ROP輕鬆談

Return Oriented Programming Easy Talk

Lays @ HackStuff

Who Am I

- Lays (L4ys)
  - l4ys.tw
- Reverse Engineering / Exploit
- Wargame / CTF
- HackStuff Member

Outline

- Buffer Overflow
- ret2libc / ret2text
- Return Oriented Programming
- Payload & More

Buffer Overflow

Buffer Overflow

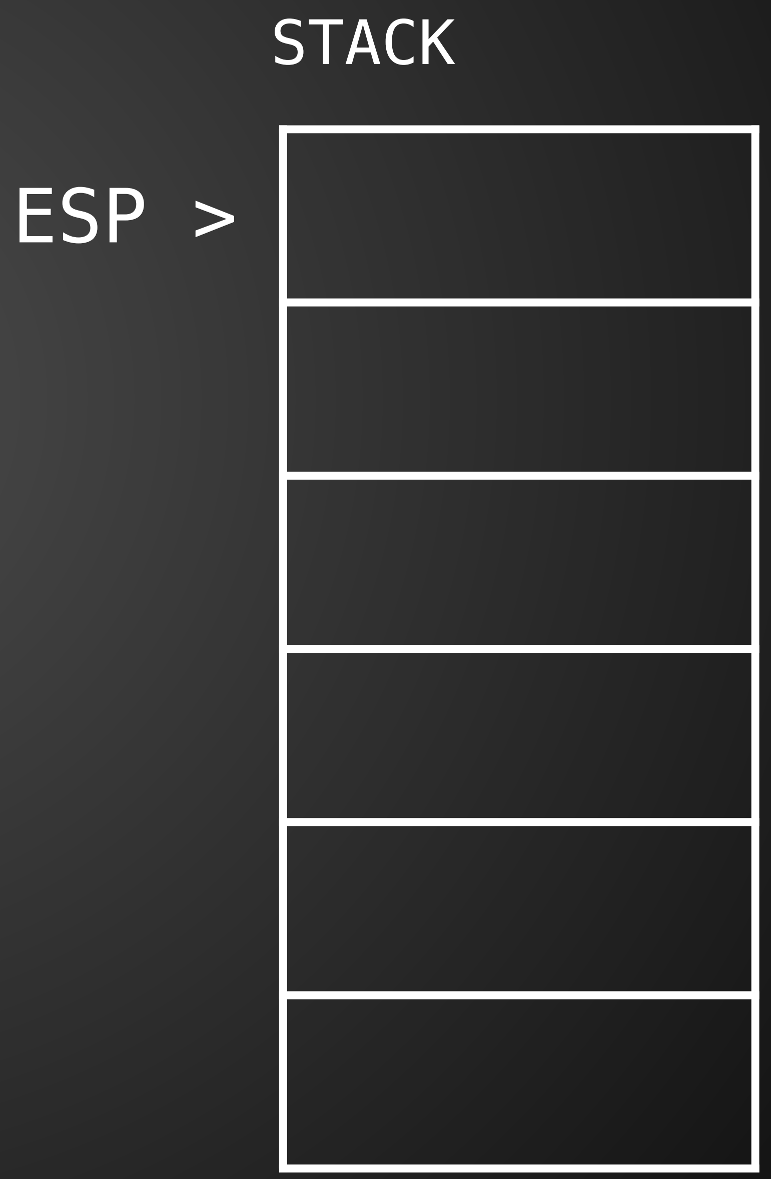
- 覆蓋函數返回地址
- 覆蓋 Function Pointer
- 覆蓋其他變數

Buffer Overflow

- 覆蓋函數返回地址
- 覆蓋 Function Pointer
- 覆蓋其他變數

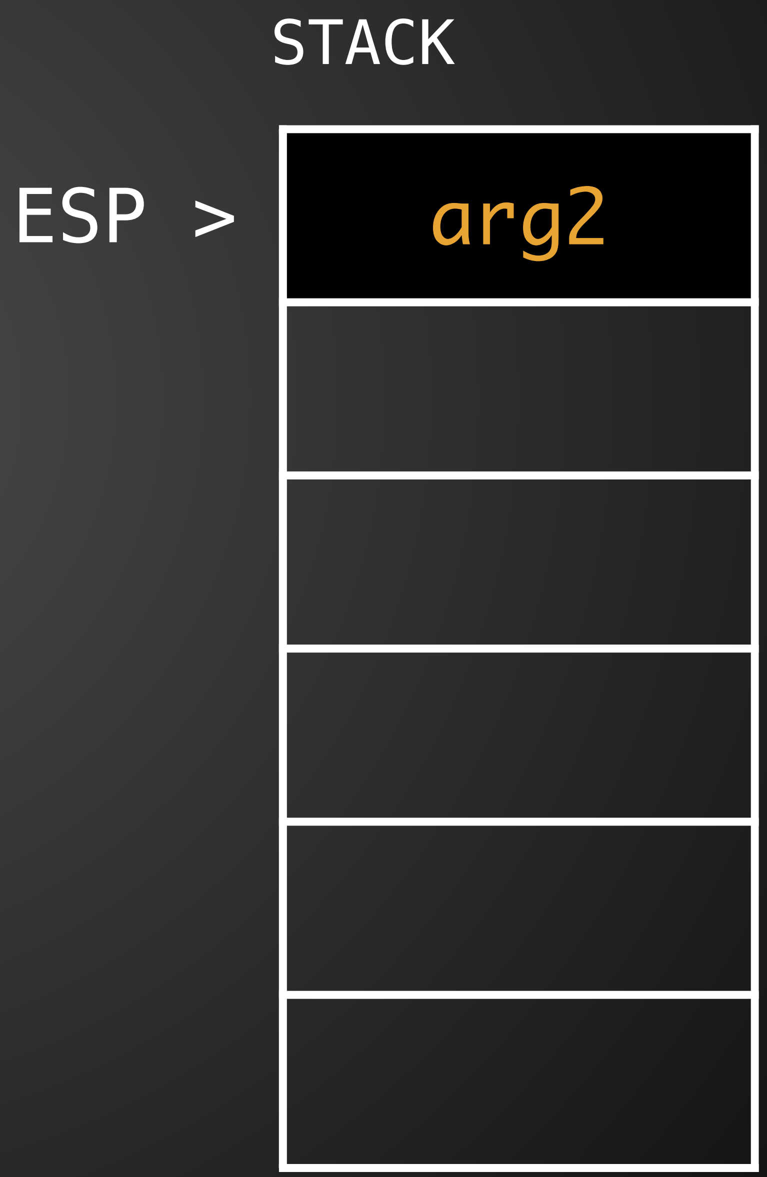
Function Call

```
...

F1( arg1, arg2 );

...

    push arg2

    push arg1

    call F1
```



Function Call

```
...

F1( arg1, arg2 );

...

    push arg2

    push arg1

    call F1
```

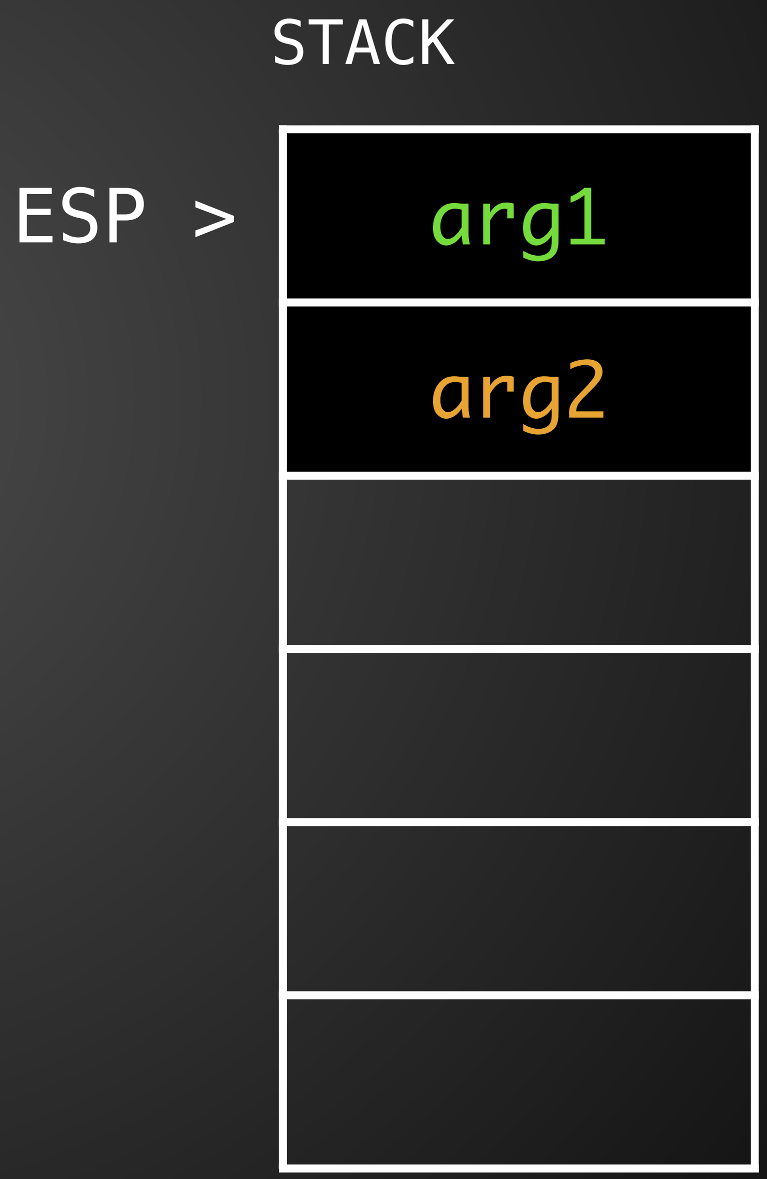


STACK

ESP > arg2

Function Call

```
...

F1( arg1, arg2 );

...

    push arg2

    push arg1

    call F1
```



STACK

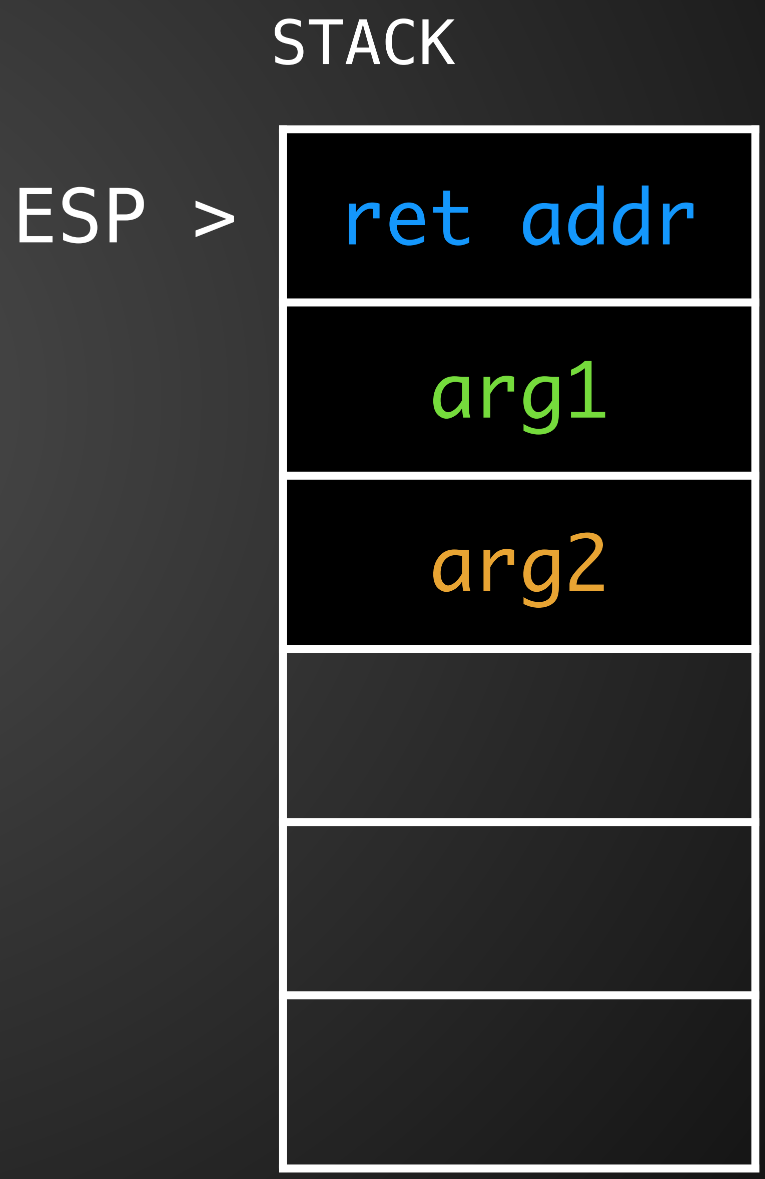
ESP >

arg1

arg2

Function Call

```
...

F1( arg1, arg2 );

...

    push arg2

    push arg1

    call F1
```



STACK

ESP >

ret addr

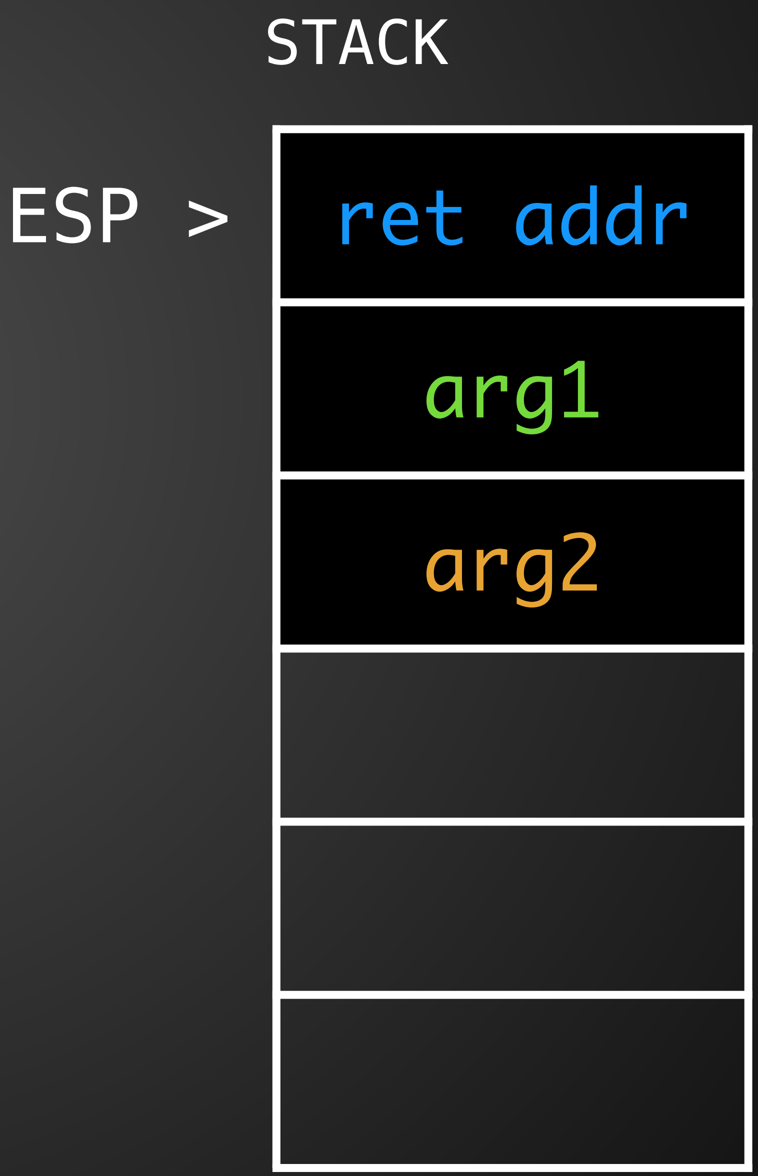
arg1

arg2

Function Call

```
void F1( arg1, arg2 ) {
  char buffer[8];
  ...
}
```

```
   push ebp
   mov ebp, esp
   sub esp, 8
   ...
```



STACK

ESP >

ret addr

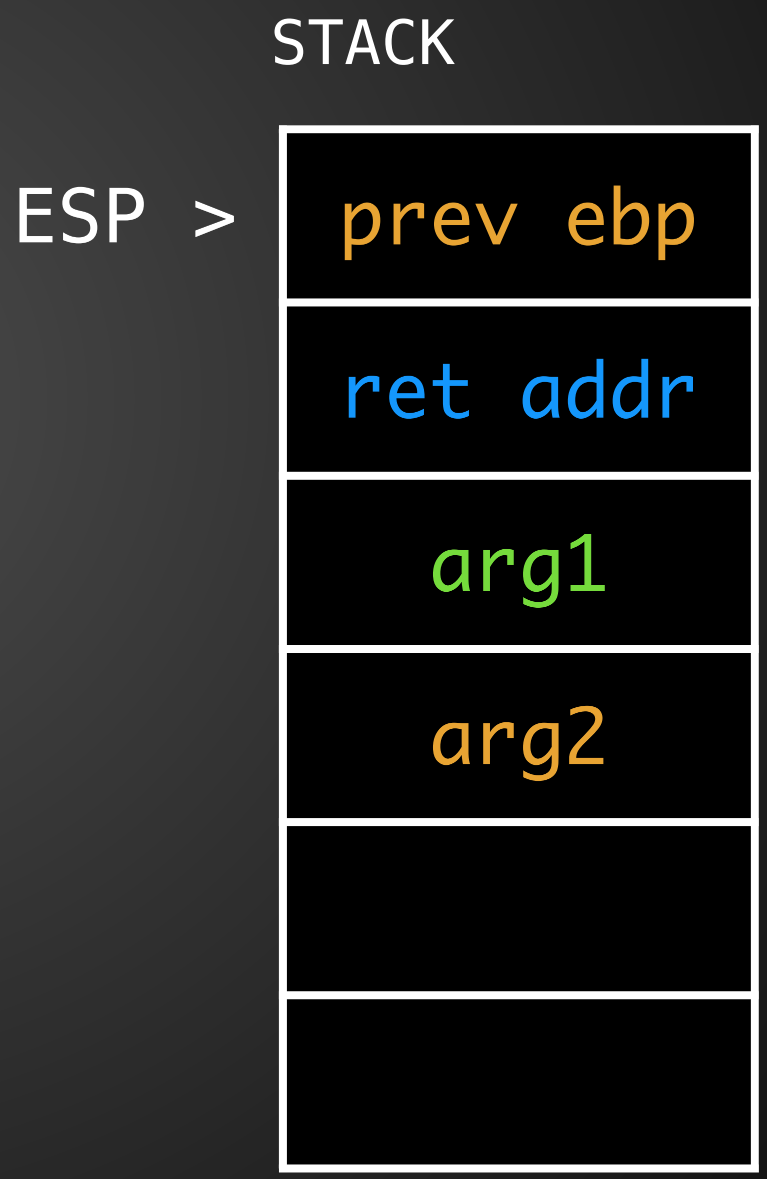
arg1

arg2

Function Call

```
void F1( arg1, arg2 ) {
  char buffer[8];
  ...
}
```

```
   push ebp
   mov ebp, esp
   sub esp, 8
   ...
```



STACK

ESP >

prev ebp

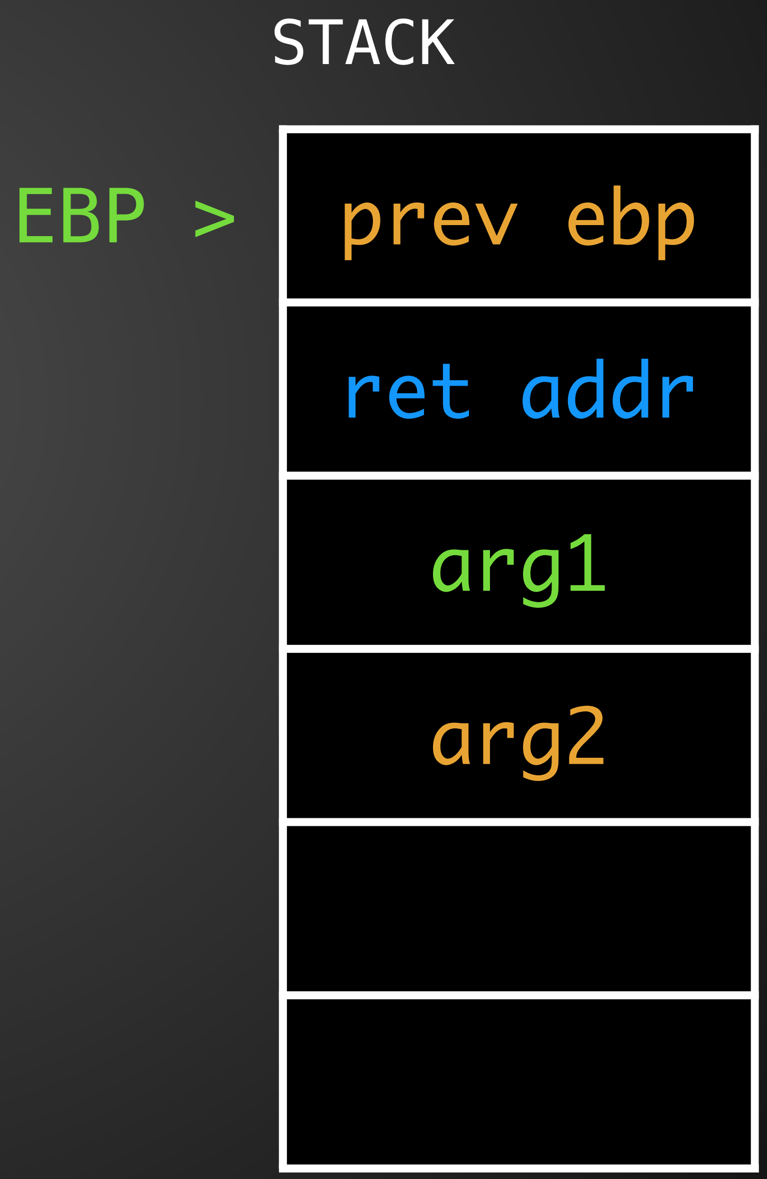
ret addr

arg1

arg2

Function Call

```
void F1( arg1, arg2 ) {
  char buffer[8];
  ...
}
   push ebp
   mov ebp, esp
   sub esp, 8
   ...
```



STACK

EBP >

prev ebp

ret addr

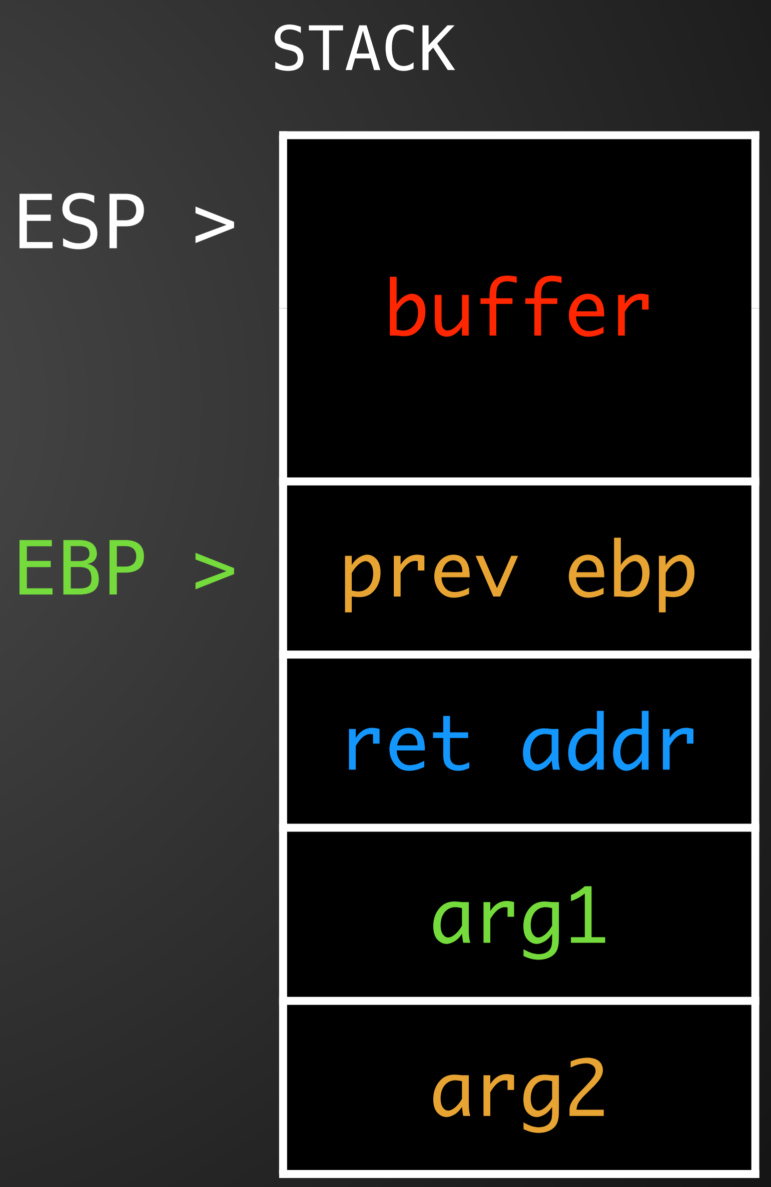
arg1

arg2

Function Call

```
void F1( arg1, arg2 ) {
  char buffer[8];
  ...
}
```

```
   push ebp
   mov ebp, esp
   sub esp, 8
   ...
```



STACK

ESP > buffer

EBP > prev ebp

ret addr

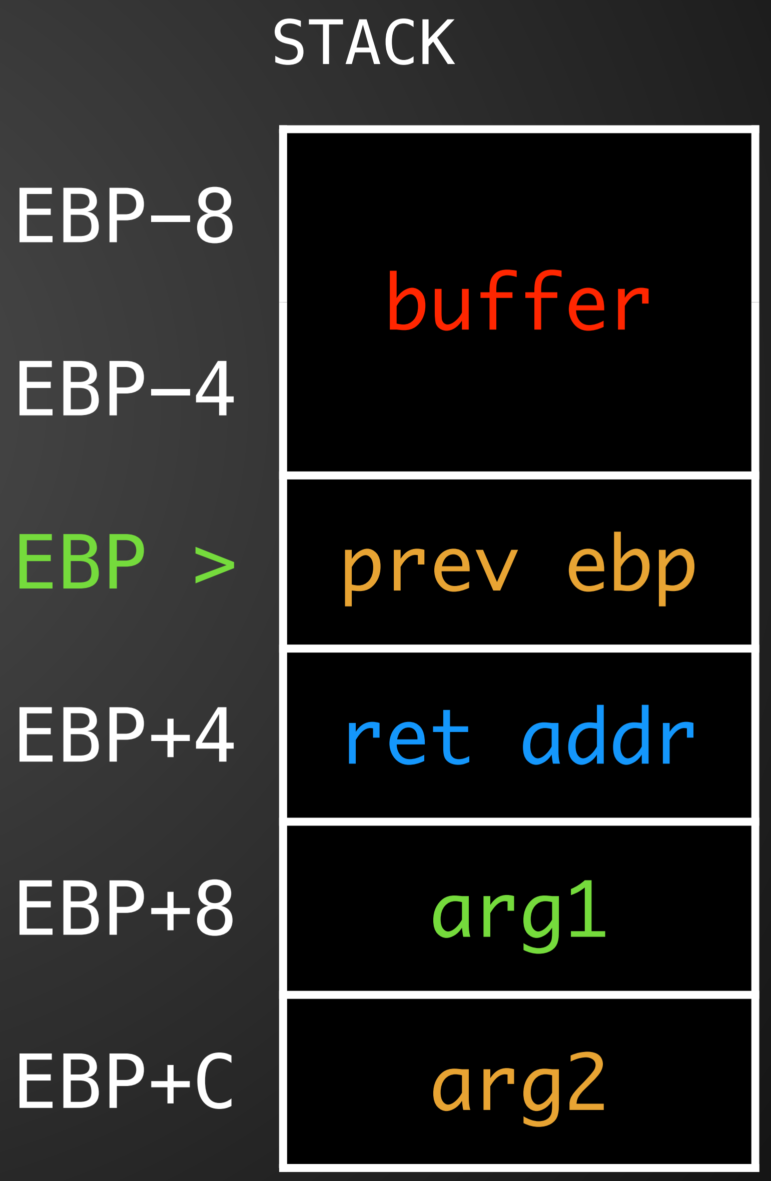
arg1

arg2

Function Call

```
void F1( arg1, arg2 ) {

  char buffer[8];

  ...

}
```

```
    push ebp

    mov ebp, esp

    sub esp, 8

    ...
```

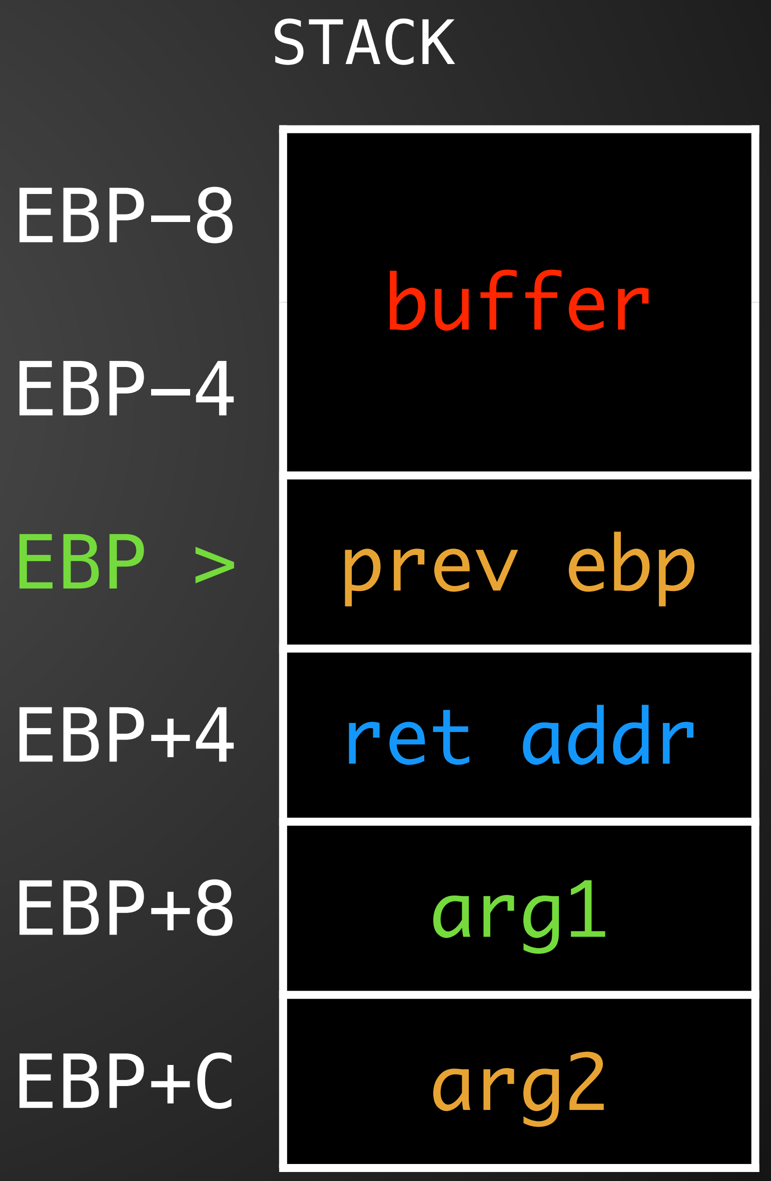


STACK

EBP–8	buffer
EBP–4	
EBP >	prev ebp
EBP+4	ret addr
EBP+8	arg1
EBP+C	arg2

Buffer Overflow

```
void F1( arg1, arg2 ) {

    char buffer[8];

    ...

    scanf( “%s”, buffer );

    ...

}
```

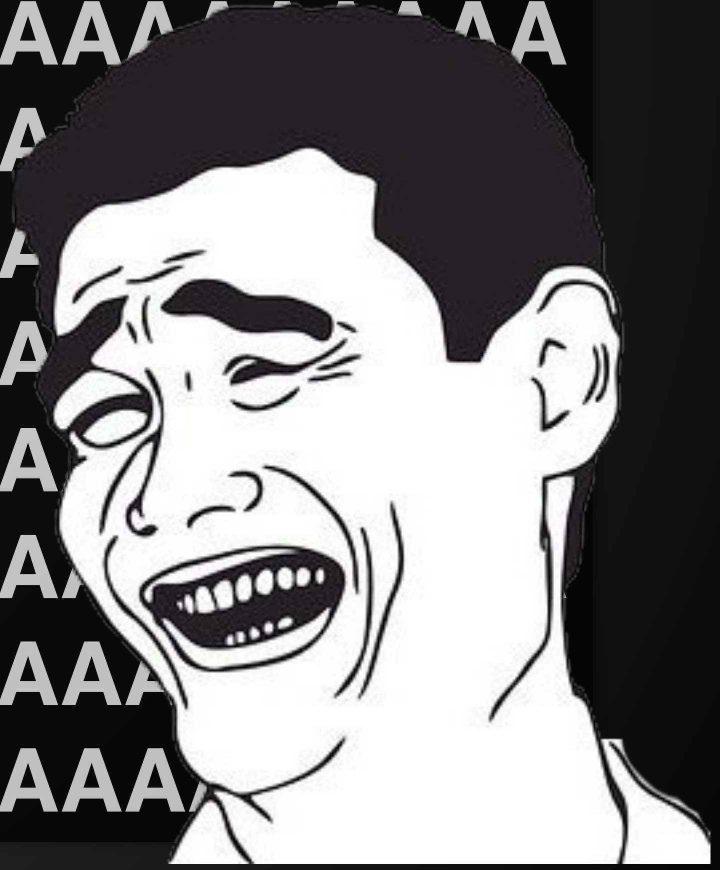


STACK

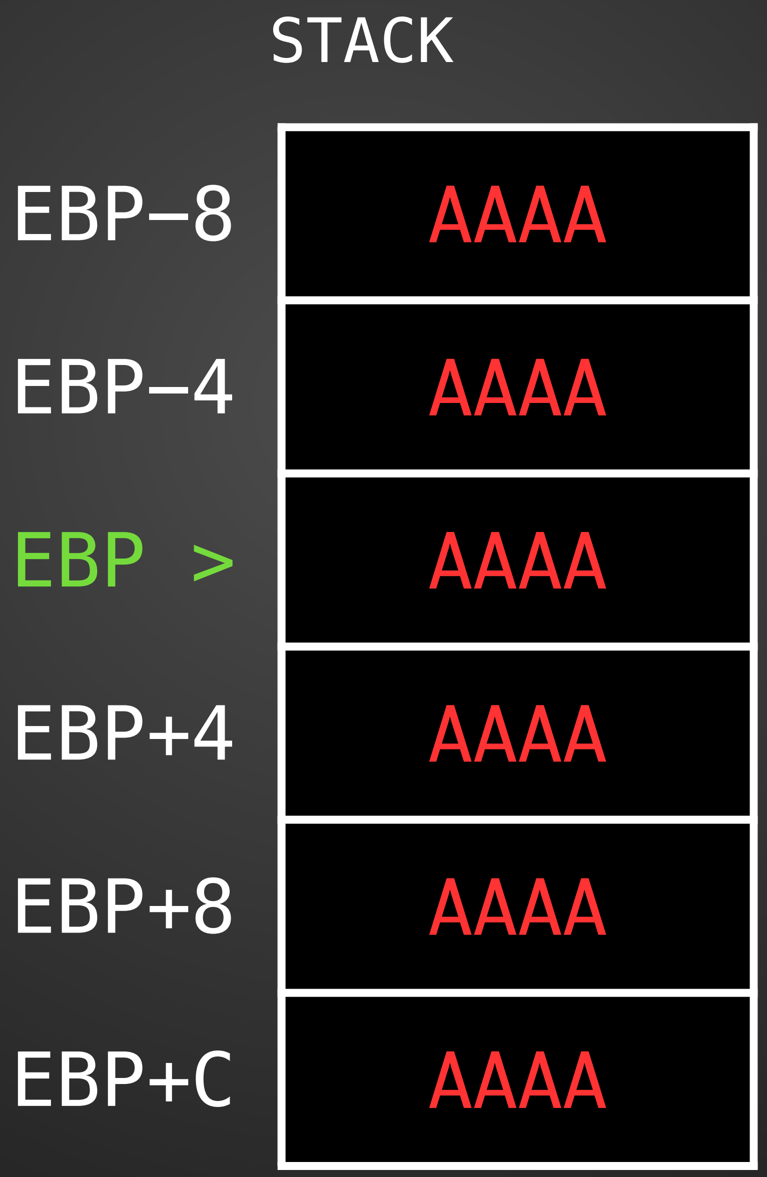
EBP–8	buffer
EBP–4	
EBP >	prev ebp
EBP+4	ret addr
EBP+8	arg1
EBP+C	arg2

Buffer Overflow

AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA



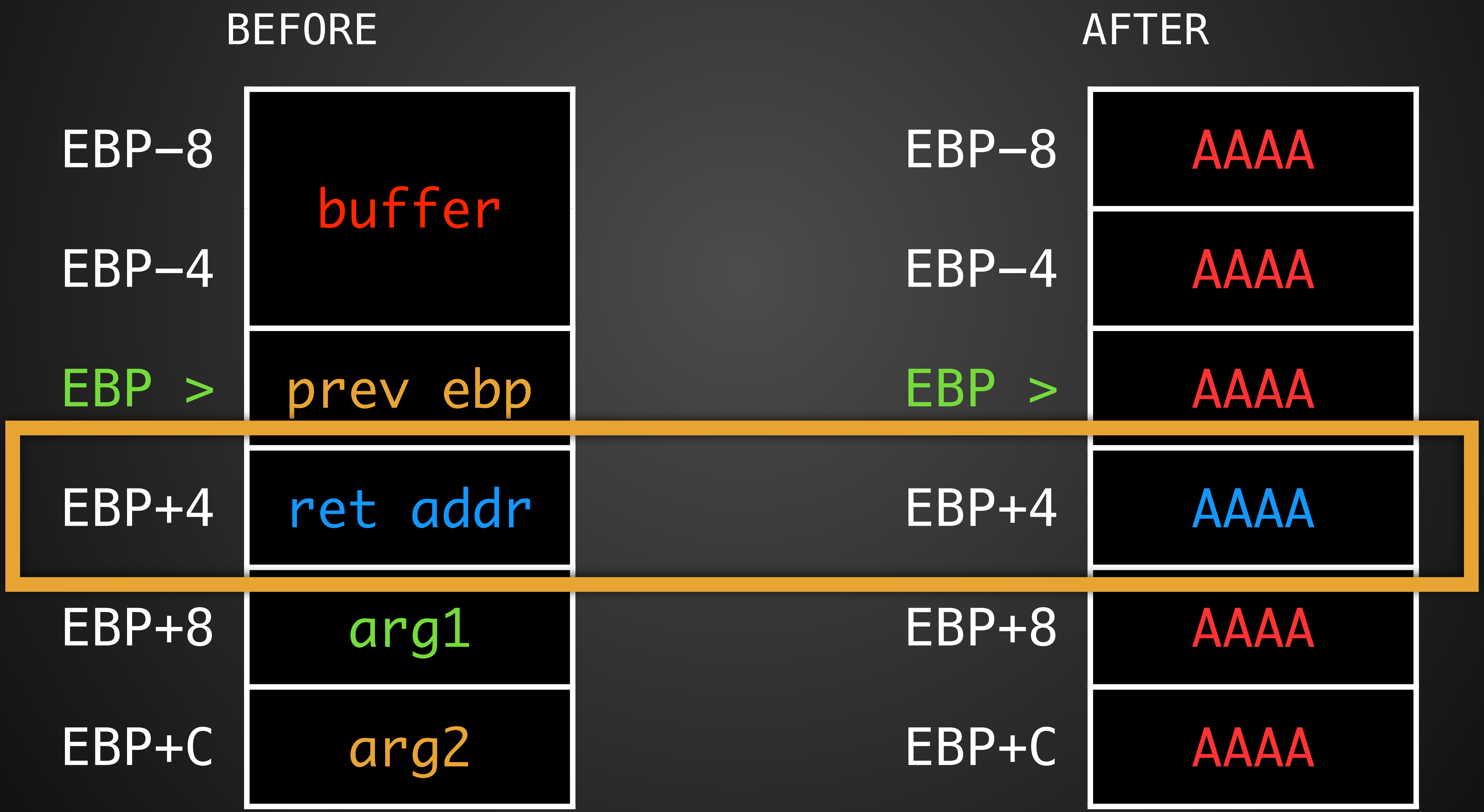
Buffer Overflow



STACK

EBP−8	AAAA
EBP−4	AAAA
EBP >	AAAA
EBP+4	AAAA
EBP+8	AAAA
EBP+C	AAAA

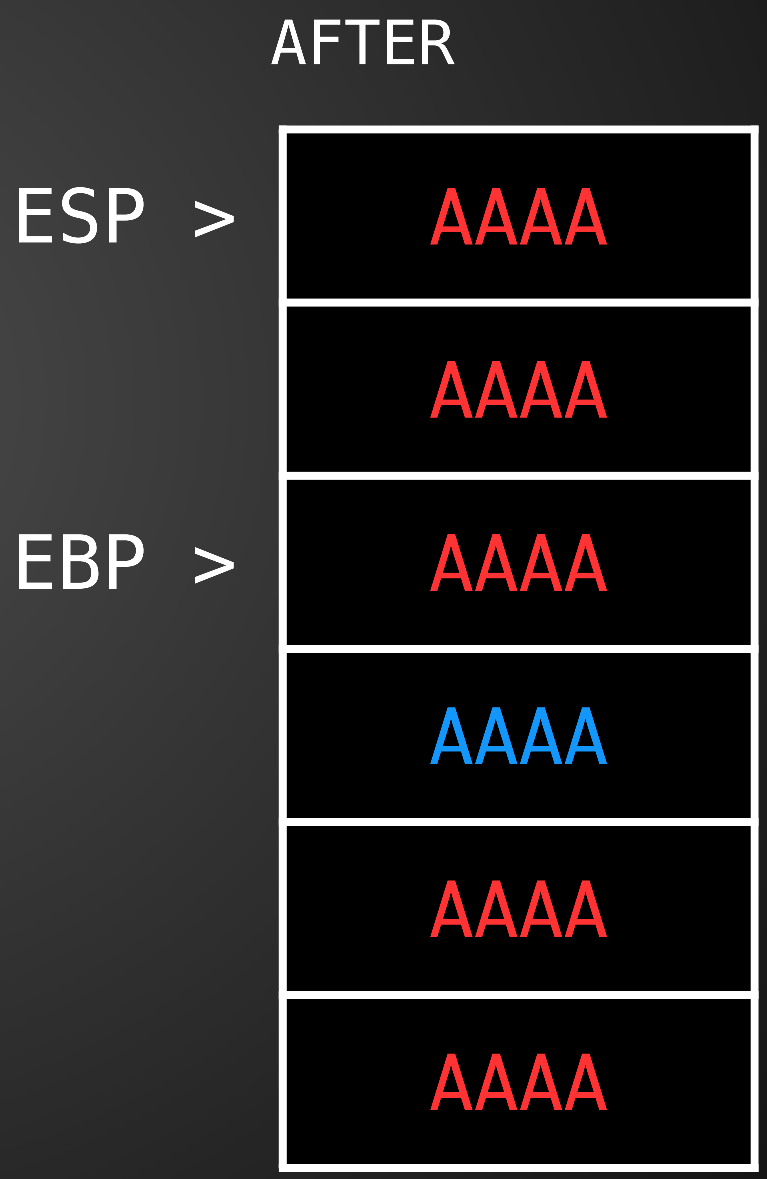
Buffer Overflow



	BEFORE		AFTER
EBP−8	buffer	EBP−8	AAAA
EBP−4		EBP−4	AAAA
EBP >	prev ebp	EBP >	AAAA
EBP+4	ret addr	EBP+4	AAAA
EBP+8	arg1	EBP+8	AAAA
EBP+C	arg2	EBP+C	AAAA

Buffer Overflow

```
...

mov esp, ebp

pop ebp

ret
```



AFTER

ESP > AAAA

AAAA

EBP > AAAA

AAAA

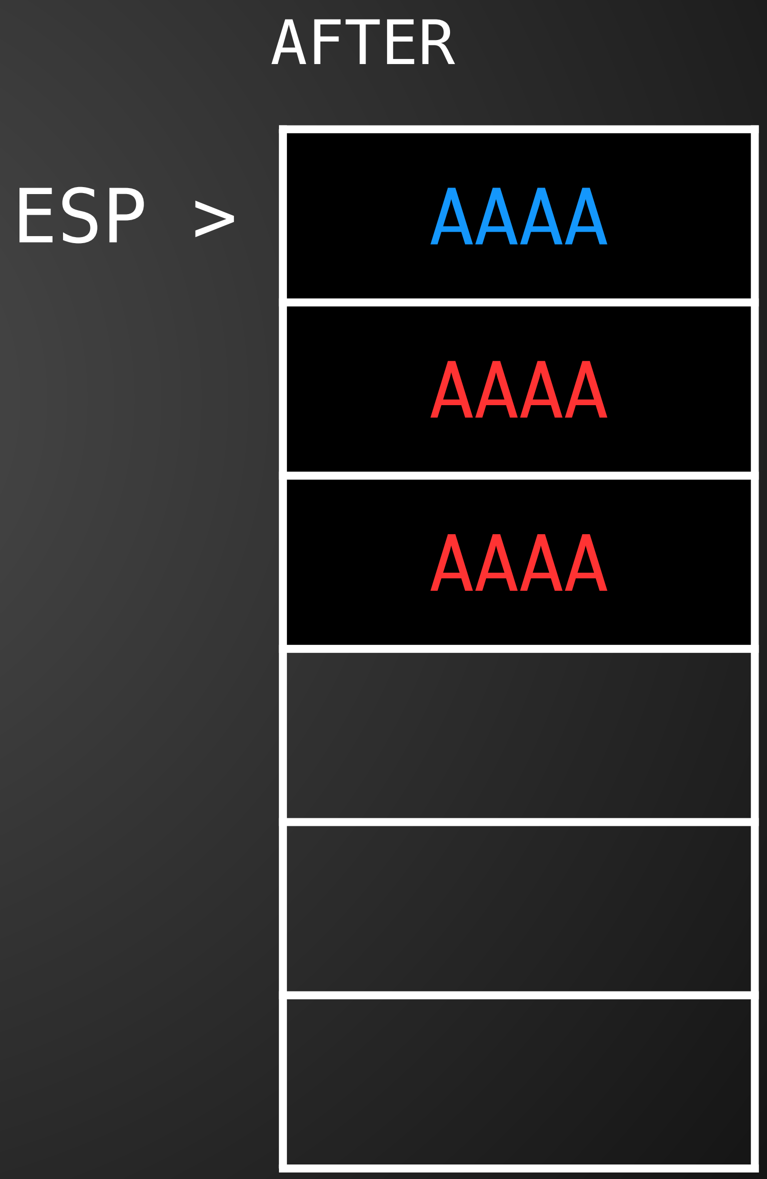
AAAA

AAAA

Buffer Overflow

```
...

mov esp, ebp

pop ebp

ret
```

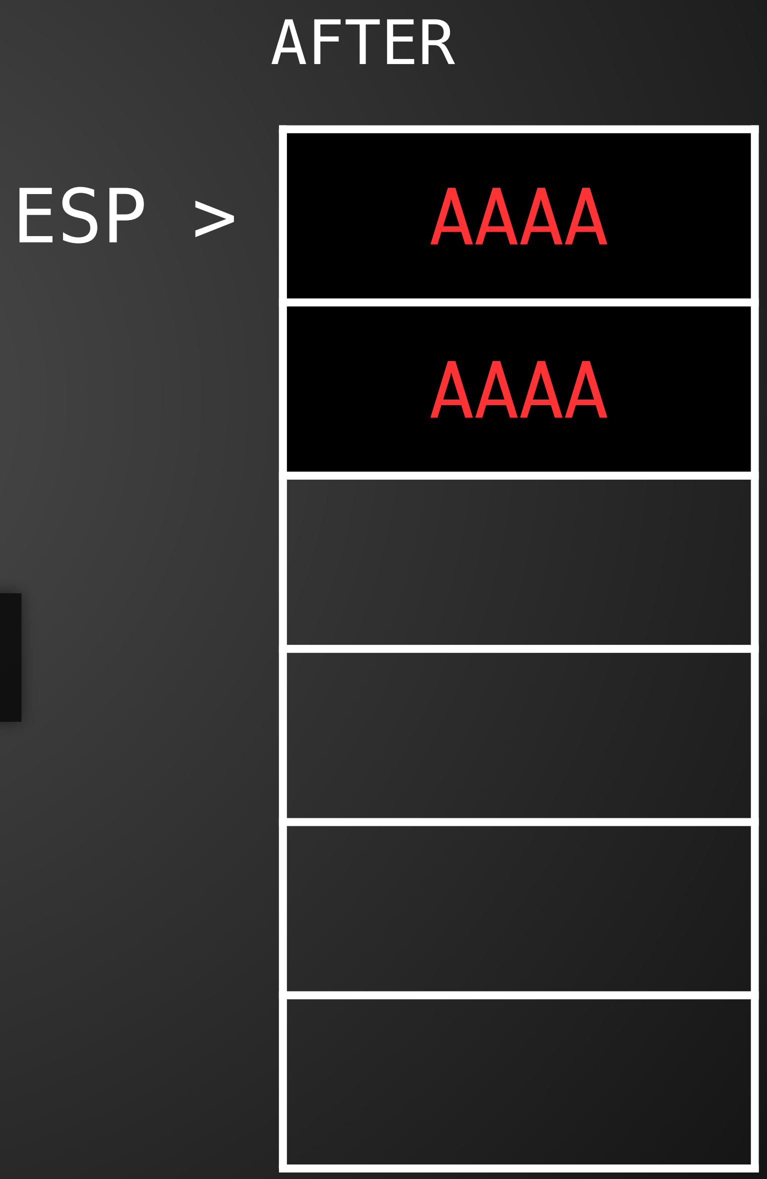
= POP EIP



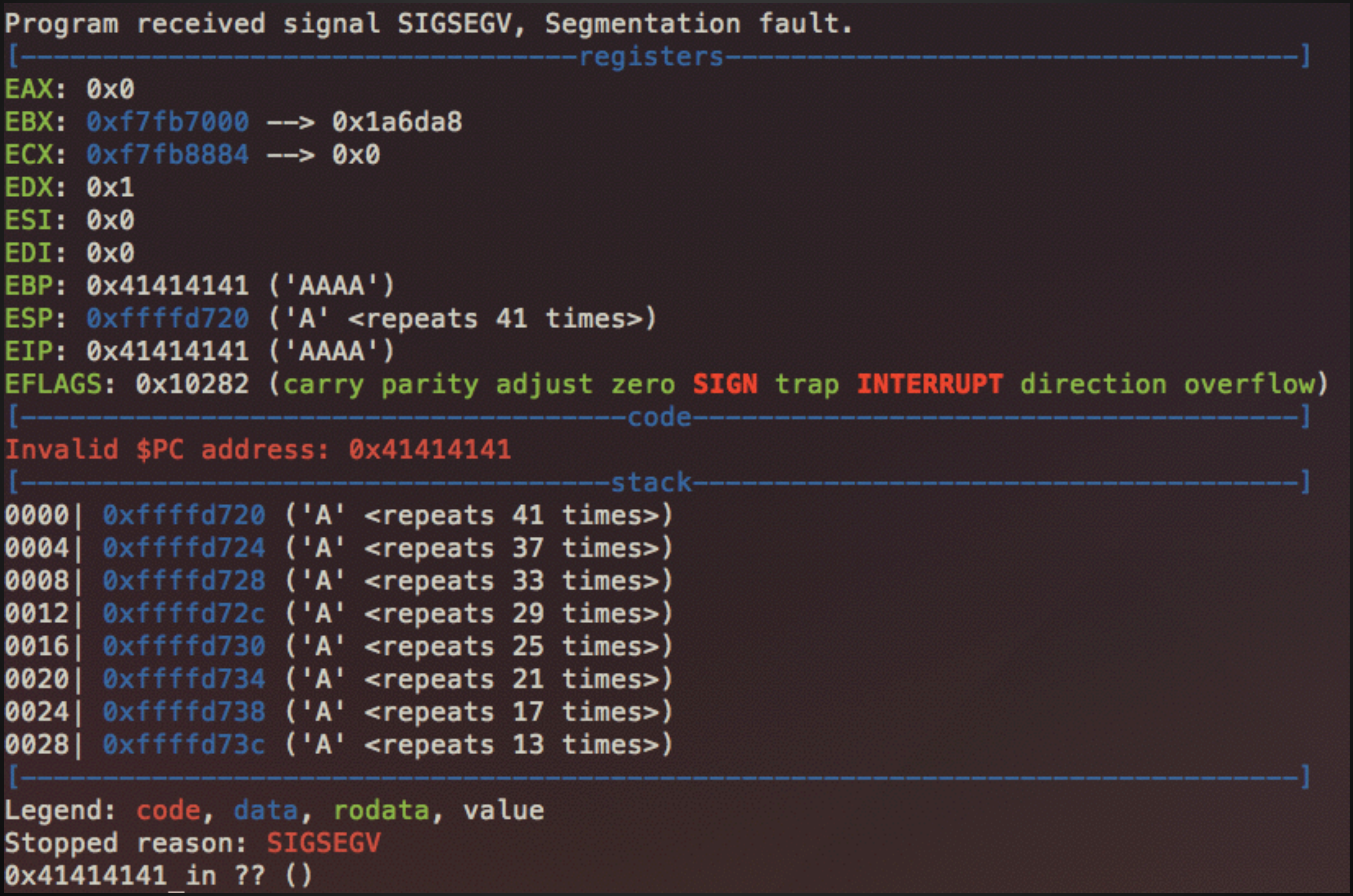
Buffer Overflow

```
...

mov esp, ebp

pop ebp

ret
```

JMP AAAA



Buffer Overflow



```
Program received signal SIGSEGV, Segmentation fault.
[----------------------------------registers-----------------------------------]
EAX: 0x0
EBX: 0xf7fb7000 --> 0x1a6da8
ECX: 0xf7fb8884 --> 0x0
EDX: 0x1
ESI: 0x0
EDI: 0x0
EBP: 0x41414141 ('AAAA')
ESP: 0xffffd720 ('A' <repeats 41 times>)
EIP: 0x41414141 ('AAAA')
EFLAGS: 0x10282 (carry parity adjust zero SIGN trap INTERRUPT direction overflow)
[-------------------------------------code-------------------------------------]
Invalid $PC address: 0x41414141
[------------------------------------stack-------------------------------------]
0000| 0xffffd720 ('A' <repeats 41 times>)
0004| 0xffffd724 ('A' <repeats 37 times>)
0008| 0xffffd728 ('A' <repeats 33 times>)
0012| 0xffffd72c ('A' <repeats 29 times>)
0016| 0xffffd730 ('A' <repeats 25 times>)
0020| 0xffffd734 ('A' <repeats 21 times>)
0024| 0xffffd738 ('A' <repeats 17 times>)
0028| 0xffffd73c ('A' <repeats 13 times>)
[------------------------------------------------------------------------------]
Legend: code, data, rodata, value
Stopped reason: SIGSEGV
0x41414141 in ?? ()
```

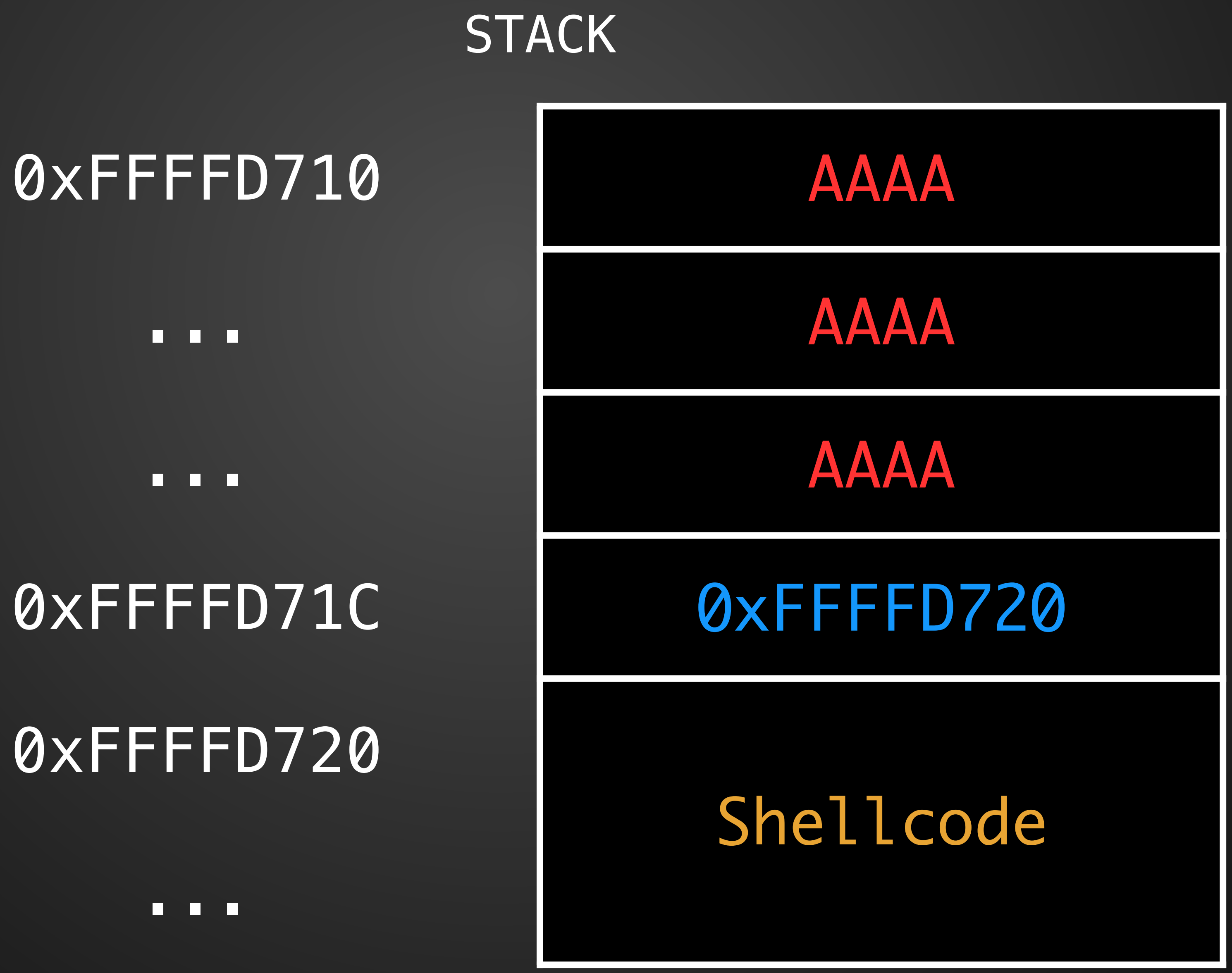
Buffer Overflow

- Shellcode
  - 預先寫好的攻擊代碼
  - in C / ASM

```
xor     %eax,%eax
push    %eax
push    $0x68732f2f
push    $0x6e69622f
mov     %esp,%ebx
push    %eax
push    %ebx
mov     %esp,%ecx
mov     $0xb,%al
int     $0x80
```

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

Buffer Overflow



STACK

0xFFFFD710

...

...

0xFFFFD71C

0xFFFFD720

...

AAAA

AAAA

AAAA

0xFFFFD720

Shellcode

Buffer Overflow

- 塞滿 Buffer
- 覆蓋函數返回地址
- 跳轉至 Shellcode 執行

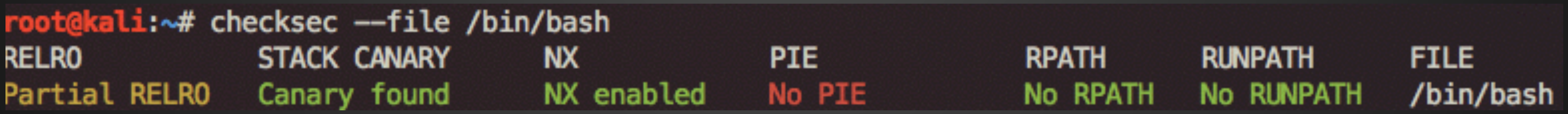
AAAAAAAAAAAAA > \x20\xD7\xFF\xFF > Shellcode

Exploit Mitigation

- DEP (Data Execution Prevention)
  - 禁止執行位於資料區塊上的代碼
- ASLR (Address Space Layout Randomization)
  - 記憶體位置隨機化
- Stack Guard
  - 函數返回前檢查 stack 結構完整

checksec.sh

- Check Security Options
  - checksec.sh --file <executable-file>
  - checksec.sh --proc <proc name>



```
root@kali:~# checksec --file /bin/bash
RELRO           STACK CANARY      NX            PIE             RPATH      RUNPATH      FILE
Partial RELRO   Canary found      NX enabled    No PIE          No RPATH   No RUNPATH   /bin/bash
```

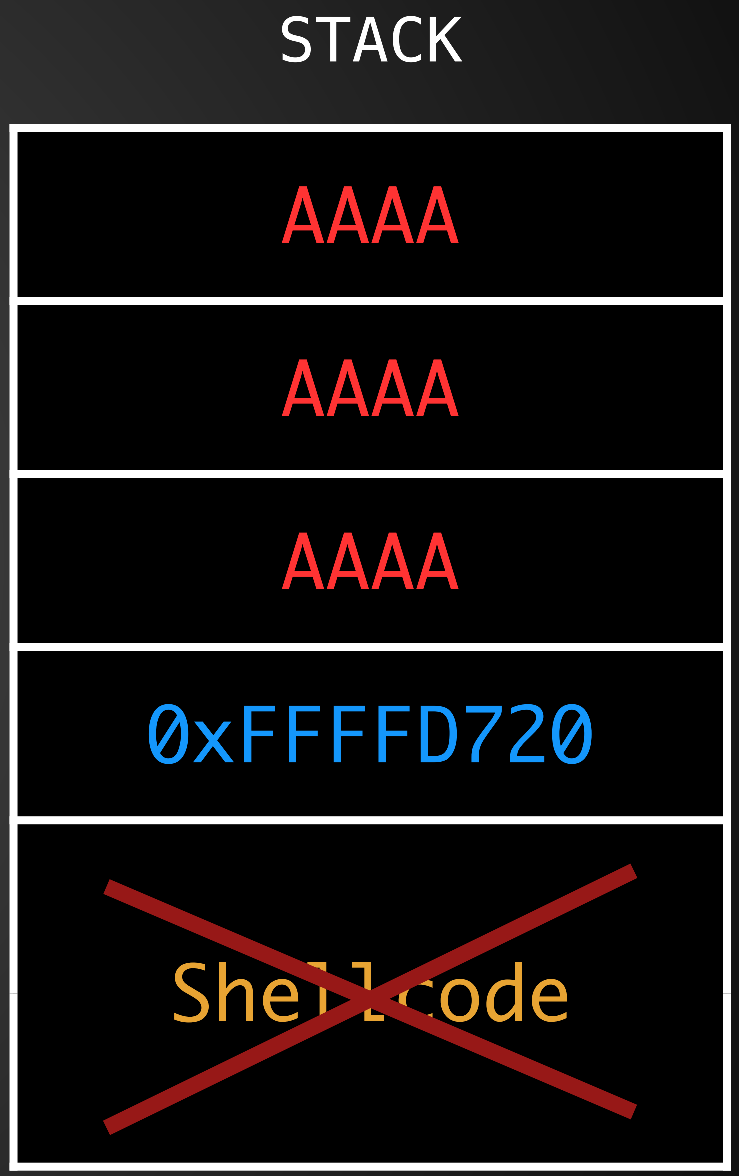
http://www.trapkit.de/tools/checksec.html

DEP

Data Execution Prevention

Data Execution Prevention

- 資料區塊上的代碼無法執行
  - [X] Stack
  - [X] Heap
- 硬體支援 (CPU NX bit)
- 可以放 shellcode ，但不能 run



STACK

AAAA

AAAA

AAAA

0xFFFFD720

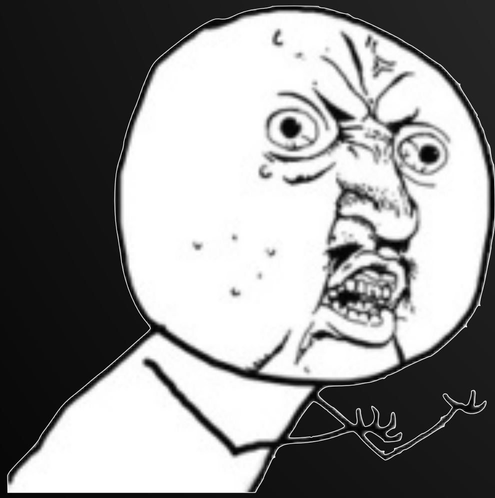
~~Shellcode~~

「世界上最遙遠的距離，不是生與死」

「而是 Shellcode 就在 Stack 上，

你卻無法執行它。」

— *DEP*



ret2libc / ret2text

Return to existing code

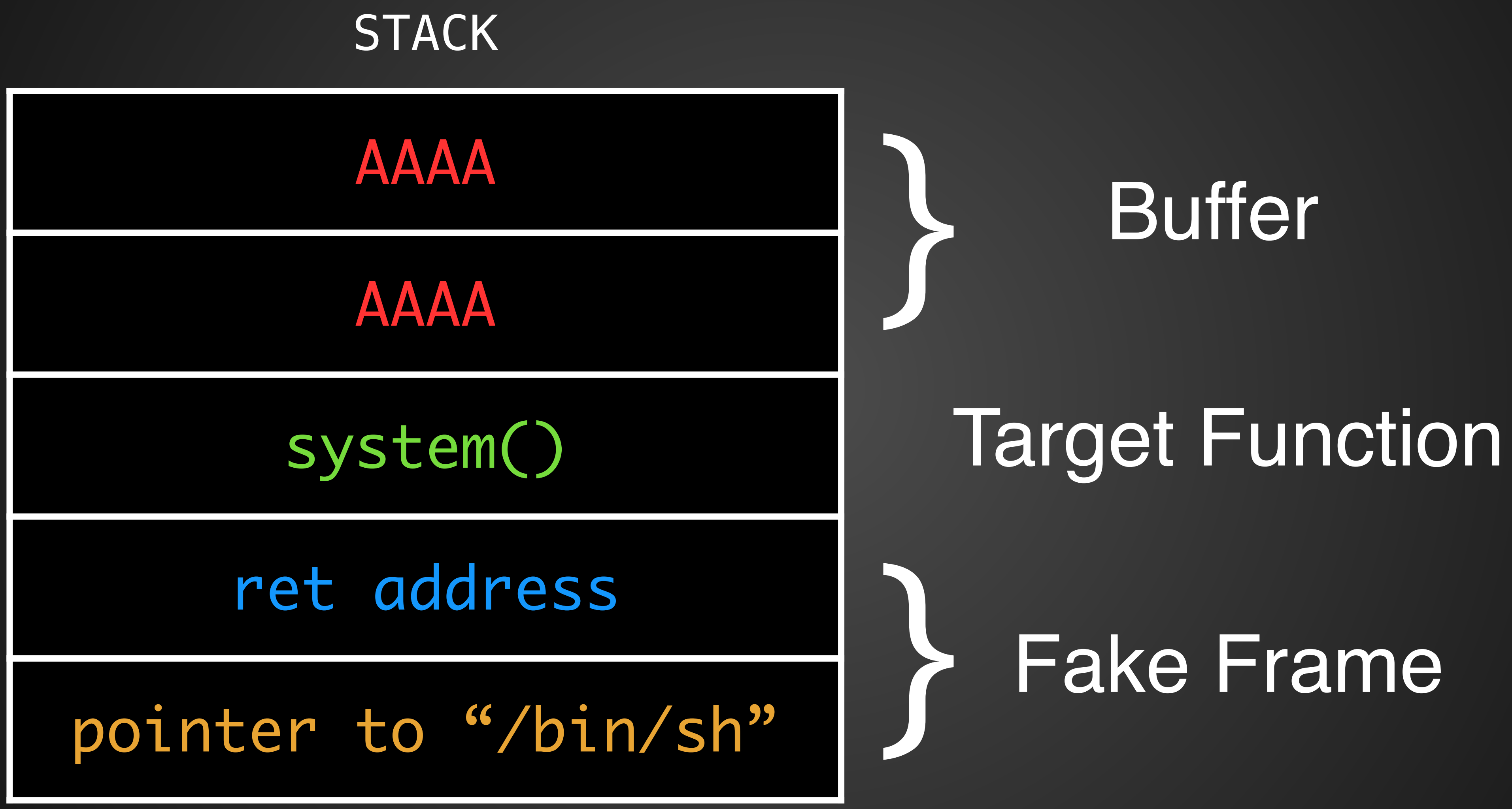
ret2libc

- DEP
  - [X] Stack
  - [X] Heap
  - [O] Binary
  - [O] Shared Library

ret2libc

- Return-to-libc
  - Buffer Overflow 後，覆蓋返回地址為程式中現有函數地址
  - 不能 return 到 shellcode，那就 return 到現有的 code 上
    - 利用 libc.so 中的函數
  - 偽造堆疊結構，建立函數呼叫
    - e.g. system(“/bin/sh”)

ret2libc



STACK

AAAA

AAAA

system()

ret address

pointer to “/bin/sh”

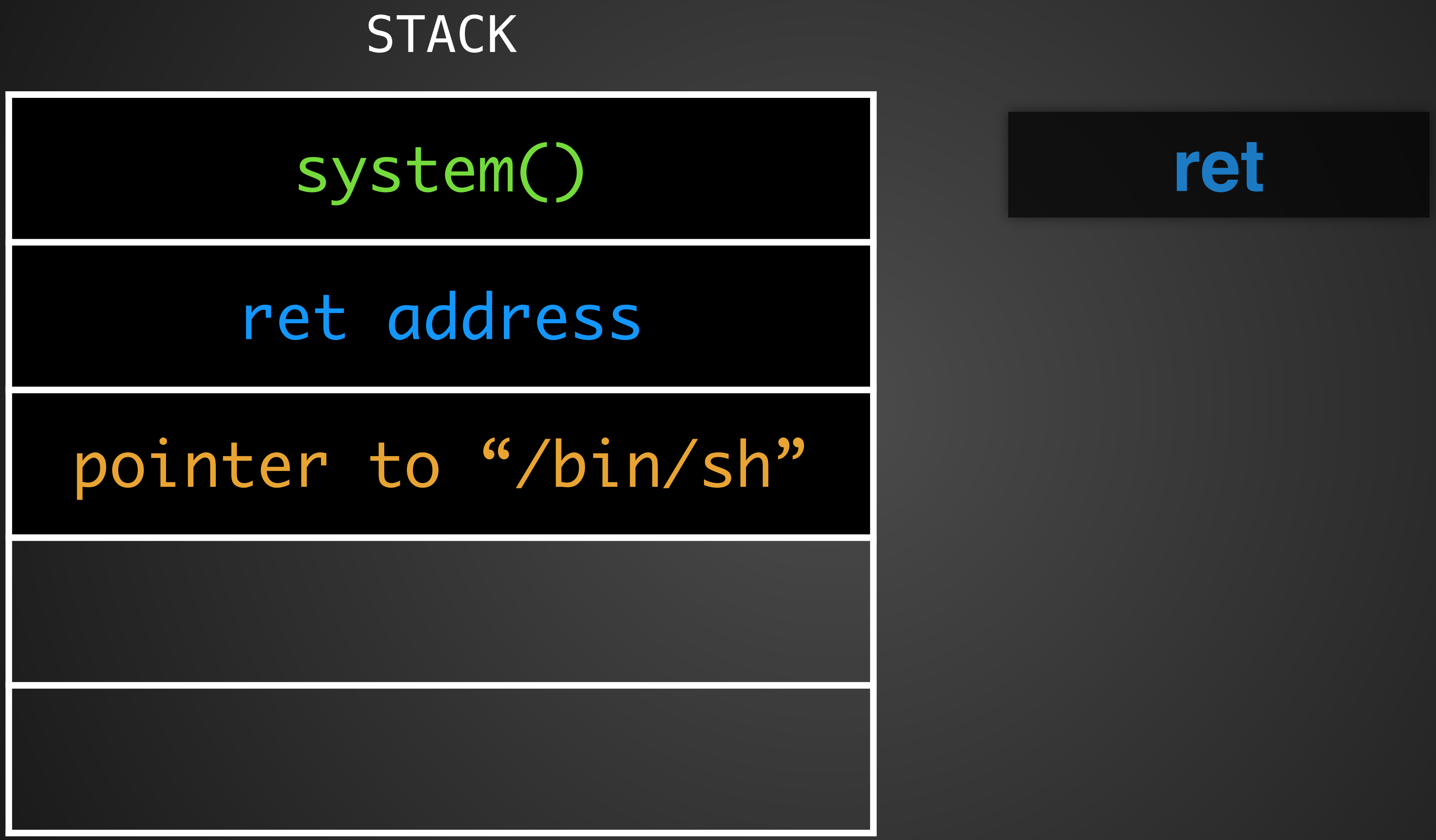
Buffer

Target Function

Fake Frame

system(“/bin/sh”)

ret2libc



STACK

system()

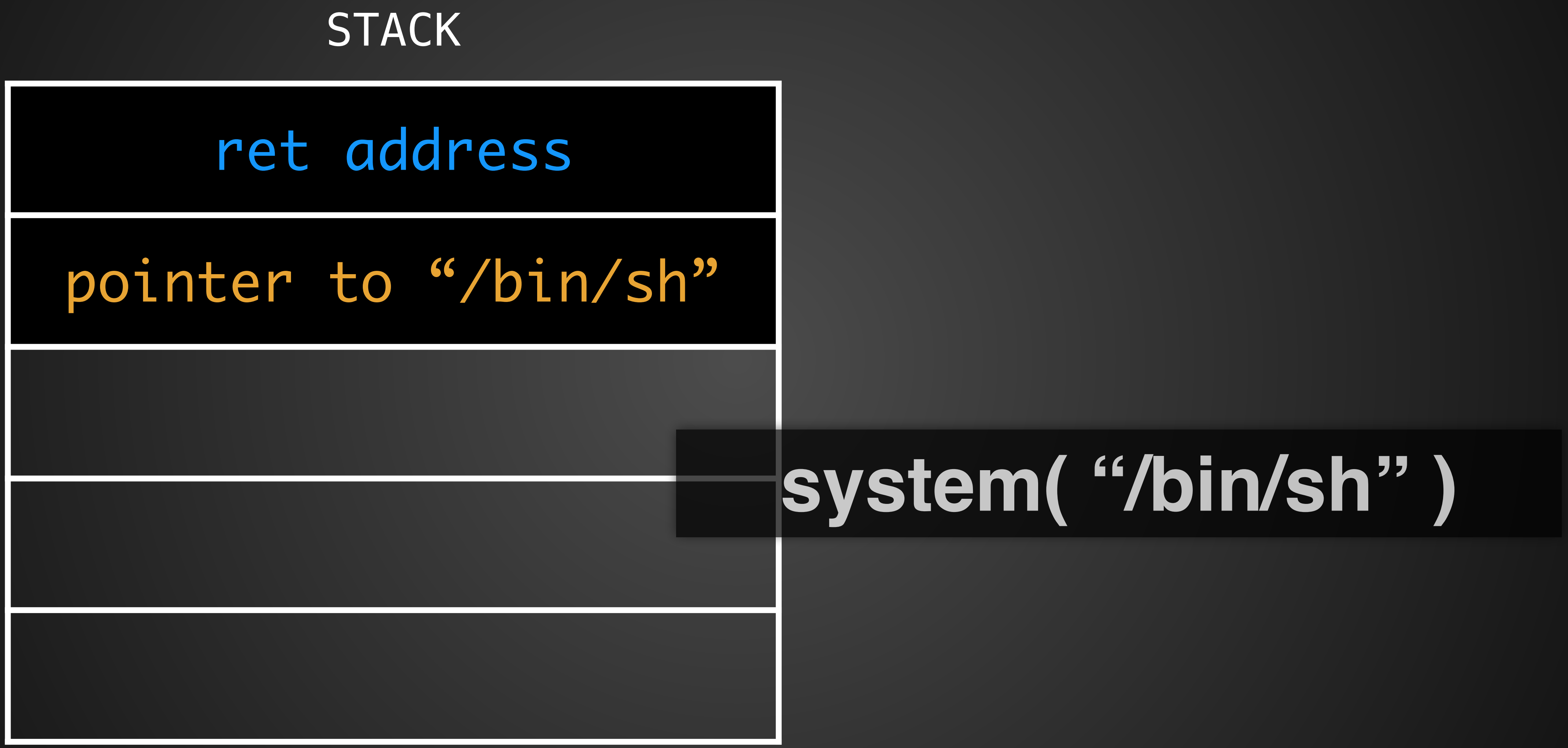
ret address

pointer to “/bin/sh”

ret

system(“/bin/sh”)

ret2libc



STACK

ret address

pointer to "/bin/sh"

system("/bin/sh")

ASLR

Address Space Layout Randomization

ASLR

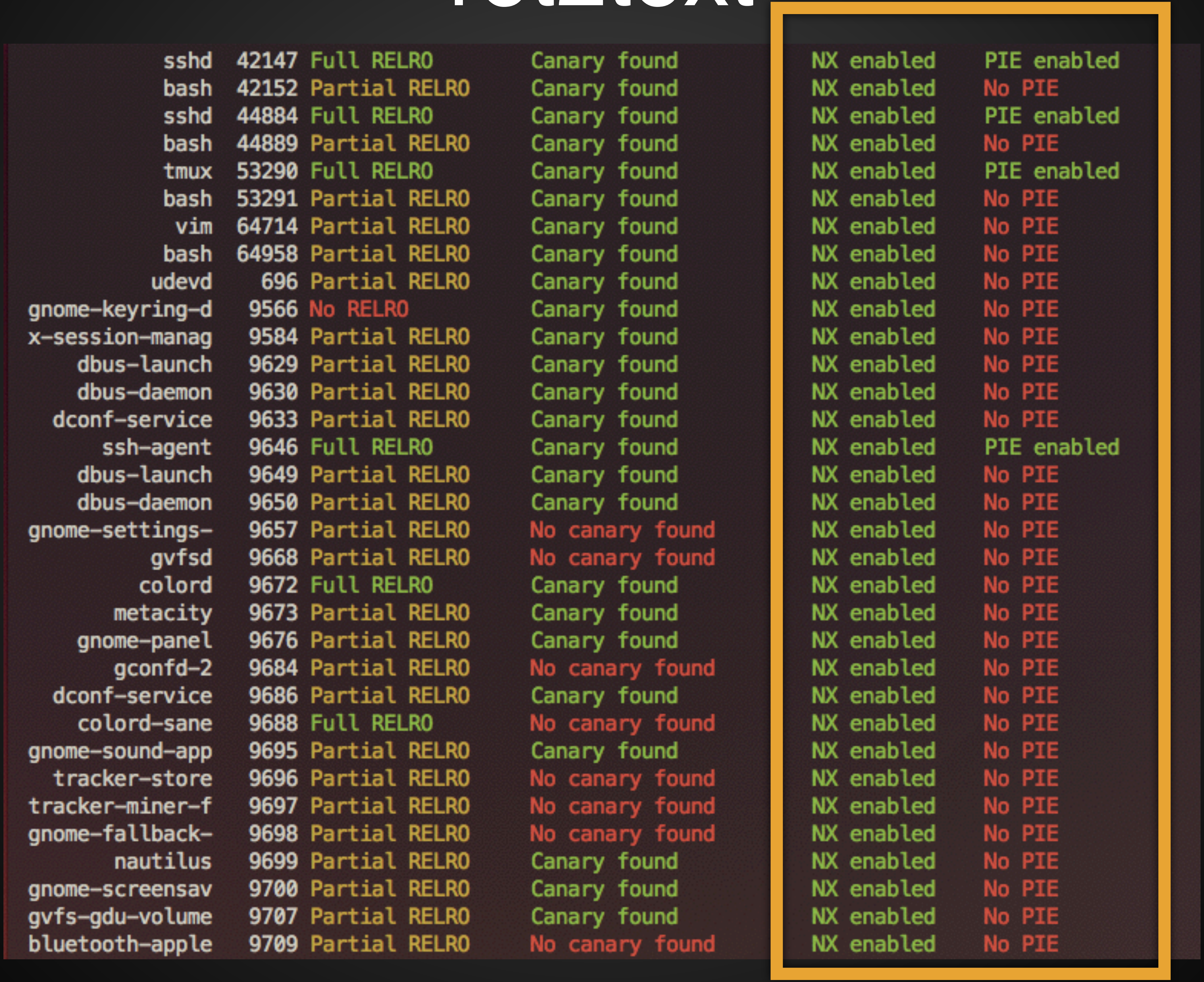
- 隨機分配記憶體位置
    - Stack
    - Heap
    - Shared library
    - VDSO
    - …
- 難以預測目標函數 / shellcode 位置

ret2text

- Return-to-text
  - return 到程式自身 code / PLT
  - 沒開啟 PIE (Position-independent Code) 時，

    .text 地址固定，不受 ASLR 影響
- 泄露有用資訊，搭配 ret2libc / ROP

ret2text



```
           sshd  42147 Full RELRO       Canary found       NX enabled   PIE enabled
           bash  42152 Partial RELRO    Canary found       NX enabled   No PIE
           sshd  44884 Full RELRO       Canary found       NX enabled   PIE enabled
           bash  44889 Partial RELRO    Canary found       NX enabled   No PIE
           tmux  53290 Full RELRO       Canary found       NX enabled   PIE enabled
           bash  53291 Partial RELRO    Canary found       NX enabled   No PIE
            vim  64714 Partial RELRO    Canary found       NX enabled   No PIE
           bash  64958 Partial RELRO    Canary found       NX enabled   No PIE
          udevd    696 Partial RELRO    Canary found       NX enabled   No PIE
gnome-keyring-d   9566 No RELRO         Canary found       NX enabled   No PIE
x-session-manag   9584 Partial RELRO    Canary found       NX enabled   No PIE
    dbus-launch   9629 Partial RELRO    Canary found       NX enabled   No PIE
    dbus-daemon   9630 Partial RELRO    Canary found       NX enabled   No PIE
  dconf-service   9633 Partial RELRO    Canary found       NX enabled   No PIE
      ssh-agent   9646 Full RELRO       Canary found       NX enabled   PIE enabled
    dbus-launch   9649 Partial RELRO    Canary found       NX enabled   No PIE
    dbus-daemon   9650 Partial RELRO    Canary found       NX enabled   No PIE
gnome-settings-   9657 Partial RELRO    No canary found    NX enabled   No PIE
          gvfsd   9668 Partial RELRO    No canary found    NX enabled   No PIE
         colord   9672 Full RELRO       Canary found       NX enabled   No PIE
       metacity   9673 Partial RELRO    Canary found       NX enabled   No PIE
    gnome-panel   9676 Partial RELRO    Canary found       NX enabled   No PIE
       gconfd-2   9684 Partial RELRO    No canary found    NX enabled   No PIE
  dconf-service   9686 Partial RELRO    Canary found       NX enabled   No PIE
    colord-sane   9688 Full RELRO       No canary found    NX enabled   No PIE
gnome-sound-app   9695 Partial RELRO    Canary found       NX enabled   No PIE
  tracker-store   9696 Partial RELRO    No canary found    NX enabled   No PIE
tracker-miner-f   9697 Partial RELRO    No canary found    NX enabled   No PIE
gnome-fallback-   9698 Partial RELRO    No canary found    NX enabled   No PIE
       nautilus   9699 Partial RELRO    Canary found       NX enabled   No PIE
gnome-screensav   9700 Partial RELRO    Canary found       NX enabled   No PIE
gvfs-gdu-volume   9707 Partial RELRO    Canary found       NX enabled   No PIE
bluetooth-apple   9709 Partial RELRO    No canary found    NX enabled   No PIE
```

ret2libc / ret2text

- Return-to-libc
  - 需要知道目標函數地址
  - 受 ASLR 影響，需配合 Memory Leak / libc.so
  - static link
- Return-to-text
  - 現有 code 不一定能滿足需求

ROP

Return-Oriented Programming

ROP

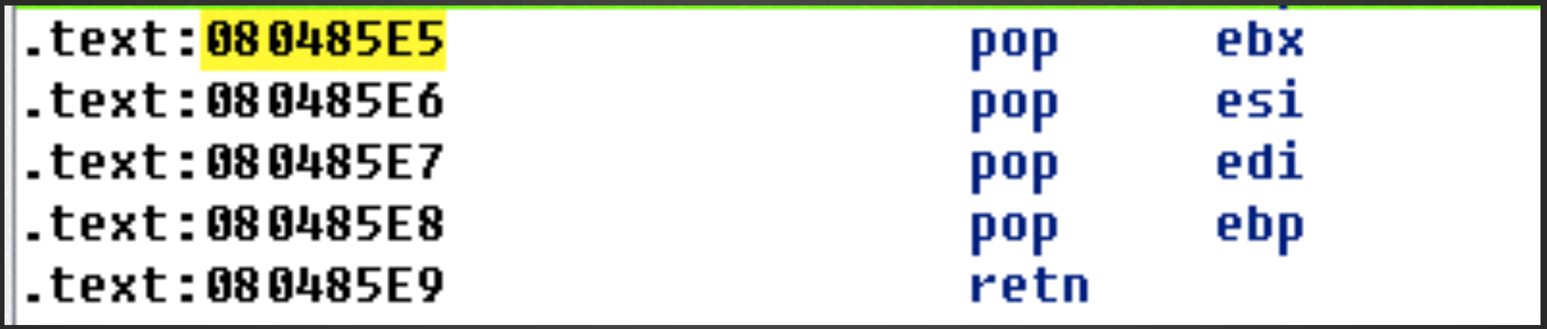
- Exploitation
  - Return to Shellcode
    - Return to Functions
      - Return to Gadgets

ROP

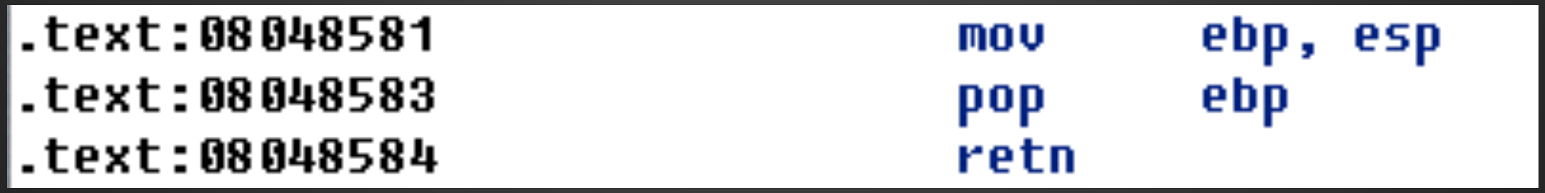
- RET 到自身程式包含 RET 指令的代碼區塊上

ROP

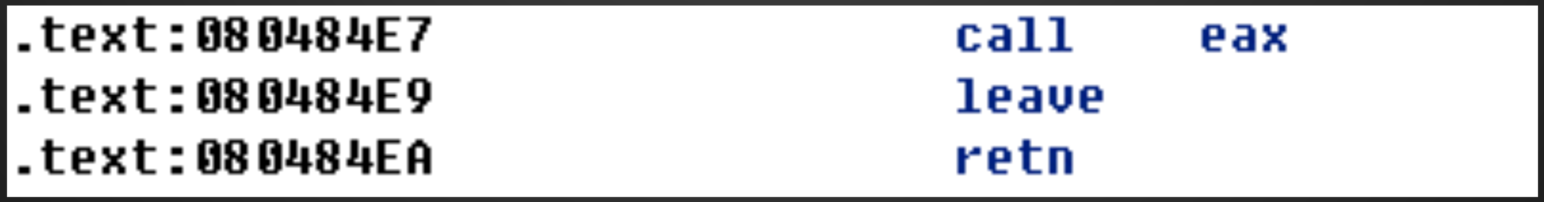
- RET 到自身程式 包含 RET 指令的代碼區塊上



```
.text:080485E5                 pop     ebx
.text:080485E6                 pop     esi
.text:080485E7                 pop     edi
.text:080485E8                 pop     ebp
.text:080485E9                 retn
```



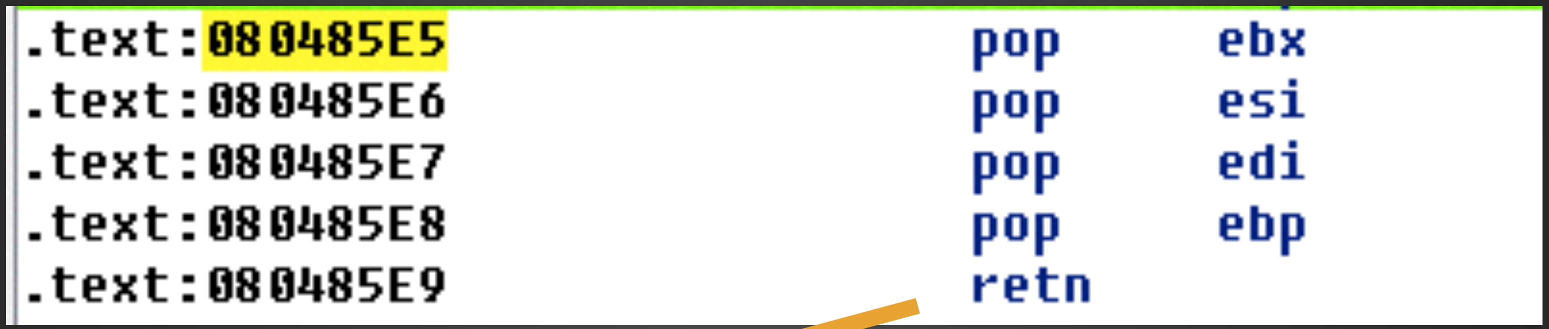
```
.text:08048581                 mov     ebp, esp
.text:08048583                 pop     ebp
.text:08048584                 retn
```



```
.text:080484E7                 call    eax
.text:080484E9                 leave
.text:080484EA                 retn
```

ROP

- Buffer Overflow AAAA… + \xE5\x85\x04\x08

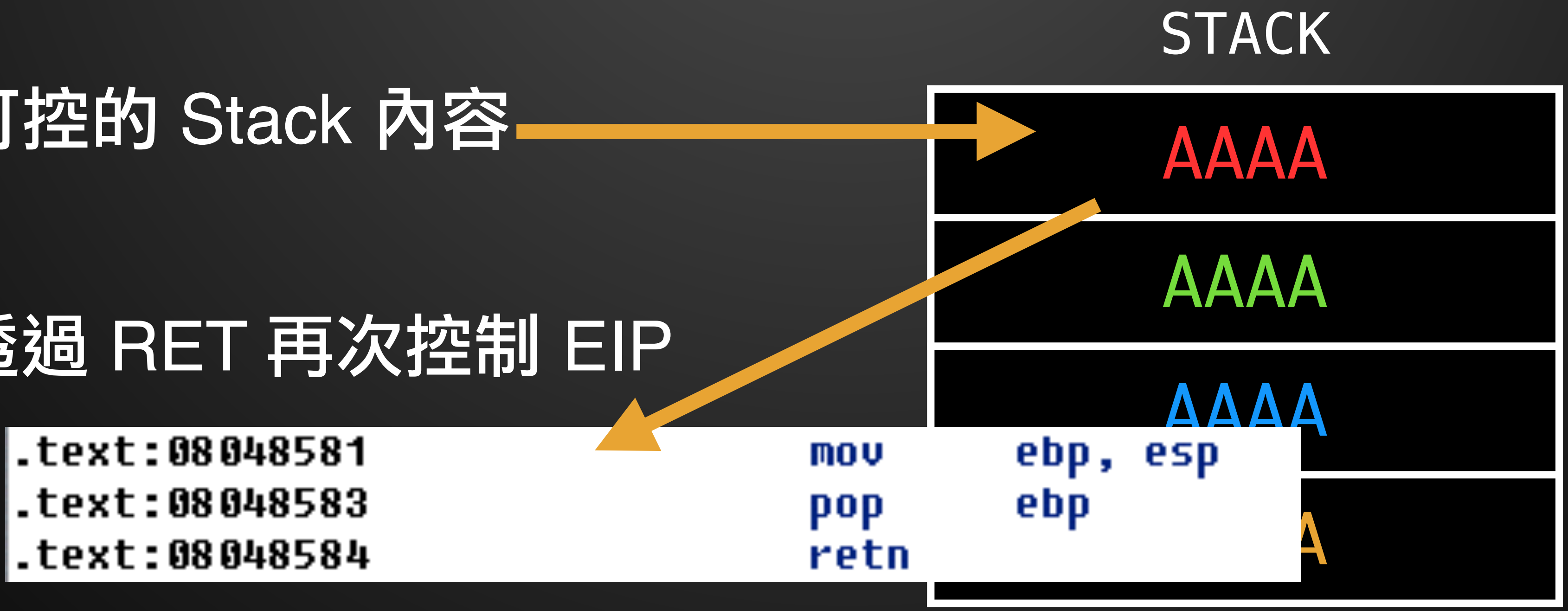


```
.text:080485E5                 pop     ebx
.text:080485E6                 pop     esi
.text:080485E7                 pop     edi
.text:080485E8                 pop     ebp
.text:080485E9                 retn
```

- RET = POP EIP

- 可控的 Stack 內容

- 透過 RET 再次控制 EIP



```
.text:08048581                 mov     ebp, esp
.text:08048583                 pop     ebp
.text:08048584                 retn
```

一直 ret

一直 ret

一直 ret

一直 ret

一直 ret

一直 ret

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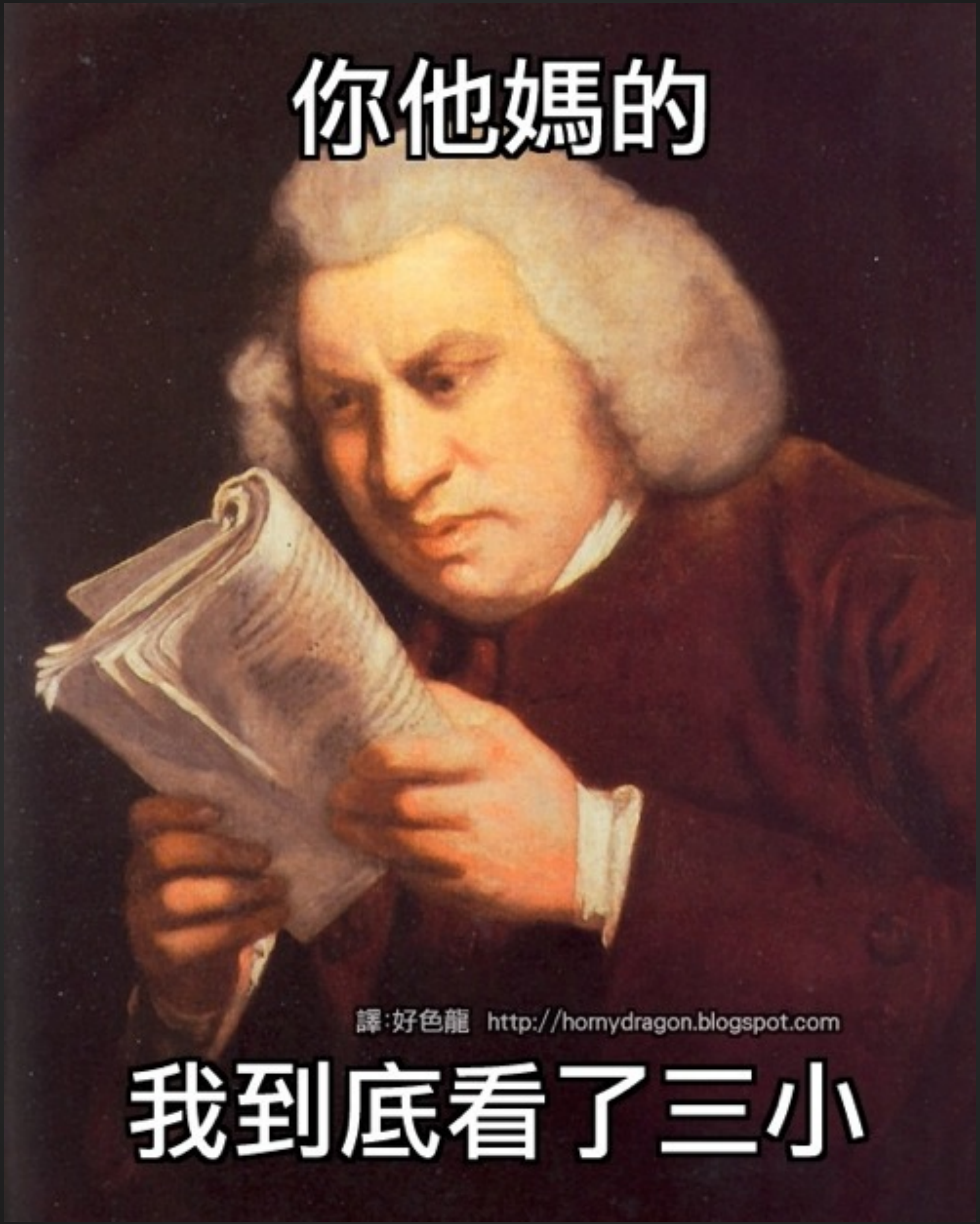
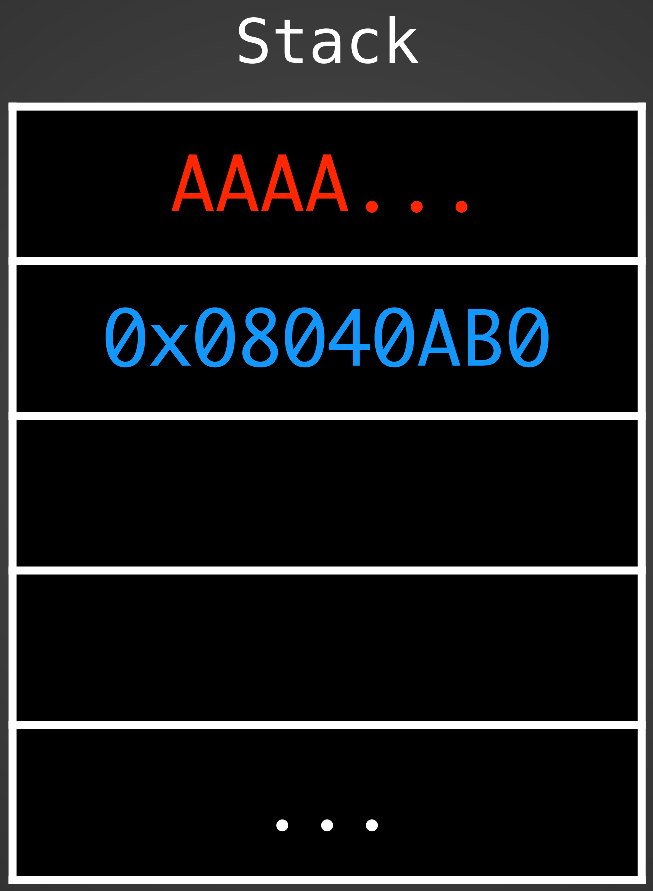
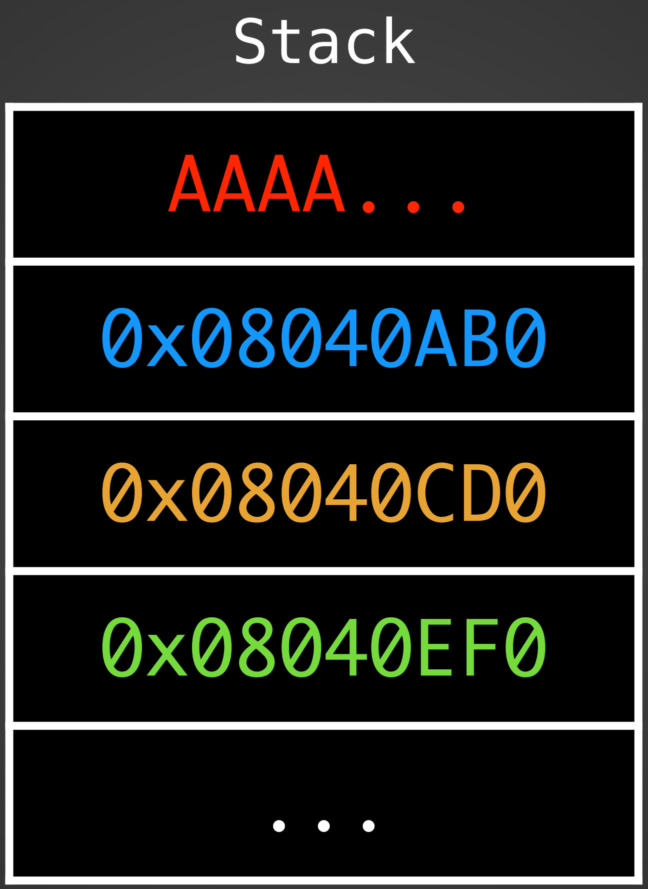

你他媽的
譯:好色龍 http://hornydragon.blogspot.com
我到底看了三小

Buffer Overflow to ROP



Overwrite return address

Buffer Overflow to ROP



Stack

AAAA...

0x08040AB0

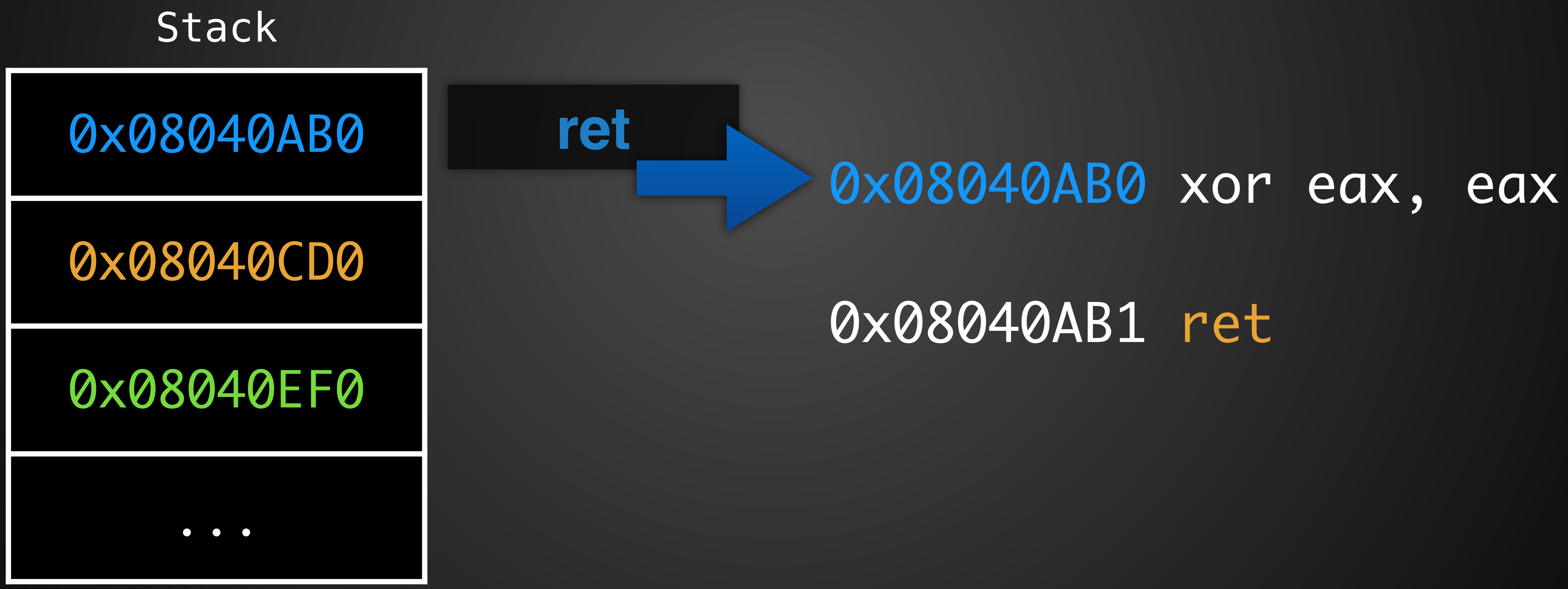
0x08040CD0

0x08040EF0

...

Append Addresses

ROP Chain



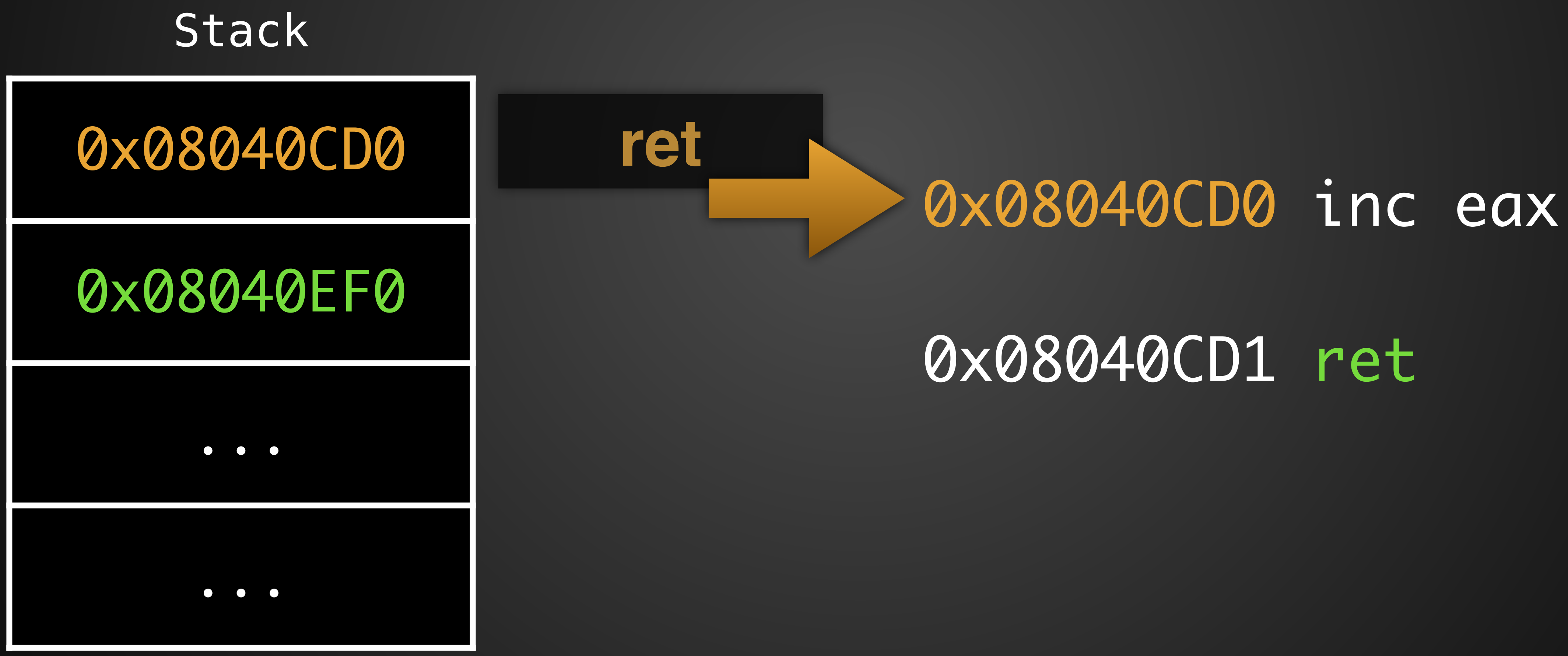
Stack

```
0x08040AB0
0x08040CD0
0x08040EF0
. . .
```

ret

```
0x08040AB0 xor eax, eax

0x08040AB1 ret
```

ROP Chain



Stack

0x08040CD0

0x08040EF0

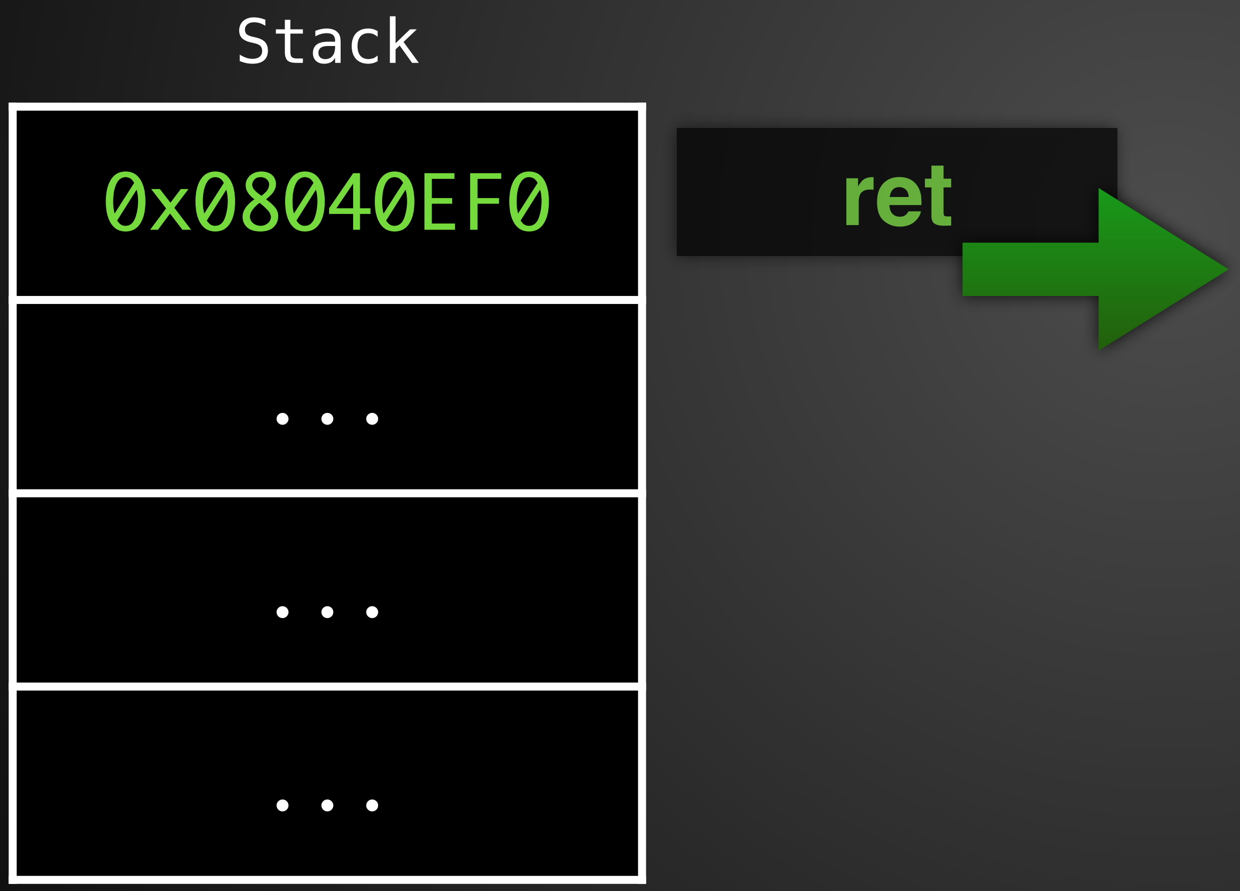
...

...

ret

```
0x08040CD0 inc eax

0x08040CD1 ret
```

ROP Chain

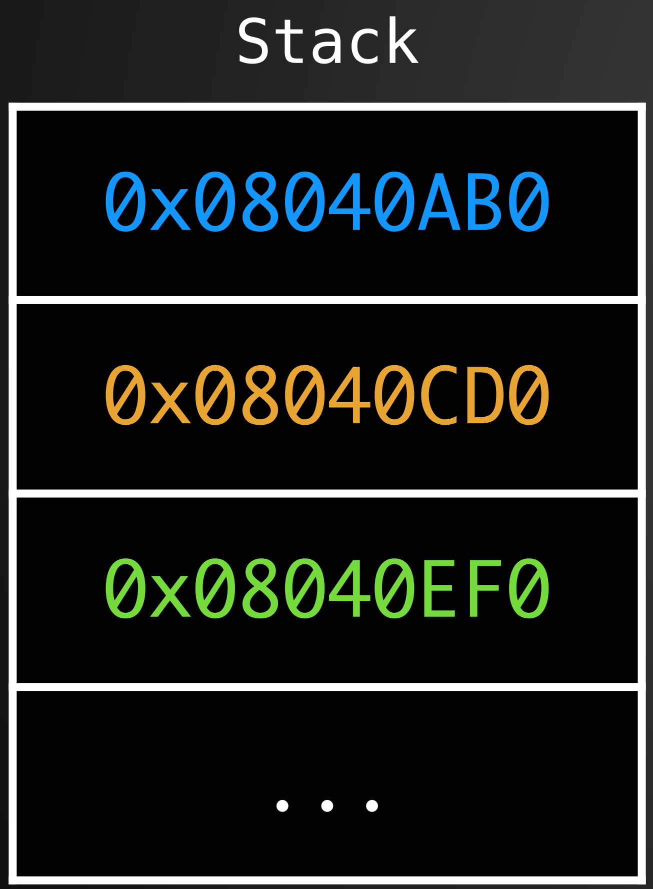


Stack

0x08040EF0
...
...
...

```
0x08040EF0 mov ecx, eax

0x08040EF2 ret
```

ROP Chain


Stack

0x08040AB0

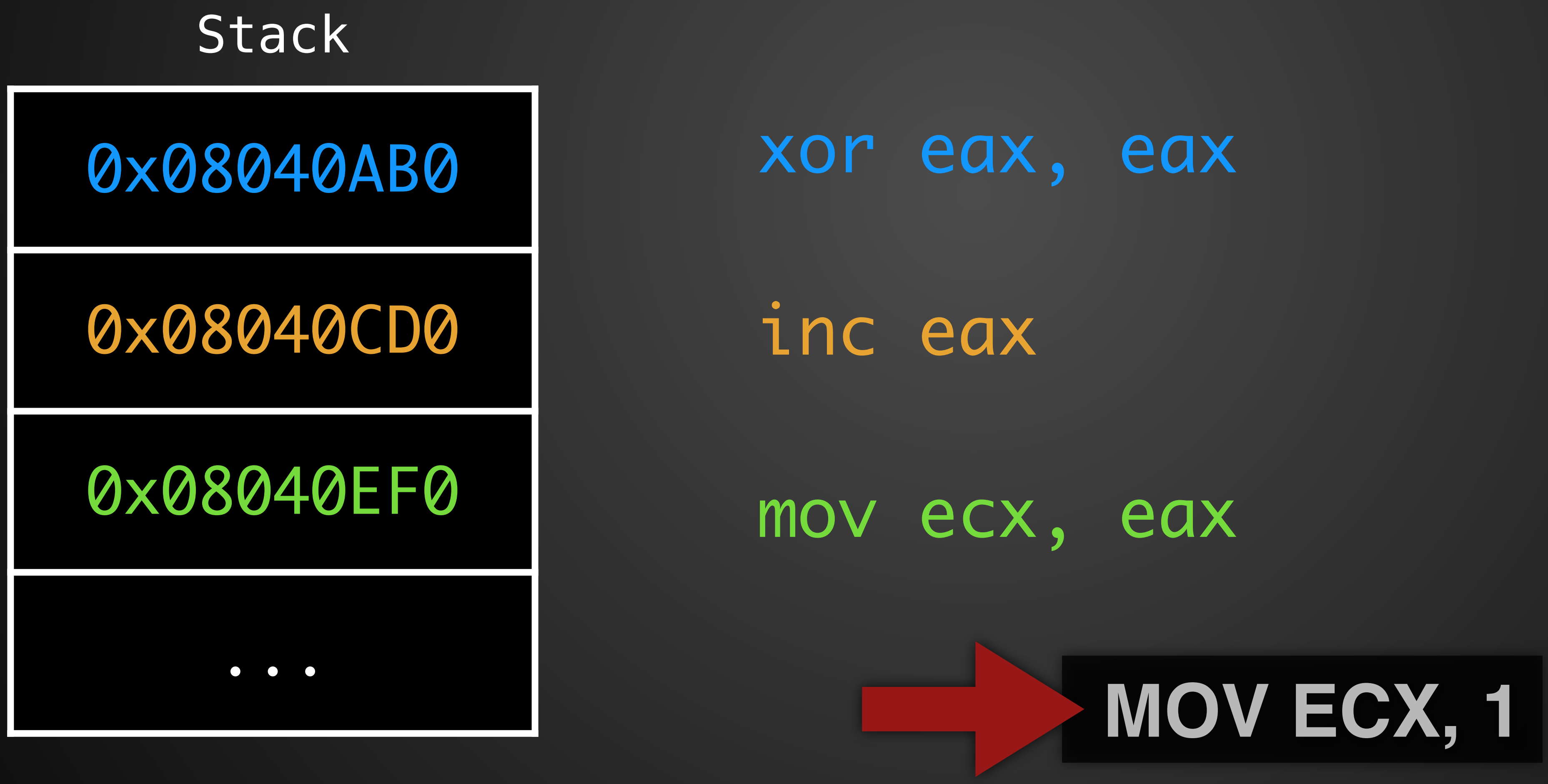
0x08040CD0

0x08040EF0

...

```
0x08040AB0 xor eax, eax
           ret

0x08040CD0 inc eax
           ret

0x08040EF0 mov ecx, eax
           ret
```

ROP Chain



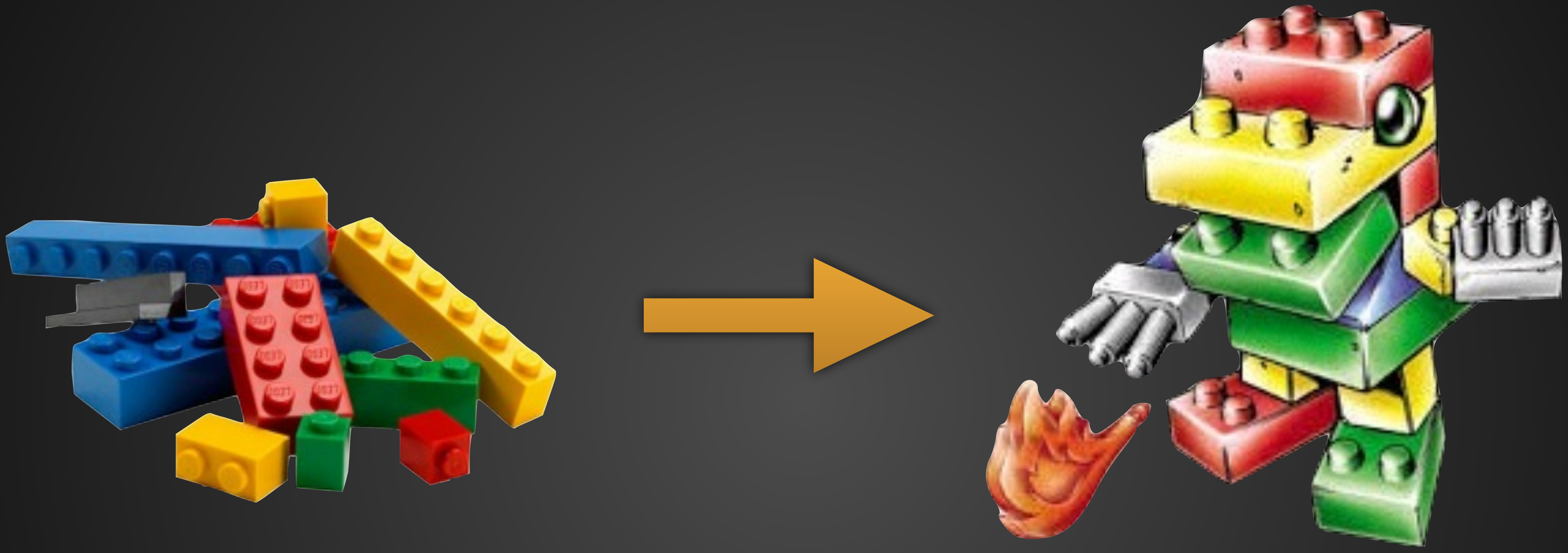
Stack

0x08040AB0
0x08040CD0
0x08040EF0
. . .

```
xor eax, eax

inc eax

mov ecx, eax
```

MOV ECX, 1

ROP Chain

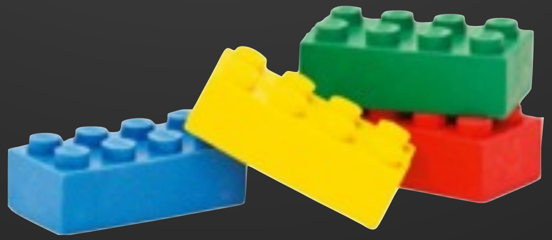


Gadgets

Payload

ROP

- Gadgets
  - 以 ret 結尾的指令序列
    - pop ebx + pop eax + ret
    - add eax, ebx + xor eax, ecx + ret
  - call eax / jmp eax
  - int 0x80



Operations

- 讀寫 Register / Memory 資料:
  - pop eax + pop ecx + ret
  - mov [eax], ecx + ret
- 調用 system call:
  - int 0x80
- 呼叫函數:
  - ret2libc + pop xxx + ret

- 算數 / 邏輯運算:
  - add eax, ecx + ret
  - xor eax, ecx + ret
  - and eax, ecx + ret
  - shr … + ret
- 修改 esp
  - leave + ret
- 條件跳轉

Operations

- 讀寫 Register / Memory 資料:
  - pop eax + pop ecx + ret
  - mov [eax], ecx + ret
- 調用 system call:
  - int 0x80
- 呼叫函數:
  - ret2libc + pop xxx + ret
- 算數 / 邏輯運算:
  - add eax, ecx + ret
  - xor eax, ecx + ret
  - and eax, ecx + ret
  - …
- 修改 esp
  - leave + ret
- 條件跳轉

Write To Register

- 寫入 Register
  - pop reg + ret
  - pop reg + pop reg + ret
  - pop reg + pop reg + pop reg + ret
  - …

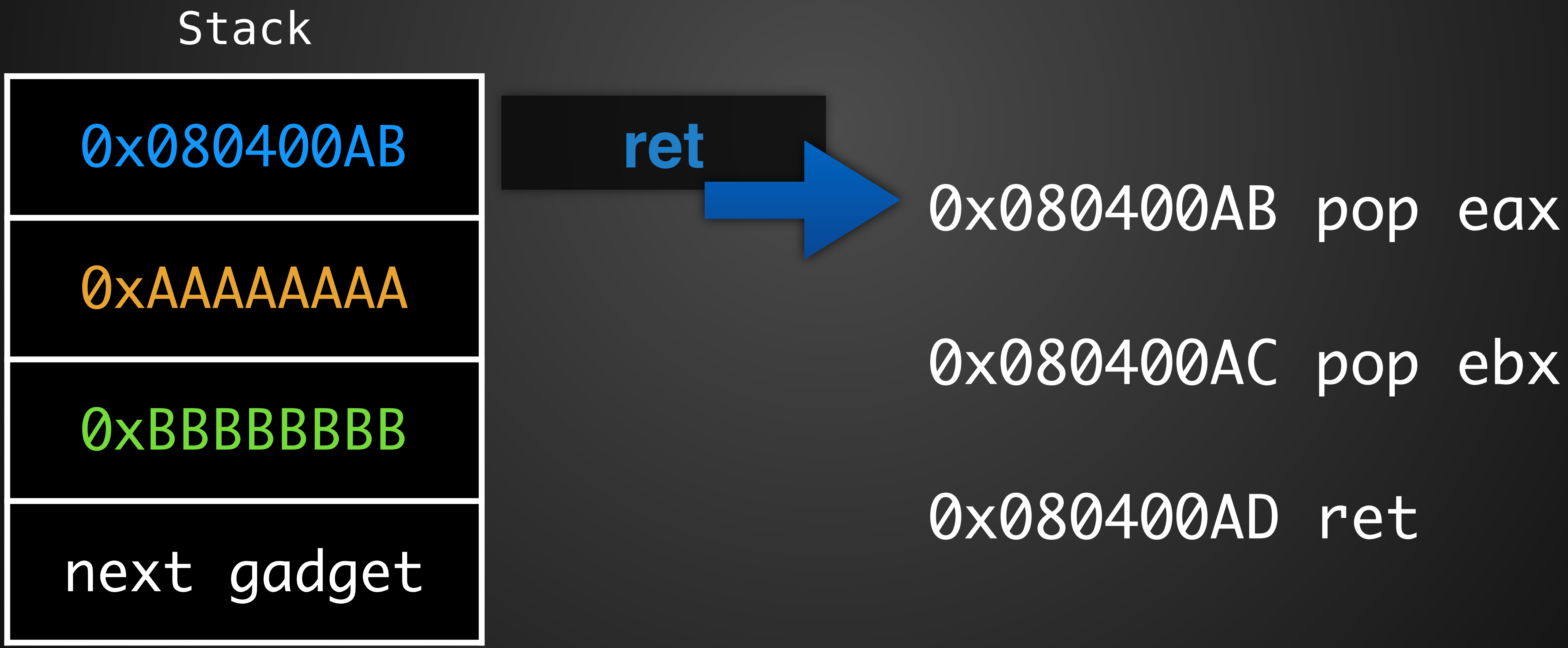
Write To Register

- 寫入 eax 及 ebx

```
pop eax

pop ebx

ret
```

Write To Register

- 寫入 eax 及 ebx



Stack

0x080400AB

0xAAAAAAAA

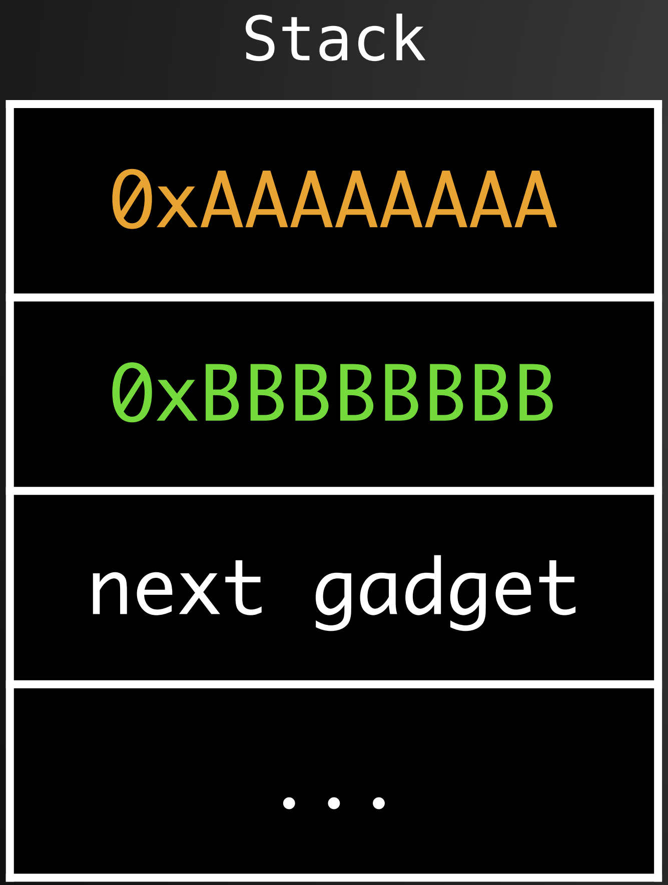
0xBBBBBBBB

next gadget

```
0x080400AB pop eax

0x080400AC pop ebx

0x080400AD ret
```

Write To Register

- 寫入 eax 及 ebx



Stack

0xAAAAAAAA

0xBBBBBBBB

next gadget

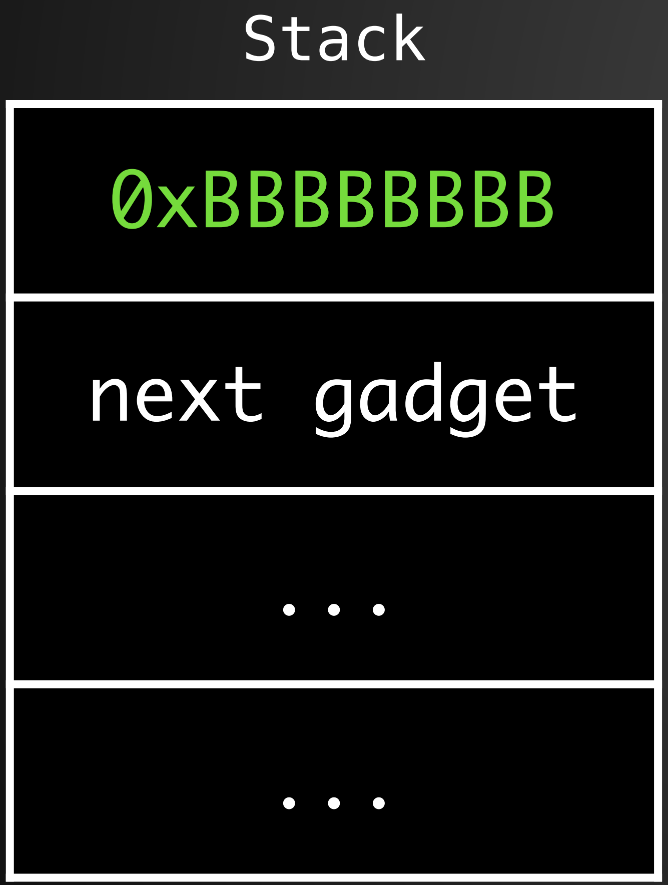
...

```
0x080400AB pop eax
0x080400AC pop ebx
0x080400AD ret
```

Write To Register

- 寫入 eax 及 ebx

eax = 0xAAAAAAAA



Stack

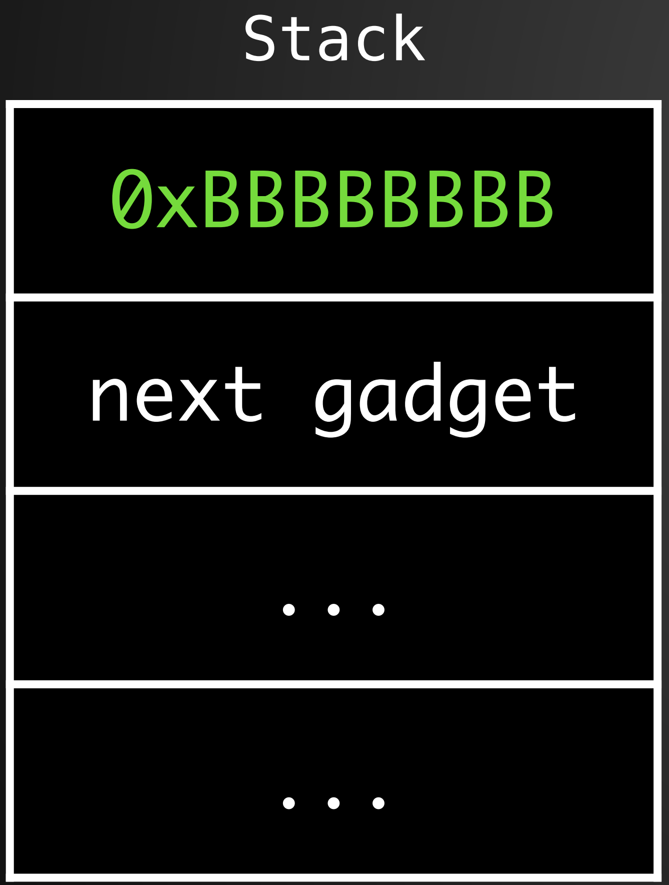
0xBBBBBBBB
next gadget
...
...

```
0x080400AB pop eax

0x080400AC pop ebx

0x080400AD ret
```

Write To Register

- 寫入 eax 及 ebx

eax = 0xAAAAAAAA



Stack

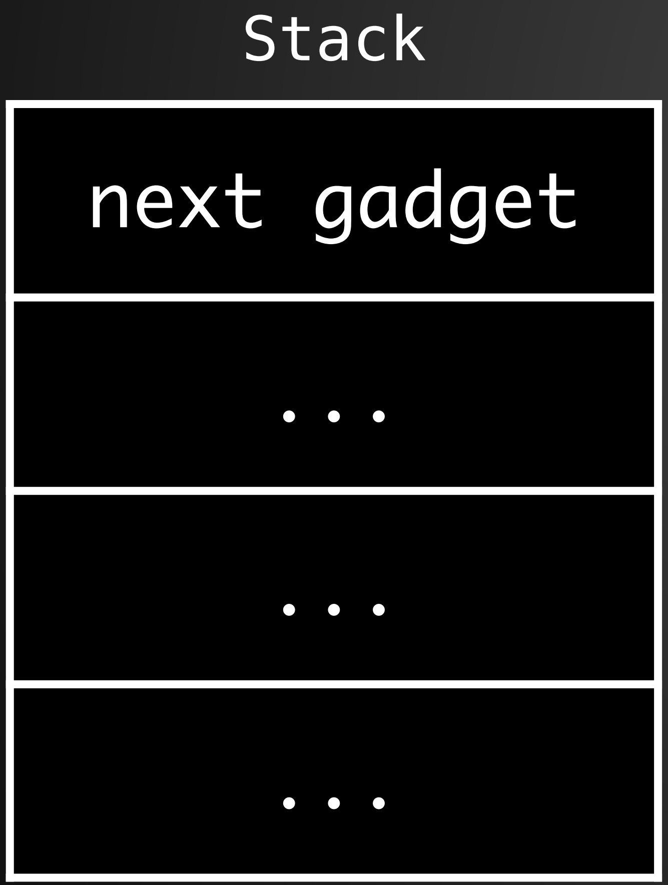
0xBBBBBBBB
next gadget
...
...

```
0x080400AB pop eax

0x080400AC pop ebx

0x080400AD ret
```

Write To Register

- 寫入 eax 及 ebx

eax = 0xAAAAAAAA
ebx = 0xBBBBBBBB


Stack

next gadget

...

...

...

```
0x080400AB pop eax

0x080400AC pop ebx

0x080400AD ret
```

Write To Memory

- 寫入 Memory
  - mov [reg], reg
  - mov [reg+xx], reg

Write To Memory

- 寫入 Memory

```
eax = 0xAAAAAAAA
ecx = 0xBBBBBBBB
```

```
mov [ecx], eax

ret
```

```
*0xBBBBBBBB = 0xAAAAAAAA
```

System Call

- System Call in ROP
  - sys_execve(“/bin/sh”, NULL, NULL);

System Call

- sys_execve(“/bin/sh”, NULL, NULL)
  - 尋找 int 0x80 指令
  - 寫入 “/bin/sh” 到記憶體
    - mov [reg], reg
  - 設置 register
    - pop reg
    - eax = 11, ebx = &“/bin/sh”, ecx = 0, edx = 0

DEMO

execve in ROP

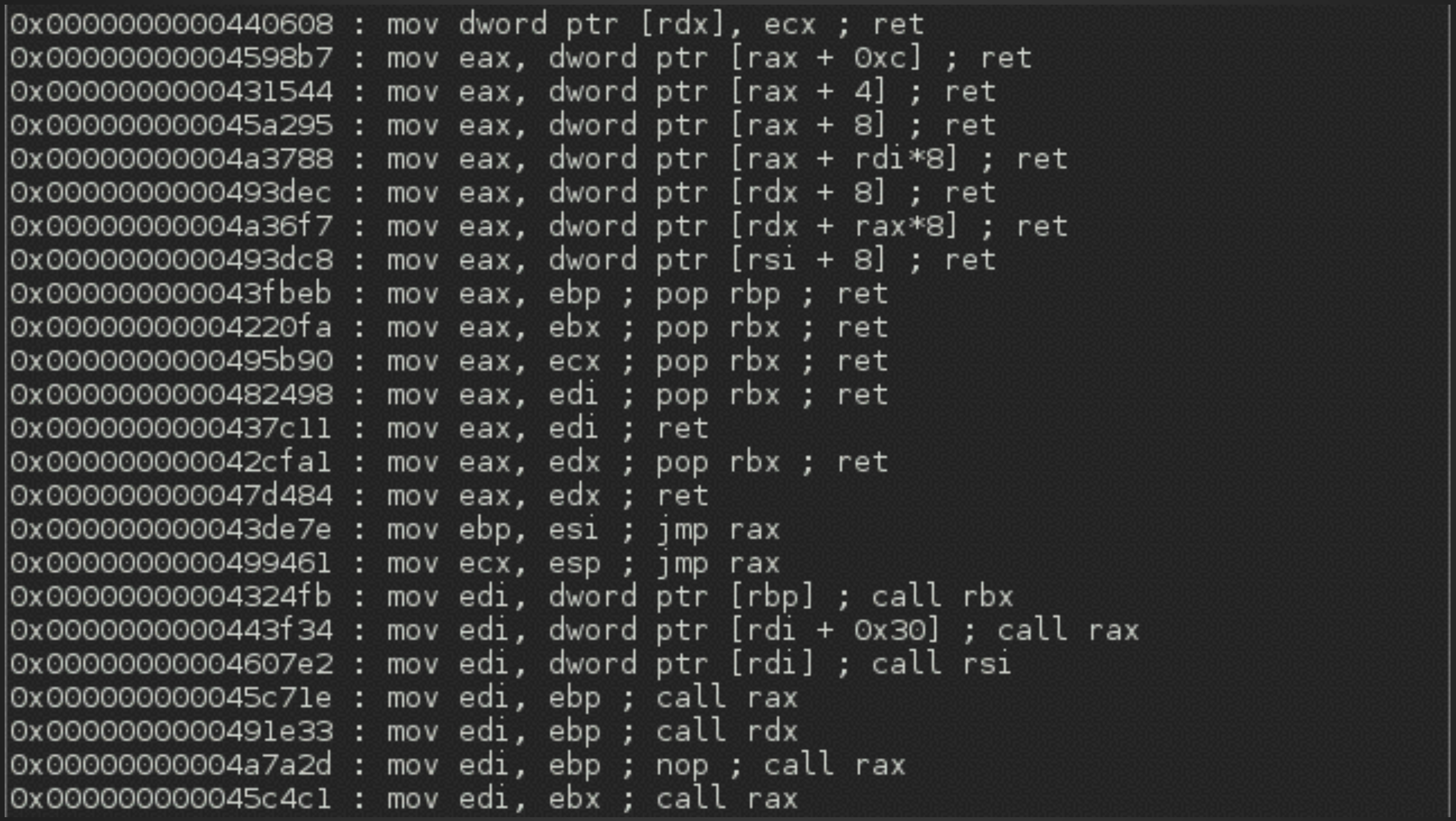
那麼……在那裡才能找得到呢？
Where is it sold?

ROPGadget

- 以 ROPGadget 尋找 Gadget
  - ropgadget --binary ./file
  - ropgadget --binary ./file --opcode
  - ropgadget --binary ./file —ropchain
  - pip install ropgadget

https://github.com/JonathanSalwan/ROPgadget

ROPGadget



```
0x0000000000440608 : mov dword ptr [rdx], ecx ; ret
0x00000000004598b7 : mov eax, dword ptr [rax + 0xc] ; ret
0x0000000000431544 : mov eax, dword ptr [rax + 4] ; ret
0x000000000045a295 : mov eax, dword ptr [rax + 8] ; ret
0x00000000004a3788 : mov eax, dword ptr [rax + rdi*8] ; ret
0x0000000000493dec : mov eax, dword ptr [rdx + 8] ; ret
0x00000000004a36f7 : mov eax, dword ptr [rdx + rax*8] ; ret
0x0000000000493dc8 : mov eax, dword ptr [rsi + 8] ; ret
0x000000000043fbeb : mov eax, ebp ; pop rbp ; ret
0x00000000004220fa : mov eax, ebx ; pop rbx ; ret
0x0000000000495b90 : mov eax, ecx ; pop rbx ; ret
0x0000000000482498 : mov eax, edi ; pop rbx ; ret
0x0000000000437c11 : mov eax, edi ; ret
0x000000000042cfa1 : mov eax, edx ; pop rbx ; ret
0x000000000047d484 : mov eax, edx ; ret
0x000000000043de7e : mov ebp, esi ; jmp rax
0x0000000000499461 : mov ecx, esp ; jmp rax
0x00000000004324fb : mov edi, dword ptr [rbp] ; call rbx
0x0000000000443f34 : mov edi, dword ptr [rdi + 0x30] ; call rax
0x00000000004607e2 : mov edi, dword ptr [rdi] ; call rsi
0x000000000045c71e : mov edi, ebp ; call rax
0x0000000000491e33 : mov edi, ebp ; call rdx
0x00000000004a7a2d : mov edi, ebp ; nop ; call rax
0x000000000045c4c1 : mov edi, ebx ; call rax
```

https://github.com/JonathanSalwan/ROPgadget

Conclusion

- ROP Payload
  - Payload 撰寫難度較高 / 重複利用性低
  - Bypass ASLR / DEP
  - 結合其他攻擊手段
    - Load Shellcode
    - ret2libc

More

- Sigreturn-Oriented Programming (SROP)
  - 利用 sigreturn system call
  - 配合假造的 frame 控制 registers
- Blind ROP (BROP)
  - 在不知道程式內容的情況下實現 ROP Exploit

Q & A

RET