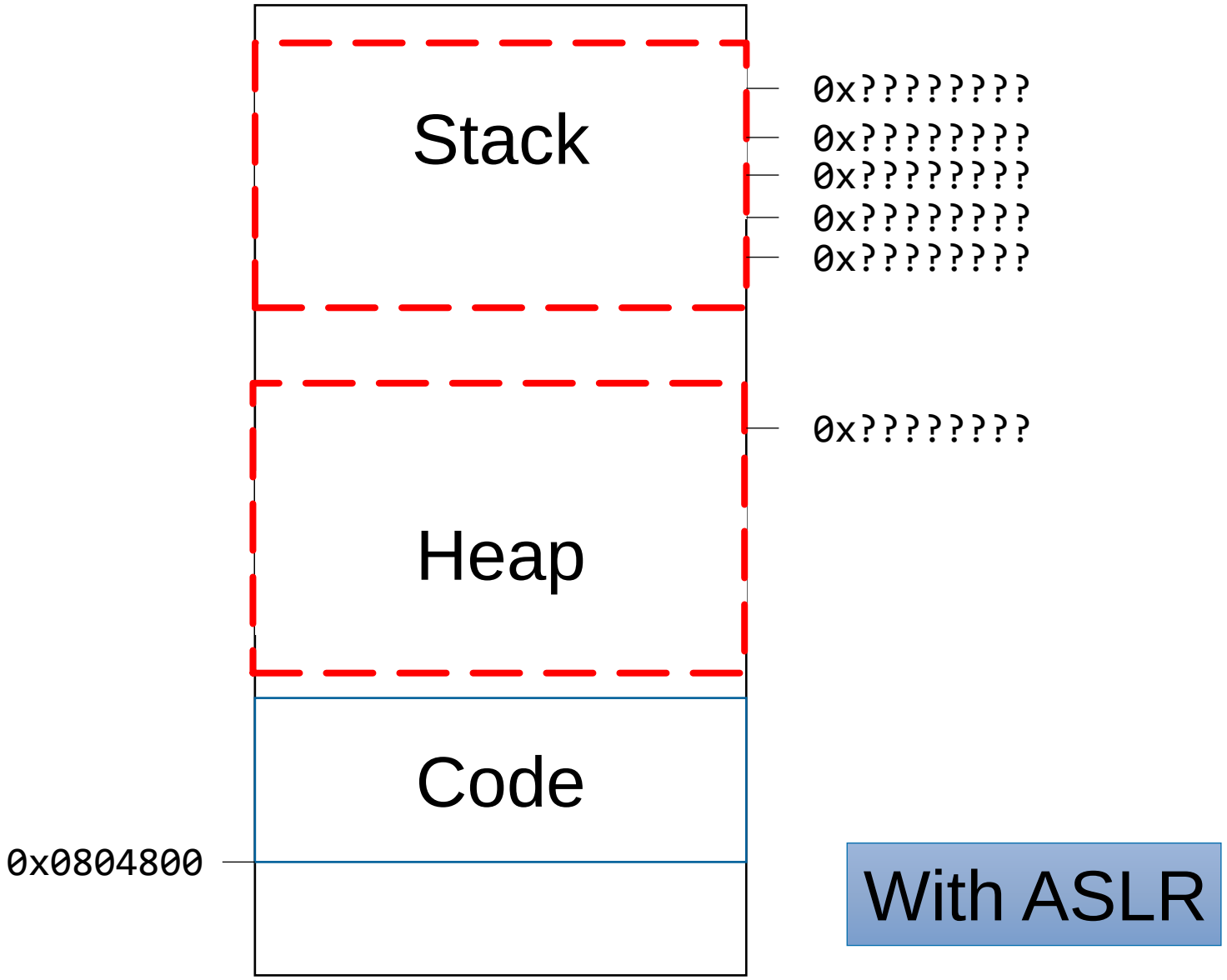
- E.g. Network service:
  - fork()
  - Parse incoming data
  - Buffer Overflow is happening at module X line Y
- On every exploit attempt, memory layout looks the same!
  - Same stack/heap/code layout
  - Same address of the buffer(s)
- ASLR: Address Space Layout Randomization
  - Introduces randomness in memory regions

Memory Layout

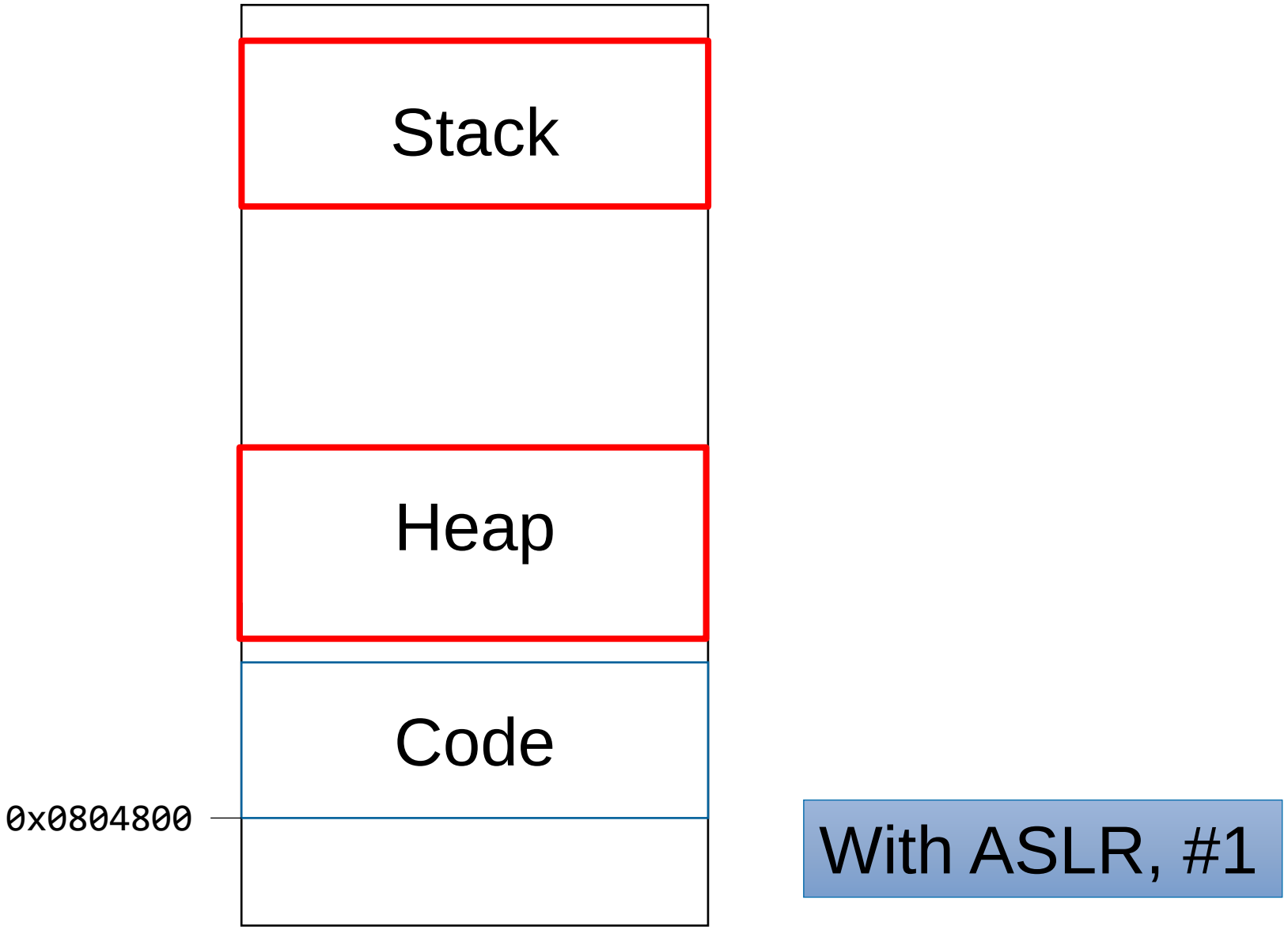


Without ASLR

Memory Layout

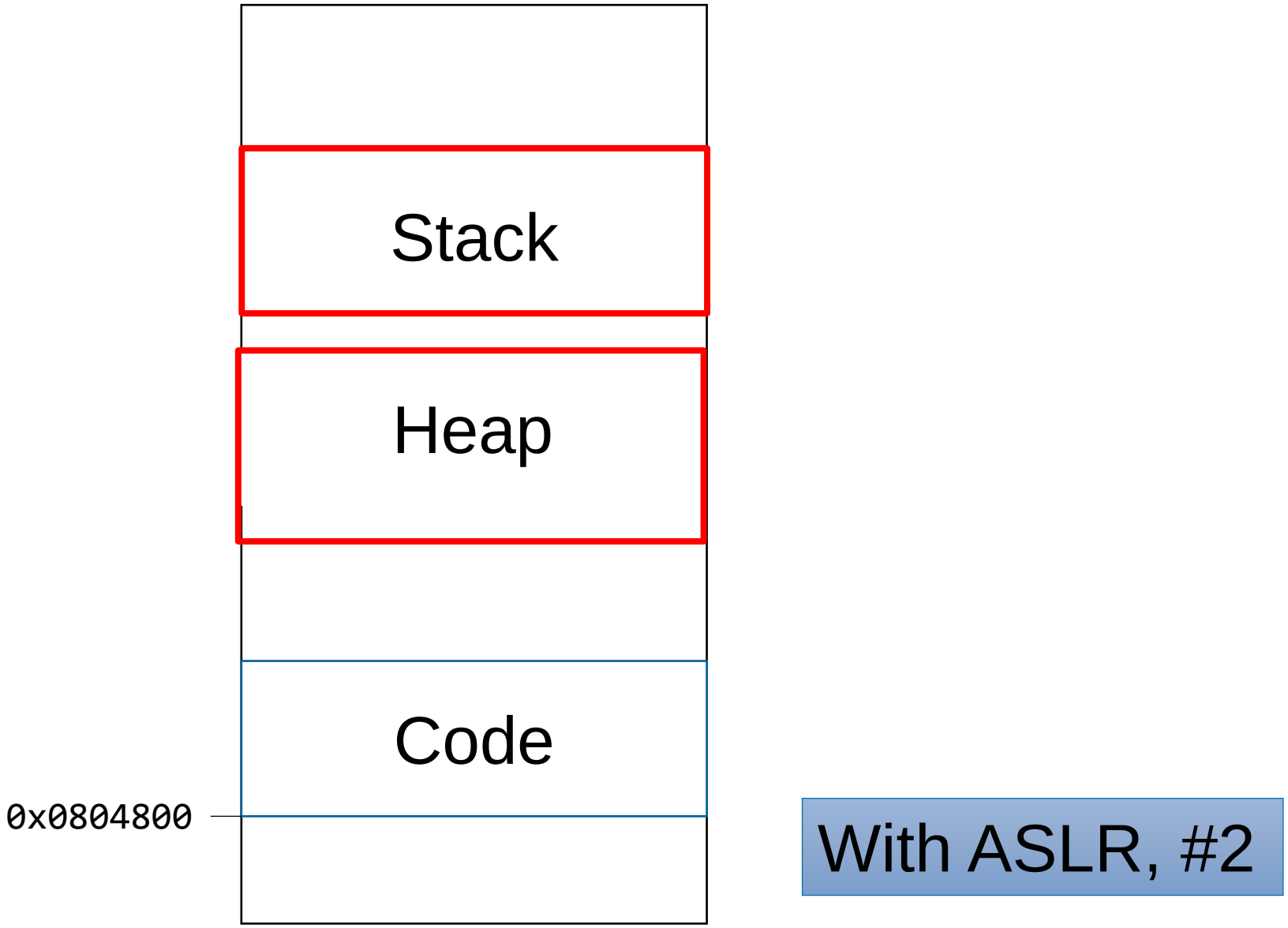


Memory Layout



With ASLR, #1

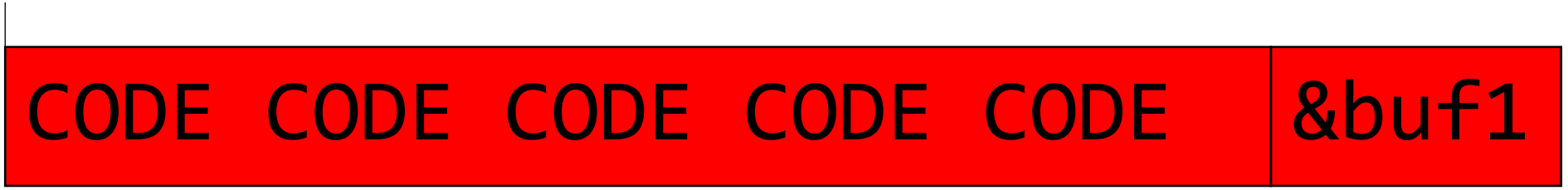
Memory Layout



With ASLR, #2

Exploit Mitigation - ASLR

0xAA00

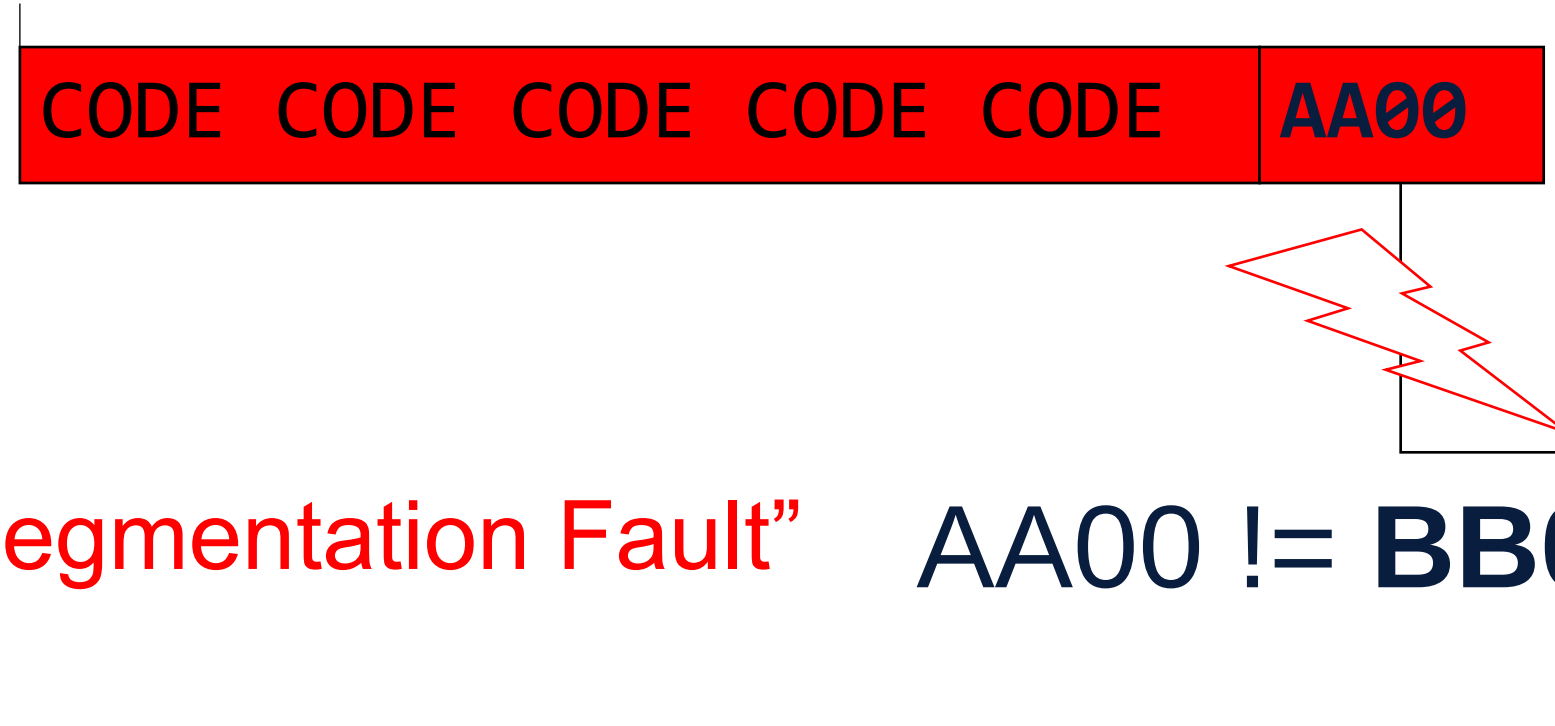


0xAA00

Exploit Mitigation - ASLR

0xBB00

0xBB00



“Segmentation Fault”

AA00 != **BB00**

Exploit Mitigation - ASLR

Randomness is measured in entropy

- Several restrictions
  - Pages have to be page aligned: 4096 bytes = 12 bit

- Very restricted address space in x32 architecture
  - ~8 bit for stack (256 possibilities)
- Much more space for x64
  - ~22 bit for stack

Exploit Mitigation - ASLR

Default ASLR:

- Stack
- Heap
- Libraries (new!)

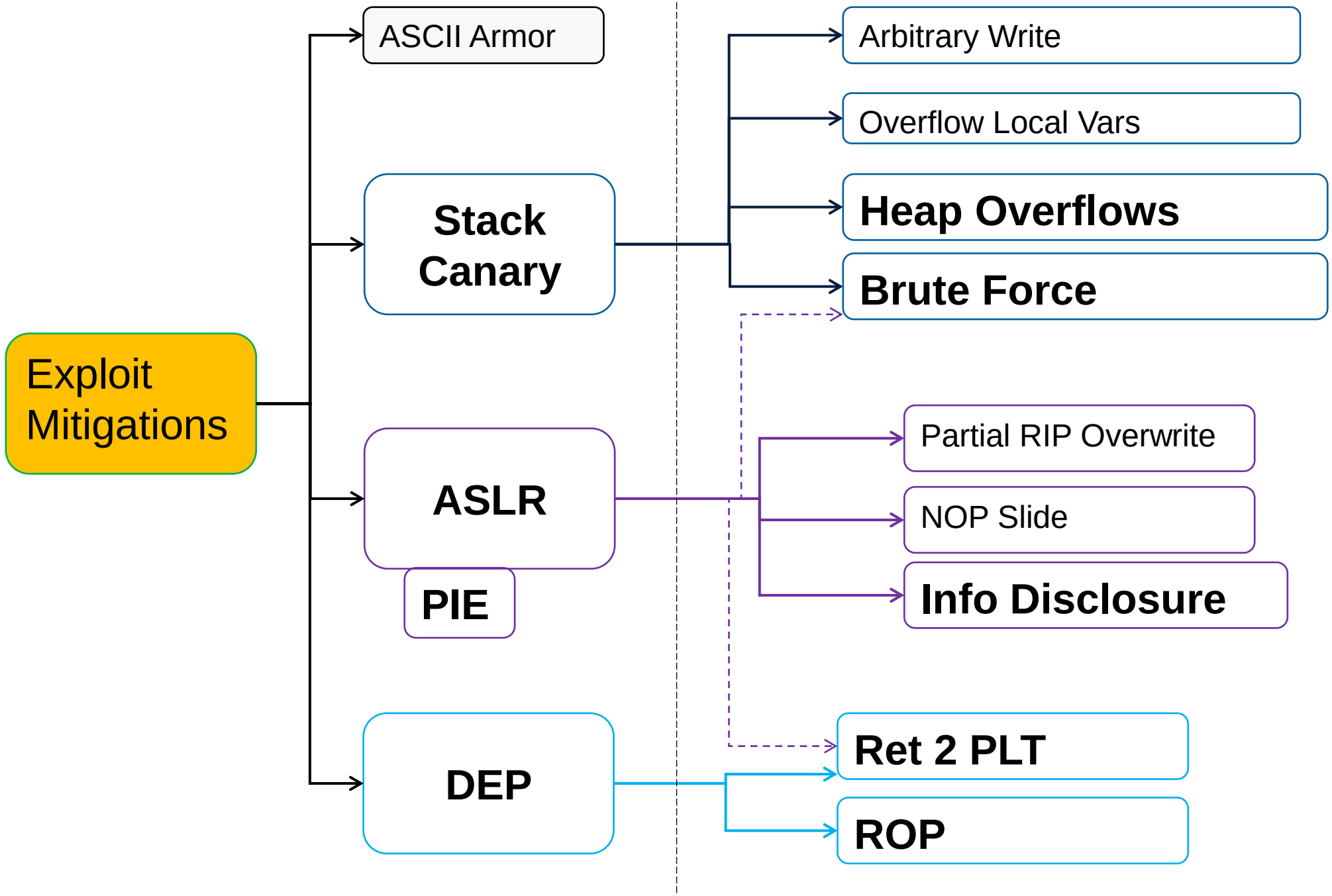
Re-randomization

- ASLR only applied on exec() [exec = execute new program]
- Not on fork() [fork = copy]

Recap! ASLR

Randomize Memory Layout

Attacker can’t call/reference what he cant find


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Exploit Mitigation: ASCII Armor

ASCII Armor:

- Maps Library addresses to memory addresses with null bytes

Exploit Mitigation: ASCII Armor

ASCII Armor:

- Maps Library addresses to memory addresses with null bytes

Why null bytes?

- In C, Null bytes are string terminator
- strcpy, strcat, strncpy, sprintf, …

```
strlen(AAAA\00BBBB\00) = 4
```

Exploit Mitigation: ASCII Armor

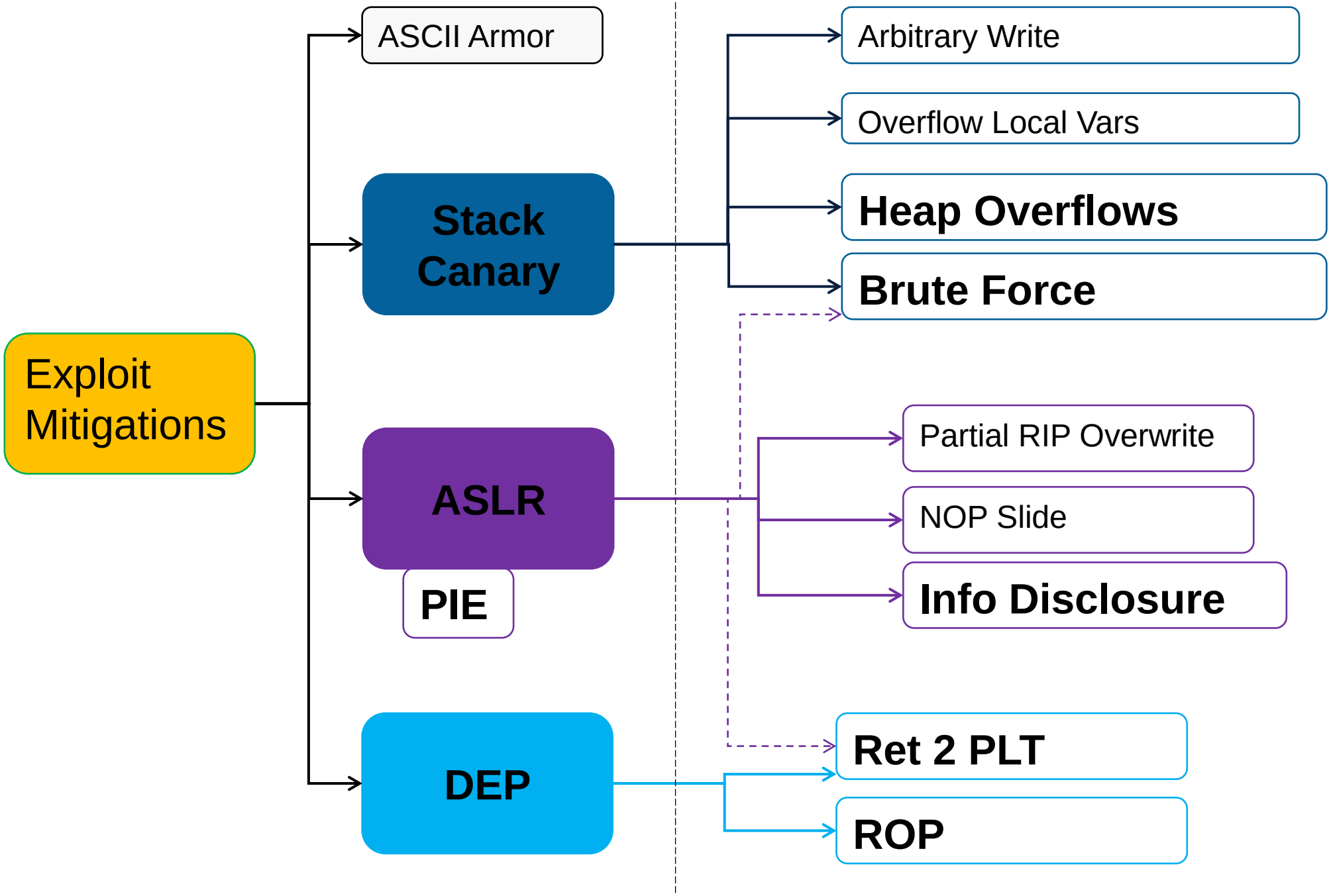
```
(gdb) info file
      0x0000000000400980 - 0x0000000000400d92 is .text
      0x0000000000400830 - 0x0000000000400980 is .plt
      0x0000000000400980 - 0x0000000000400d92 is .text
      0x00000000006011f8 - 0x0000000000601200 is .got
      0x0000000000601200 - 0x00000000006012b8 is .got.plt


      0x00007ffff7b9ed80 - 0x00007ffff7b9eff8 is .got in
      /lib/x86_64-linux-gnu/libc.so.6


      0x00007ffff7b9f000 - 0x00007ffff7b9f078 is .got.plt in
      /lib/x86_64-linux-gnu/libc.so.6
```

Exploit Mitigation: ASCII Armor

Recap:

- Putting important stuff at addresses with 0 bytes breaks strcpy etc.

Exploit Mitigation - Conclusion


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

cts
@gf_256

'90s hackers in 2021

7:22 PM · Mar 30, 2021

50 722 3.3K 65

Recap! All Exploit Mitigations

Stack canary: **detects/blocks** overflows

DEP: makes it impossible to **execute** uploaded code

ASLR: makes it impossible to **locate** data

ASCII Armor: makes it impossible to **insert** certain data

Anti Exploiting in Linux

How is the state of Exploit Mitigations in Linux?

Easy: Everything active by default!

ASLR: System-level

DEP: System level + Per-program

Stack Canary: Per-program (3rd party programs?)

Linux Hardening

Enable **DEP**:

- **Default** since like forever
- (for old cpus: kernel.exec-shield = 1)
- To disable for a binary: gcc -z noexecstack

Enable **ASLR**:

- **Default** since like forever
- /proc/sys/kernel/randomize_va_space = 2

Enable **Stack protector**:

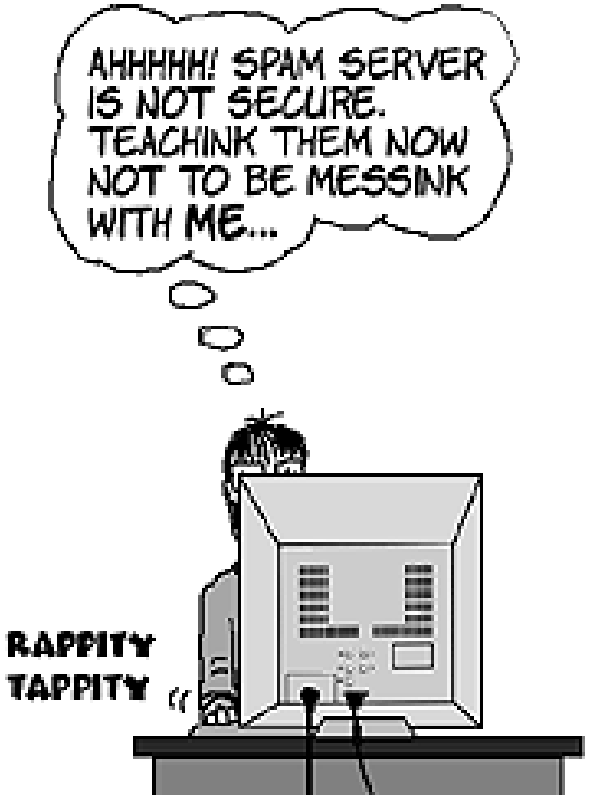
- -fstack-protector (**Default**)
- -fstack-protector-all (ALL Functions)
- -fstack-protector-strong (Better)

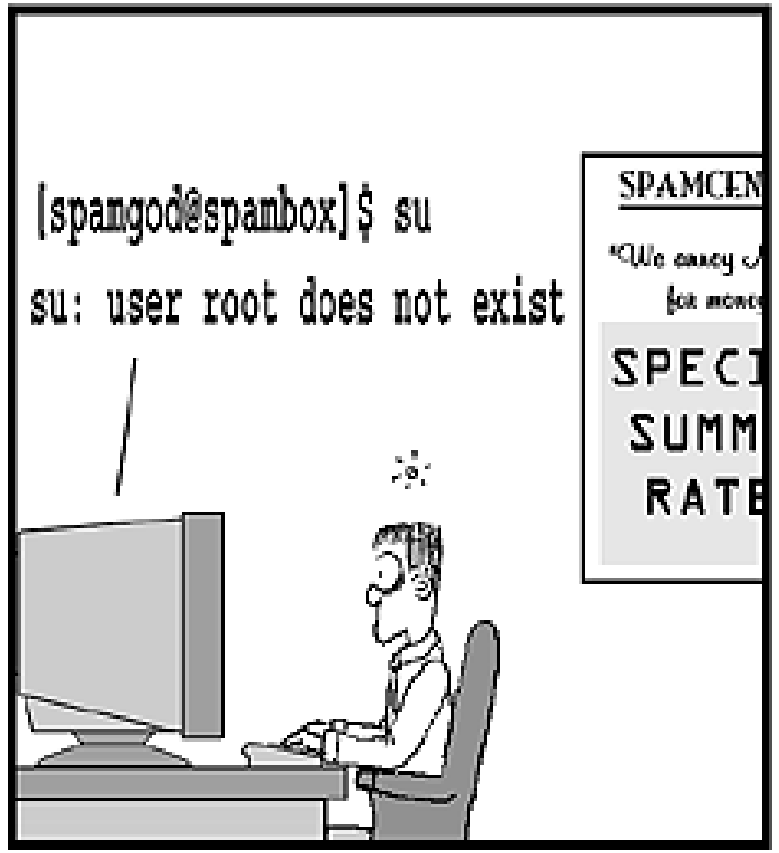
Linux Hardening - More

More Compiler options:

- **-D_FORTIFY_SOURCE=2**
  - FORTIFY_SOURCE provides (lightweight) buffer overflow checks for the following functions: `memcpy, mempcpy, memmove, memset, strcpy, stpcpy, strncpy, strcat, strncat, sprintf, vsprintf, snprintf, vsnprintf, gets.`
  - Compile time warnings
  - **Default** in Ubuntu
- **Formatstring**
  - **Default** in Ubuntu
  - -Wformat -Wformat-security
- **Full Static Relocation:**
  - **Default** in Ubuntu
  - -Wl,-z-,relro -Wl,-z,now
- **Position independent code**
  - ~~**NOT**~~ **Default** in Ubuntu (*performance penalty*)
  - -pie –fPIE

Recap! All Exploit Mitigations





References

https://www.elttam.com.au/blog/playing-with-canaries/

- Playing with canaries
- Looking at SSP over several architectures.