Lab #3. ROP

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General Information

- **Check "Lab #3" in *Assignment* tab of *Cyber Campus***
  - Skeleton code (`Lab3.tgz`) is attached in the post
  - Deadline: **11/14** Tuesday 23:59
  - Submission will be accepted in that post, too
  - Late submission deadline: **11/16** Thursday 23:59 **(-20% penalty)**
  - Delay penalty is applied uniformly **(not problem by problem)**
- **Please read the instructions in this slide carefully**
  - This slide is step-by-step tutorial for the lab
  - It also contains important submission guidelines
    - If you do not follow the guidelines, you will get penalty

Remind: Cheating Policy

- **Cheating (code copy) is strictly forbidden in this course**
  - Read the orientation slide once more
- **Don’t ask for solutions in the online community**
  - TA will regularly monitor the communities
- **Sharing your code with others is as bad as copying**
  - Your cooperation is needed to manage this course successfully
- **Starting from this lab, you must submit a report as well**
  - More instructions are provided at the end of this slide

From now on, I also forbid discussion on the approach

Overall structure is the same

- **Don’t forget to use** cspro**5**.sogang.ac.kr
- **Decompress skeleton code (same directory structure)**
  - **`3-1/ ... 3-4/`**: Problems you have to solve
  - **`check.py`**: Self-grading script
  - **`config`**: Used internally by the self-grading script
- **In this slide, we will focus on how to use the `pwntools` library to write ROP exploit**

```
jason@ubuntu:~$ tar -xzf Lab3.tgz
jason@ubuntu:~$ ls Lab3
3-1  3-2  3-3  3-4  check.py  config
```

Example: Problem 3-1

- **Target program `gadget-exercise1.*` are given**

```
void execv_wrapper(char *progpath) {
  execv(progpath, NULL);
}

void safe(void) {
  printf("Input your message in global buffer: ");
  read(0, global_buf, sizeof(global_buf));
}

void vuln(void) {
  char buf[20];
  printf("Input your message in stack buffer: ");
  read(0, buf, 64);
}
```

Your goal is to execute this function with "**`/bin/sh`**"

And there is a BOF again

About Exec*()

- **In the lecture slide, we talked about `execve()` function**
- **But there are other variants of `execve()`, too**
  - Ex) **`execv()`**, **`execl()`**, **`execle()`**
  - Each has different function prototype (for more details, read the manual by typing "**`man execve`**")
  - For ROP, functions with less arguments are preferred

```
// execv() takes in command-line args as a vector (array)
char *argv[] = { "/bin/ls", "-a", "-l", NULL };
execv("/bin/ls", argv);

// execl() takes in command-line args as a list
execl("/bin/ls", "/bin/ls", "-a", "-l", NULL);
```

Sometimes, we can pass NULL instead

Finding ROP Gadgets

- **In principle, you must disassemble all the addresses in code section (that can contain instructions)**
- **`Pwntools` offers `ROP()` API that does this automatically**
  - **`print(rop.rdi)`**: Print gadgets that can affect **`%rdi`** register
- **Side-note: You can use `p64()` to write a concise exploit**

```
# Write your exploit logic here.
p = process("./gadget-exercise1.bin")

# The following lines give us "pop rdi; ret" gadget at 0x4007b3.
rop = ROP("./gadget-exercise1.bin")
print(rop.rdi)

rdi_gadget = b"\xb3\x07\x40" + b"\x00" * 5
rdi_gadget = p64(0x4007b3) # Same meaning!
```

Attaching GDB to Process

- **Assume that you wrote the exploit code below**
  - Using gadget to change the value of **`%rdi`** into **`0x4142`**
- **Let's use GDB to check if it works as expected**
  - Previously, we ran **`gdb`** and started a process from there
  - This time, we run the exploit and attach to the ***running process***

```
p = process("./gadget-exercise1.bin")
# Give time to attach GDB.
input("Pause for a while. Enter something to continue: ")

...
print(p.recvuntil(b"stack buffer: "))
rdi_gadget = p64(0x4007b3)
p.send(b"a" * ? + rdi_gadget + p64(0x4142))

# Do not finish the exploit yet
input("Delay the termination...")
```

Note the use of `input()`

Attaching GDB to Process

- **You must open two terminals and switch between them**
  - When running **gdb**, specify the **process id (pid)** to attach

Step 1. Start the exploit (1st terminal)

```
jason@ubuntu:~/Lab3/3-1$ ./exploit-gadget-exercise1.py
[+] Starting local process './gadget-exercise1.bin': pid 3684
Pause for a while. Enter something to continue:
```

Step 2. Attach and set breakpoints (2nd terminal)

```
jason@ubuntu:~/Lab3/3-1$ gdb -q gadget-exercise1.bin 3684
Reading symbols from gadget-exercise1.bin...
(No debugging symbols found in gadget-exercise1.bin)
Attaching to program: /home/jason/Lab3/3-1/gadget-exercise1.bin
(gdb) b * 0x4006f1
Breakpoint 1 at 0x4006f1
(gdb) c
Continuing.
```

Attaching GDB to Process

- **You must open two terminals and switch between them**
  - When running **gdb**, specify the **process id (pid)** to attach

Step 3. Resume the exploit (1st terminal)

```
Pause for a while. Enter something to continue: go
b'Input your message in global buffer: '
b'Input your message in stack buffer: '
Delay the termination...
```

Type this to resume

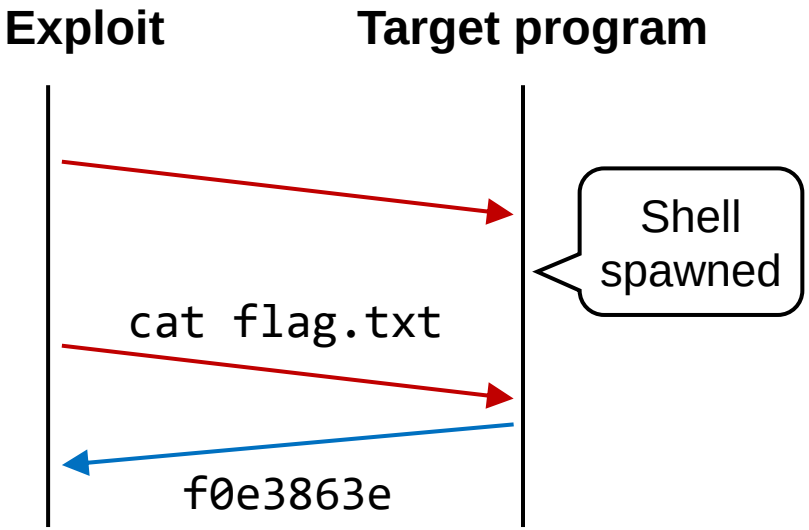
Step 4. Now breakpoint is hit (2nd terminal)

```
Breakpoint 1, 0x00000000004006f1 in vuln ()
(gdb) x/i $rip
=> 0x4006f1 <vuln+45>:  retq
(gdb) x/4xg $rsp
0x7fff337a6788: 0x00000000004007b3      0x0000000000004142
0x7fff337a6798: 0x00007f2337f7e083      0x00007f233818c620
(gdb) si
0x00000000004007b3 in __libc_csu_init ()
```

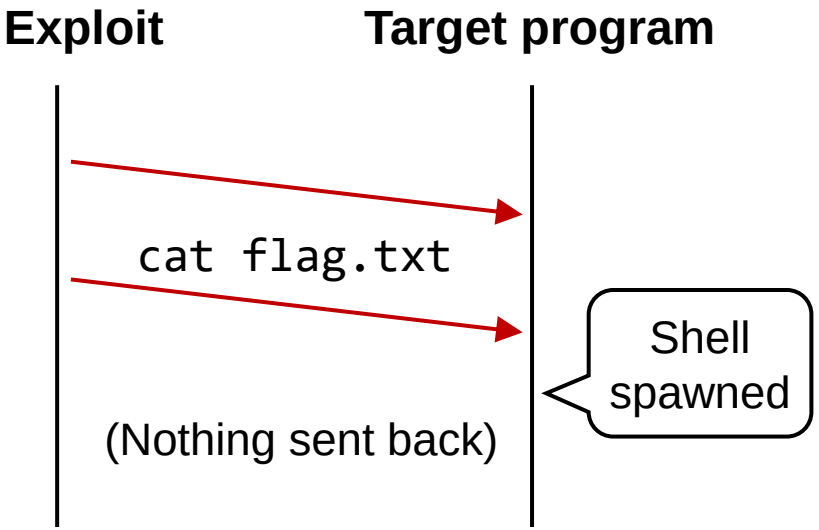
Demonstration

Reading `secret.txt`

- **If you successfully performed an ROP exploit and spawned a shell, then it's time to read `secret.txt`**
  - By typing "**`cat secret.txt`**" and read in the output
  - But if you send this command too early, the sync can go wrong



This is what we want



But this can happen

Reading `secret.txt`

- **If you successfully performed an ROP exploit and spawned a shell, then it's time to read `secret.txt`**
  - By typing "**`cat secret.txt`**" and read in the output
  - But if you send this command too early, the sync can go wrong
  - For reliability of your exploit, please add **`sleep()`** to have a delay before sending "**`cat secret.txt`**"
  - More reliable approach is to use a loop and specify **`timeout`** argument to **`recvline()`**: but this is unnecessarily complex

```
...
p.send(b"a" * ? + rdi_gadget + ?)

sleep(0.2)
p.sendline(b"cat secret.txt")
print(p.recvline())
```

Tip for 3-2

- **For problem 3-2, read the comment on top of the `safe()` function carefully**
  - There is a constraint on **`%rsp`** value to run the function properly
  - Stack alignment issue (you don't need to understand this deeply)

```
/* Note: This function crashes if %rsp value is
 * not "16N + 8" at the entry */
void safe(void) {
  printf("Input your message in global buffer: ");
  read(0, global_buf, sizeof(global_buf));
}
```

Analyzing Function Offset

- **For problem 3-3 and 3-4, you will have to investigate the function offset within the `libc` library**
- **You may use `gdb` to find out offsets, but it will be more convenient to use the `pwntools` API**
  - Then you don't have to hard-code constants in the code

```
# Investigate the libc library.
libc = ELF("/lib/x86_64-linux-gnu/libc.so.6")
write_offset = libc.symbols['write']
read_offset = libc.symbols['read']
execv_offset = libc.symbols['execv']
print("Offset of write() : %s" % hex(write_offset))
print("Offset of read() : %s" % hex(read_offset))
print("Offset of execv() : %s" % hex(execv_offset))
```

Problem Information

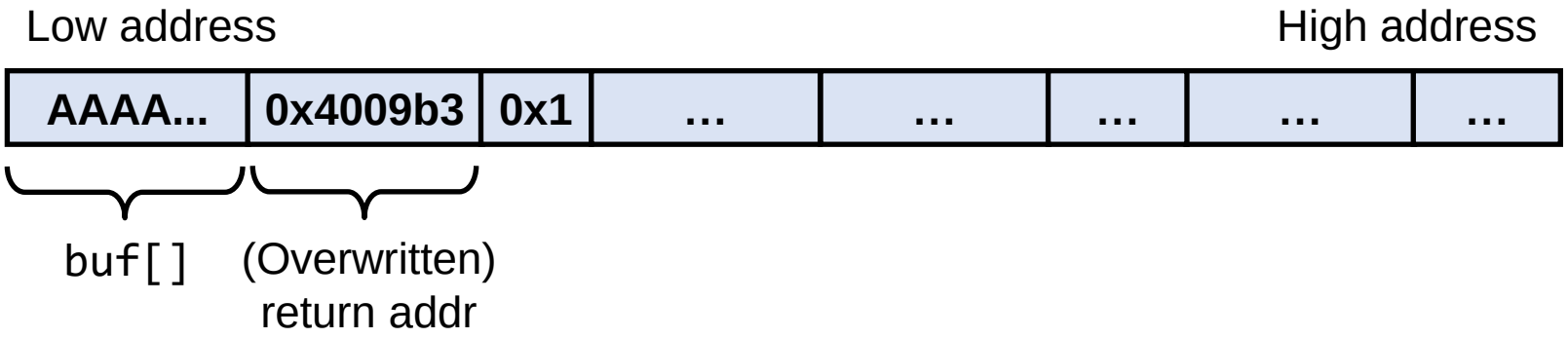
- Four problems, 100pt in total
  - 3-1 (20pt): `gadget-exercise1.bin`
  - 3-2 (20pt): `gadget-exercise2.bin`
  - 3-3 (30pt): `simple.bin`
  - 3-4 (30pt): `echo-twice.bin`
- You'll get the point for each problem if the exploit works
  - No partial point for non-working exploit
- If the report does not clearly explain your exploit code, you will many (even all the) points
  - This time, I will grade your reports strictly

Report Guideline

- **Write report for 3-3 and 3-4 (not required for 3-1 and 3-2)**
  - The role of report is to prove that you solved them on your own
  - If you couldn't solve a problem, don't have to write its report
  - Report will not give you score; it is only used to deduct score
- **This time, I will provide concrete template for the report**
  - Your report **must contain** the materials that I request
  - Otherwise, you will lose points
  - Especially, **do not** explain your exploit **with the memory dump** obtained with **`x/*`** commands of **gdb**

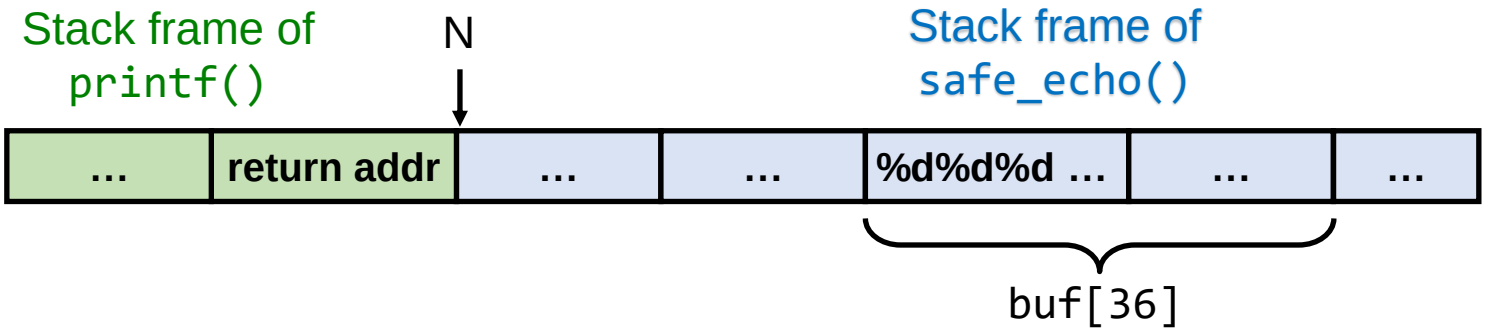
Report Template for 3-3

- **Draw a figure that describes the state of stack after your input is received (like the example below)**
  - Explain the **meaning of each memory** block in the figure
  - Ex) If it's a gadget address, list the instructions in gadget
  - Ex) Also, explain what you are trying to do with those gadgets
  - Ex) If you are calling a function, explain which arguments you are trying to pass, and why you are doing that



Report Template for 3-4

- **For FSB, draw the state of `safe_echo()`'s stack frame**
  - Indicate the offset of each local variable, and explain the assembly instructions you analyzed to figure out the offset
  - If you entered format specifiers as input ("%d%d%d"), explain which stack position is consumed by each format specifier
  - Justify why you repeat certain format specifier for certain number of times (be as specific as possible)
- **For BOF and ROP, draw a figure and explain as in 3-3**



Make-up Class for Lab #3

- **11/10 Friday 19:00 (K202)**
  - No attendance check
  - We will review the materials for Lab #3
  - Questions on Lab #3 will be accepted **only here**
    - But limited to 3-1 and 3-2
- **No office hour will be offered for Lab #3**
- **Also, I will not answer the questions about Lab #3 problems via email or after the lectures**
  - Questions are allowed only in the make-up class above

Submission Guideline

- **You should submit four exploit scripts and report**
  - Problem 3-1: **`exploit-gadget-exercise1.py`**
  - Problem 3-2: **`exploit-gadget-exercise2.py`**
  - Problem 3-3: **`exploit-simple.py`**
  - Problem 3-4: **`exploit-echo-twice.py`**
  - **Don’t forget the report**: **report.pdf**
- **Submission format**
  - Upload these files directly to *Cyber Campus* (**do not zip them**)
  - **Do not change the file name** (e.g., adding any prefix or suffix)
  - If your submission format is wrong, you will get **-20% penalty**