SIGPwny

General SP2026 • 2026-02-05

# Pwn III: ROP

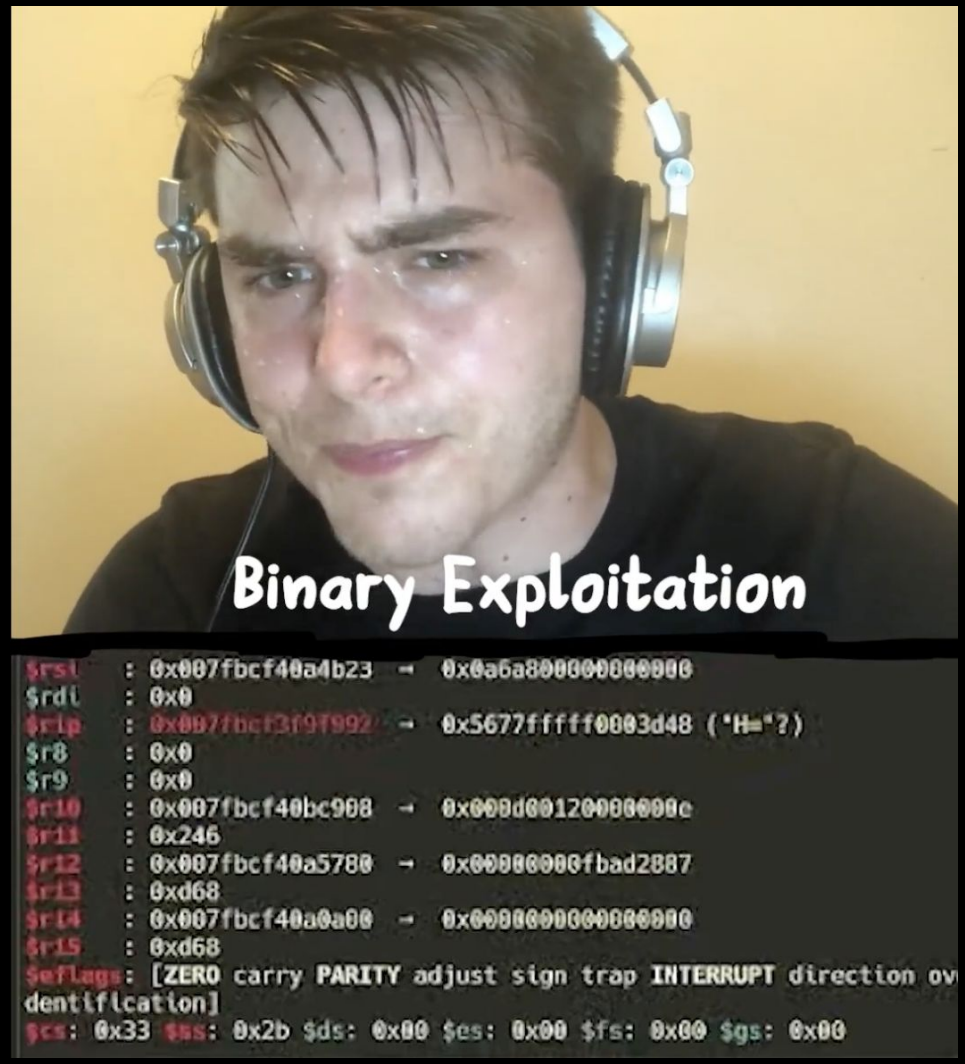
Tyler Mercado

# Announcements

- LA CTF 2026 tomorrow at 7:45 PM!
  - Our first CTF of the semester and one of the best of the entire year!
  - We will meet in person in Siebel CS 2406

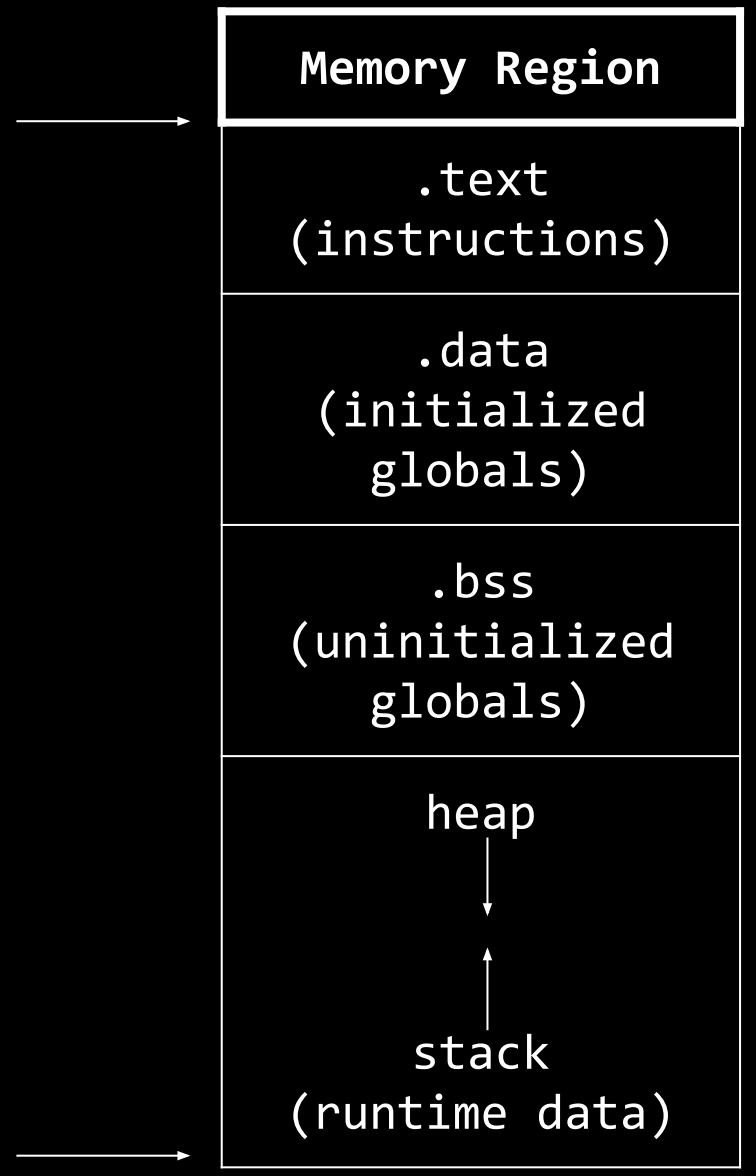
ctf.sigpwny.com

# sigpwny{r3turn_2_l1bc_m4st3r}



# Review

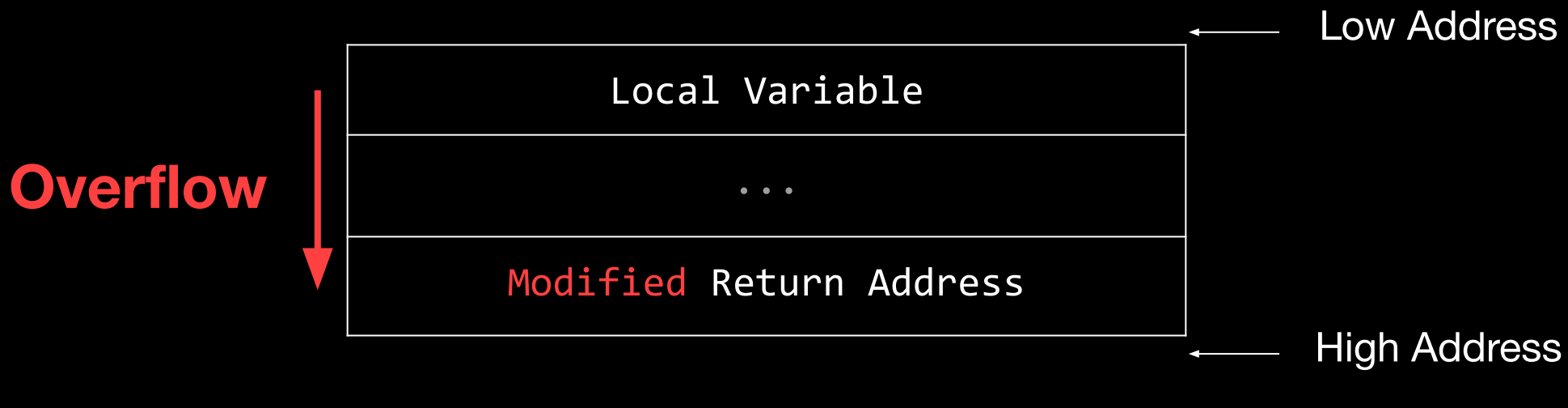
Bottom of memory
(0x0000000000000000)




Top of memory
(0xFFFFFFFFFFFFFFFF)

# Review: PWN I

- Buffers and variables are stored on the stack, at a fixed size, contiguous in memory.
- Unsafe functions can write more data than the buffer can store, leading to Buffer Overflow Vulnerabilities.
- We can control the program flow by overflowing the buffer (`local variable`) to overwrite the `return address`.

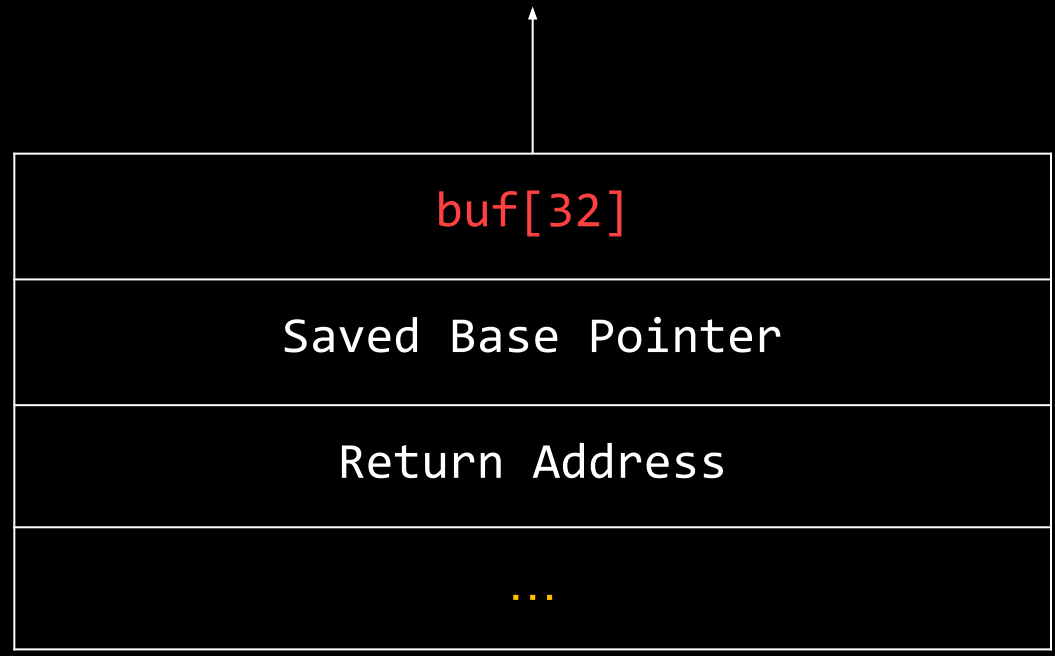


# “ret2win”

```
void win() { // at 0x4011b3
    // prints flag
}

int vuln() {
    puts("Say Something!\n");
    char buf[32];
    gets(buf);
    return 0;
}

int main() {
    vuln();
}
```

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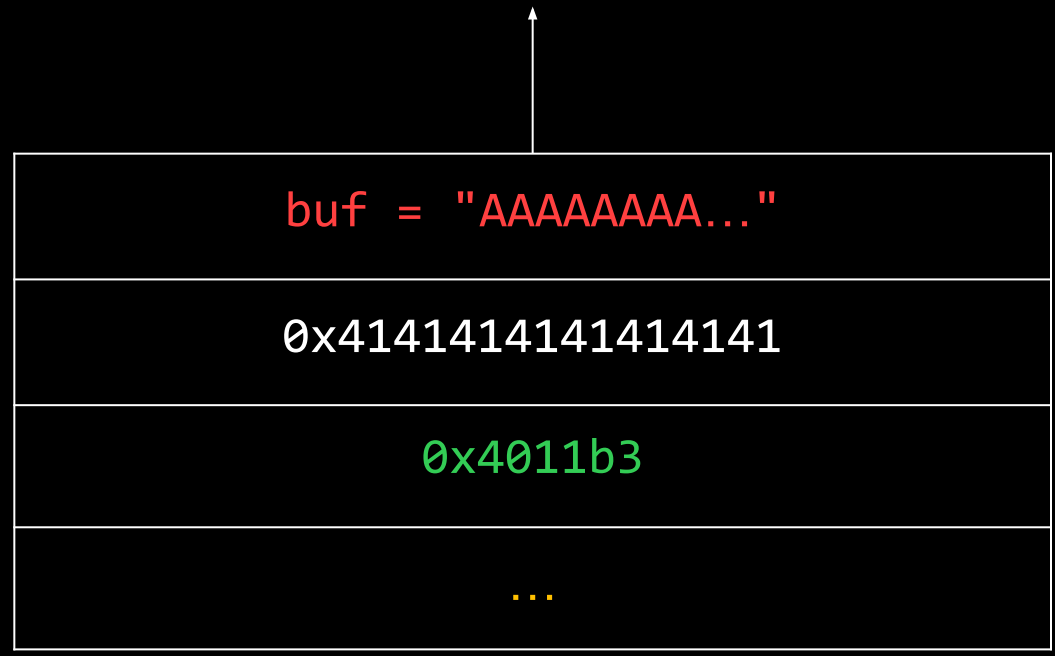


# “ret2shellcode”

```
int vuln() {
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    gets(buf);
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}

int main() {
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}
```

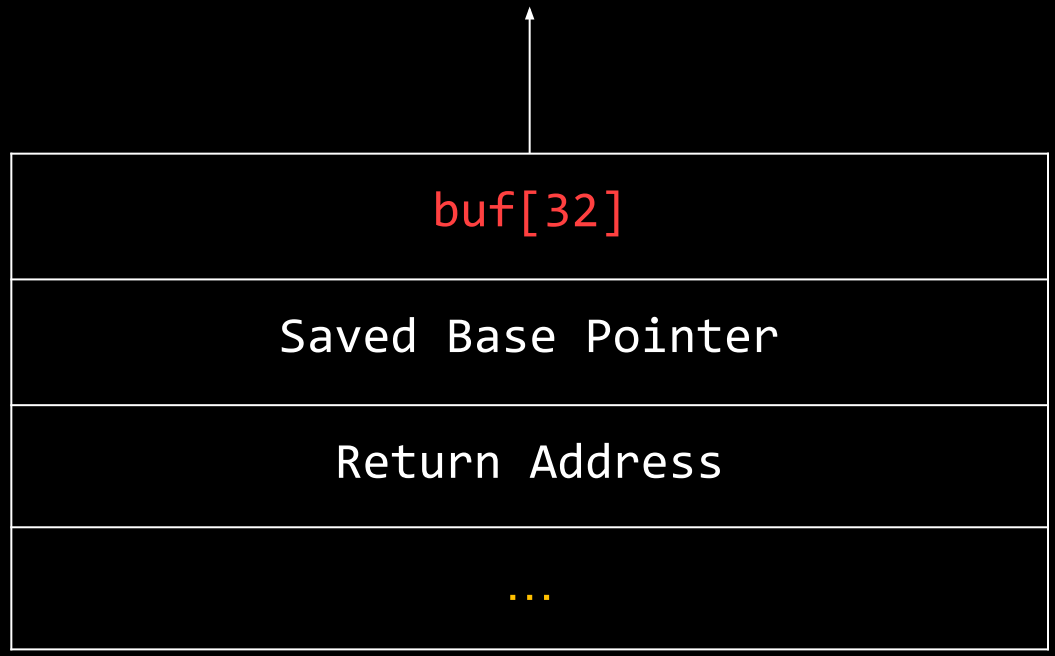


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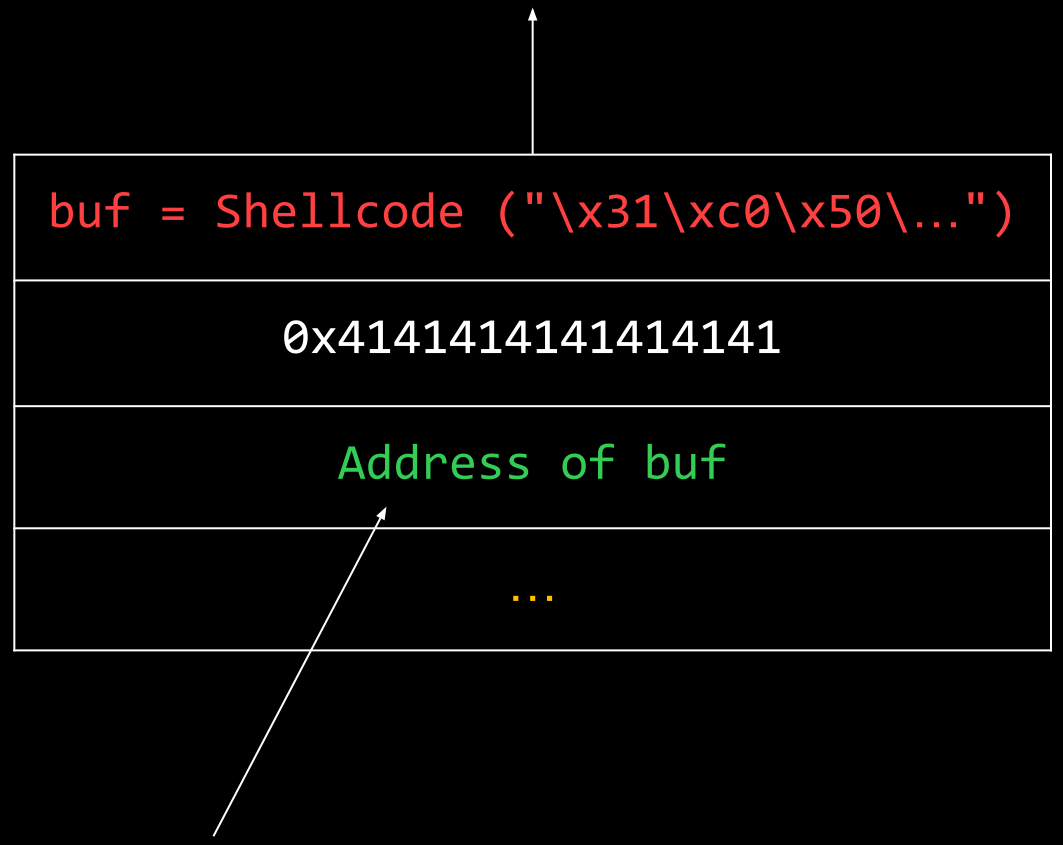
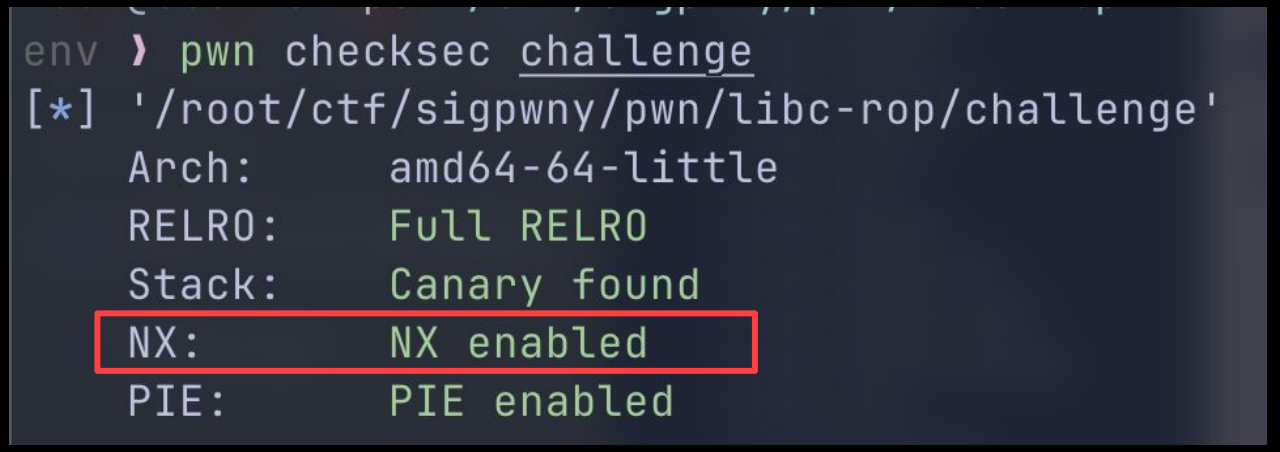



vuln() now returns to the
shellcode we put on the stack

# Mitigation

## NX

- Stack is **not** executable
- W^X: Region of memory can't be both *writable* and *executable*
  - Stack and Heap: **RW**
  - .text (Code): **RX**
- No more shellcode (ノ°益°)ノ




# Mitigation

**NX**

- Stack is **not** executable
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```
env ❱ pwn checksec challenge
[*] '/root/ctf/sigpwny/pwn/libc-rop/challenge'
    Arch:     amd64-64-little
    RELRO:    Full RELRO
    Stack:    Canary found
    NX:       NX enabled
    PIE:      PIE enabled
```

How do we bypass this?

# Code Reuse!

- **R**eturn **O**riented **P**rogramming (**ROP**)
  - Idea: We can interpret arbitrary bytes in program data as instructions
  - Chain small pieces of code together with the `ret` instruction
  - (See https://langsec.org/papers/Bratus.pdf for a history lesson)

- **Gadgets!**
  - Little pieces of code that we chain together (ROP chain) to do what we want
  - End with a `ret` instruction
  - These are already in `.text` - don't have to worry about NX!

# ROP - High Level

Gadget 1
A = A + 1

Gadget 2
A = 0

Gadget 3
B = A

Gadget 4
C = B

Execute a series of gadgets to achieve:

B = 3

# ROP - High Level

Gadget 1
A = A + 1

Gadget 2
A = 0

Gadget 3
B = A

Gadget 4
C = B

B = 3

- Gadget 2
- Gadget 1
- Gadget 1
- Gadget 1
- Gadget 3

# ROP - Slightly Less High Level

Hint:
swap rax and
rbx

Gadget 1
```
xchg rax, rbx
ret
```

Hint:
rbx = 0

Gadget 2
```
nop
xor rbx, rbx
ret
```

Hint:
rcx = 0
rax = rax + 1

Gadget 3
```
xor rcx, rcx
add rax, 1
ret
```

Hint:
rax = rax - rbx

Gadget 4
```
sub rax, rbx
nop
ret
```

Using a sequence of gadgets, can we achieve:

rbx = 3

(ignore the `ret` for now!)

# ROP - Slightly Less High Level

Hint: swap rax and rbx

Gadget 1
```
xchg rax, rbx
ret
```

Hint: rbx = 0

Gadget 2
```
nop
xor rbx, rbx
ret
```

Hint: rcx = 0 rax = rax + 1

Gadget 3
```
xor rcx, rcx
add rax, 1
ret
```

Hint: rax = rax - rbx

Gadget 4
```
sub rax, rbx
nop
ret
```

Using a sequence of gadgets, can we achieve:

rbx = 3

(ignore the `ret` for now!)

| Gadget 2 (set rbx to 0) |
| --- |
| Gadget 1 (set rax = rbx) |
| Gadget 3 (rax = 1) |
| Gadget 3 (rax = 2) |
| Gadget 3 (rax = 3) |
| Gadget 1 (set rbx = rax) |

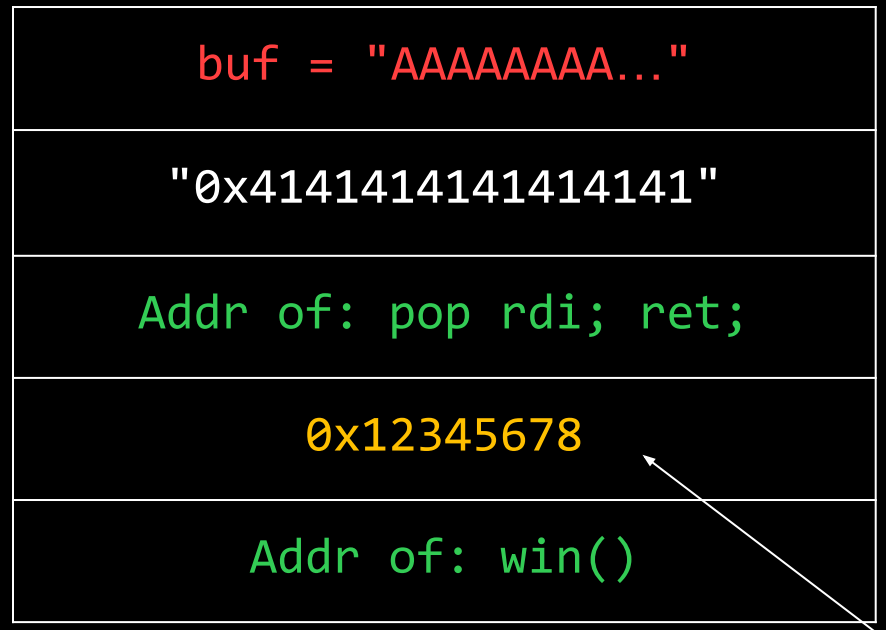
# New Exploit

| buf[32] |
| --- |
| Saved Base Pointer |
| Return Address |
| ... |



| buf = "AAAAAAAA..." |
| --- |
| 0x4141414141414141 |
| GADGET 1 ADDR |
| GADGET 2 ADDR |
| GADGET 3 ADDR |

# Example




```
void win(int a) {
    if (a == 0x12345678) {
        // print flag
    }
}
```

- rdi, rsi, rdx, rcx, r8, r9 - argument registers for x86_64 (in that order)
  - Useful for one of the ROP challenges!
- In 32 bit, arguments are on the stack after the return address

`pop rdi` causes this to go into the rdi register

# ROP in practice

- Usually, there's no win function, so we need to do something else
  - Most of the time, we'll try to pop a shell (run `/bin/sh`)

- Find and order gadgets to call `execve("/bin/sh", NULL, NULL)` or `system("/bin/sh")`
  - Need gadgets to set up register(s)
  - Need registers to call `syscall`

# Finding and Ordering Gadgets

- Can do it yourself (highly recommended, it's fun!)
  - `objdump -d -M intel myprogram | grep ret -B 5`
- ROPGadget
  - List gadgets: `./ROPGadget.py --binary chal`
  - Create ropchain: `./ROPGadget.py --ropchain --binary chal`
- Pwntools (rop.rop) and Pwndbg (Pwndbg ROP) can help too!
- one_gadget
  - Gadget that pops a shell immediately

# Libc

- Libc = giant file full of standard library functions
  - linked near the top of memory: `0x7ff…`
- The challenge binary usually doesn't have a lot of useful gadgets… but libc does!

- Often, the goal is to leak a libc address, calculate the libc base address, and then ROP with libc gadgets
  - This can help: Libc Database

```
Unique gadgets found: 101496
```

# ROP Mitigations

- PIE (Position Independent Executable)
  - Randomizes binary base address: functions are at different addresses every time!
- ASLR (Address Space Layout Randomization)
  - Like PIE - randomizes locations of memory regions (stack, heap, etc.)
  - Libc location also gets randomized!

- Base addresses change, but offsets stay the same
  - Only need to leak one binary address (or one libc address for libc)

# Pwntools example

```
exe = ELF("./main")
libc = ELF("./libc-2.27.so")

libc_leak = # acquire the address of libc 'func_name' from binary (e.g. puts)
libc.address = libc_leak - libc.symbols["func_name"] - offset
POP_RDI = (rop.find_gadget(['pop rdi', 'ret']))[0] + libc.address
RET = (rop.find_gadget(['ret']))[0] + libc.address
SYSTEM = libc.sym["system"]
payload += b'A'*8 # buffer
payload += p64(RET) + p64(POP_RDI) + p64(BIN_SH) + p64(SYSTEM) # ROP chain
```

To make the stack aligned to 16 bytes

# Further Reading

- Shadow stack: keep another read-only copy of the stack in a hardware register and compare
  - Merged into Linux 6.6 in 2023 (over *15 years after* the first ROP paper!)
- *Sig*return-oriented programming (SROP): Use a signal handler to set registers

# Resources

pwntools - Essential for scripting your exploit
pwndbg - gdb but good
ROPGadget - find gadgets/generate ropchains
one_gadget - find one gadgets
Libc Database Search - find libc offsets
ROP Emporium - Beginner oriented practice

# Next Meetings

`2026-02-08` • **This Sunday**

- No meeting!
- Enjoy the Super Bowl!

`2026-02-12` • **Next Thursday**

- Esolangs
- Learn several esoteric languages and how to reverse engineer programs written in them!

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`sigpwny{r3turn_2_l1bc_m4st3r}`

**Meeting content can be found at sigpwny.com/meetings.**

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