15-213 Recitation 5

Attack Lab and Stacks

Your TAs

Monday, September 27th, 2021

OH Etiquette

- **In Person vs Remote:** Students must add the **remote tag** if you are joining OH over zoom. If you fail to, you may be frozen / kicked from the queue.
- **Check Piazza for new OH rooms!** Rooms for evening OH sessions have been updated to clusters in Wean.

Agenda

- Attack Lab Overview
- Stacks Review
- Activity 1
- Procedure Calling Review
- Activity 2

Learning objectives

By the end of this recitation, we want you to know:

- Stack discipline and calling conventions
- How to perform a simple buffer overflow attack

Refer to Lecture from Thursday:
Machine-Level Programming V: Advanced Topics

Reminders and Lab Overview

Reminders

- Attack Lab is due this **Thursday, Sept. 30**
- C Review Bootcamp this **Sunday, Oct. 3** from 7-9pm in Rashid
  - Will be very useful for cachelab coming up!
  - Details will be on piazza

Attack Lab overview

- Attack programs by crafting buffer overflow attacks that hijack the control flow
- Provide inputs to the `rtarget` and `ctarget` programs that cause them to call certain functions
- Unlike in bomblab, the targets don't explode!

Stacks Review

Manipulating the stack

What instructions do we typically use to change the stack pointer, %rsp?

Growing the stack:

Shrinking the stack:

Manipulating the stack`

What instructions do we typically use to change the stack pointer, %rsp?

Growing the stack:

- `sub $0x28, %rsp`
- `push %rbx`
- `callq my_function`

Shrinking the stack:

Manipulating the stack

What instructions do we typically use to change the stack pointer, %rsp?

Growing the stack:

- `sub $0x28, %rsp`
- `push %rbx`
- `callq my_function`

Shrinking the stack:

- `add $0x28, %rsp`
- `pop %rbx`
- `retq`

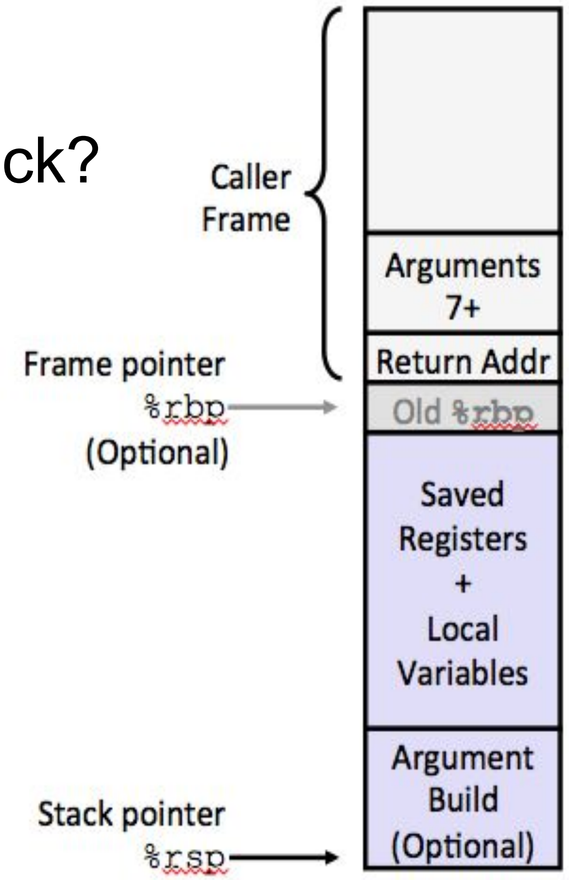
x86-64 Stack Frames

What kinds of data are stored on the stack?

x86-64 Stack Frames

What kinds of data are stored on the stack?

- Saved registers
- Local variables
- Arguments (7+)
- Saved return address



Which way does the stack grow?

- Up?
- Down?
- Left?
- Right?

Which way does the stack grow?

- Up?
- Down?
- Left?
- Right?

It depends on how you draw it!

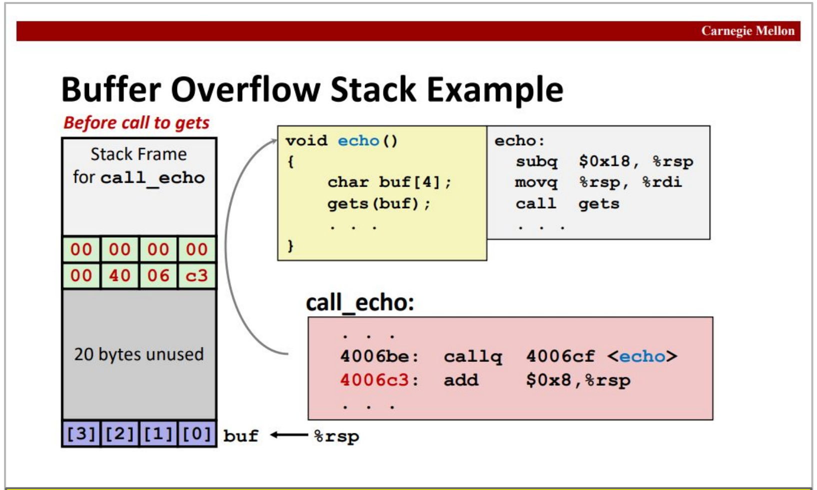
The stack always grows towards **lower addresses** in x86-64.

(Informally, this usually means "down".)

Be aware of this possible ambiguity when reading diagrams.

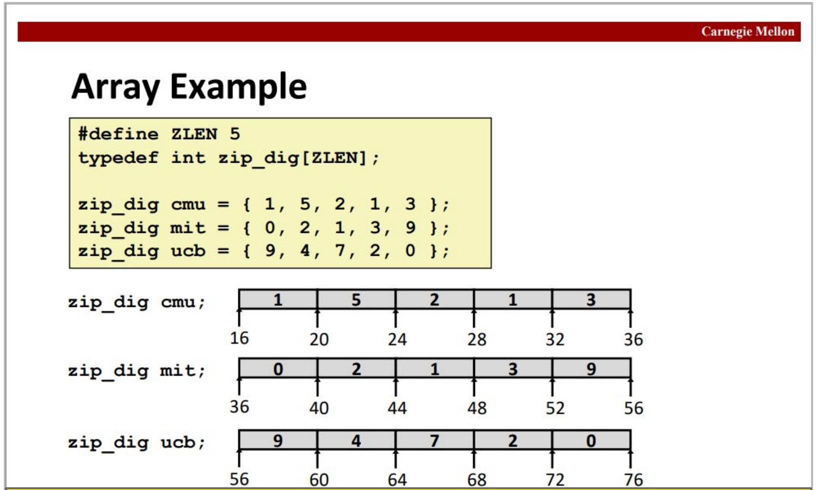
Drawing memory

Stack diagrams



Addresses are displayed increasing to the **left**, and then **upwards**.

Everything else



Addresses are displayed increasing to the **right**, and then **downwards**.

Endianness

- Describes how integers are represented as bytes.
- Little-endian means that the least-significant 8 bits of an integer are stored at the lowest address.

32-bit integer

`0x01020304`

"Big end" "Little end"

	A[0]	A[1]	A[2]	A[3]
Little-endian				
Big-endian				
Middle-endian				

Endianness

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32-bit integer

`0x01020304`

"Big end" "Little end"

	A[0]	A[1]	A[2]	A[3]
Little-endian	0x04	0x03	0x02	0x01
Big-endian	0x01	0x02	0x03	0x04

Activity 1

Part 1: Introduction to solve()

Let's look at `solve()` in the `src/activity.c` file.

What is it doing?

Is it possible for the program to call `win()`?

```
void solve(void) {
    long before = 0xb4;
    char buf[16];
    long after = 0xaf;

    Gets(buf);

    if (before == 0x3331323531)
        win(0x15213);

    if (after == 0x3331323831)
        win(0x18213);
}
```

Part 1: The gets() function

```
char *gets(char *s);
```

- `gets()` reads from standard input and writes characters into `s` until it reaches a newline.
- Since it has no information about the **size** of the buffer `s`, its design is fundamentally flawed. **Never use `gets()` yourself!**
- `Gets()` is a CS:APP wrapper function that checks for errors, and exits if it encounters any.

Part 1: Activity setup

- Split up into groups of 2-3 people
- One person needs a laptop
- Log in to a Shark machine, and type:

```
$ wget https://www.cs.cmu.edu/~213/activities/rec5.tar
$ tar xvf rec5.tar
$ cd rec5
```

- Take a look at the code in `src/activity.c`.

Part 1: Diving into assembly

- Look at the disassembly of `solve()`.
- Try drawing a stack diagram.
  - How large is the stack frame?
  - Where is the saved return address?
  - Where are `before`, `buf`, and `after`?
- **Which variable will be overwritten if we perform a buffer overflow, `before` or `after`?**

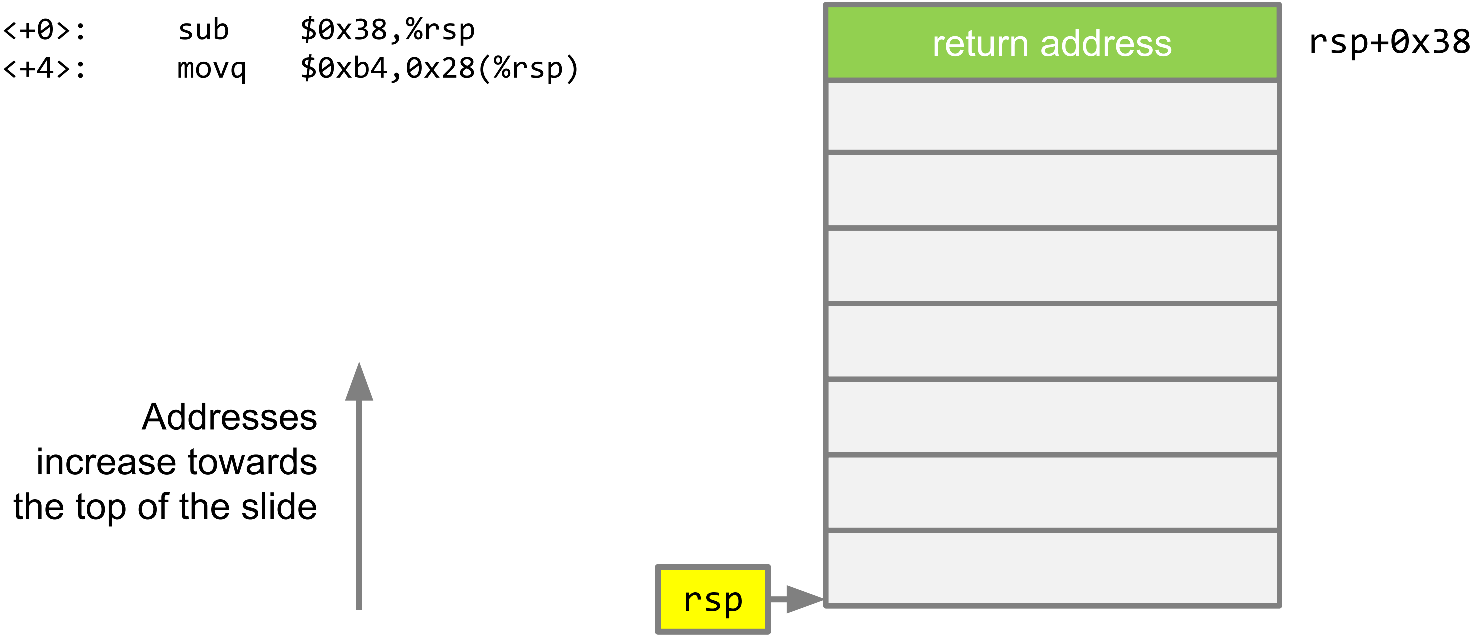
Part 1: Drawing the stack diagram

```
=> 0x4006b5 <+0>:     sub    $0x38,%rsp
```

Addresses
increase towards
the top of the slide

Part 1: Drawing the stack diagram

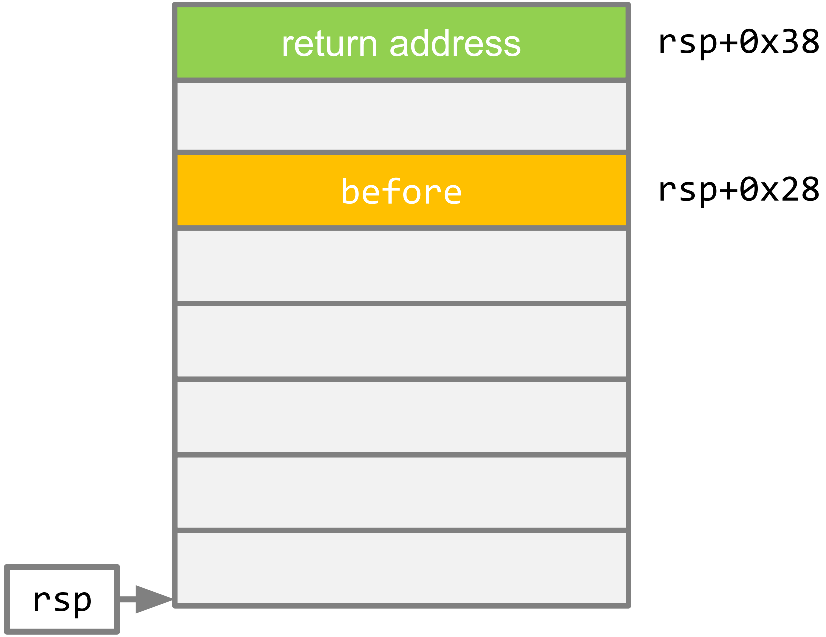
```
   0x4006b5 <+0>:     sub    $0x38,%rsp
=> 0x4006b9 <+4>:     movq   $0xb4,0x28(%rsp)
```



Part 1: Drawing the stack diagram

```
   0x4006b5 <+0>:      sub    $0x38,%rsp
   0x4006b9 <+4>:      movq   $0xb4,0x28(%rsp)
=> 0x4006c2 <+13>:     movq   $0xaf,0x8(%rsp)
```

Addresses increase towards the top of the slide



Part 1: Drawing the stack diagram

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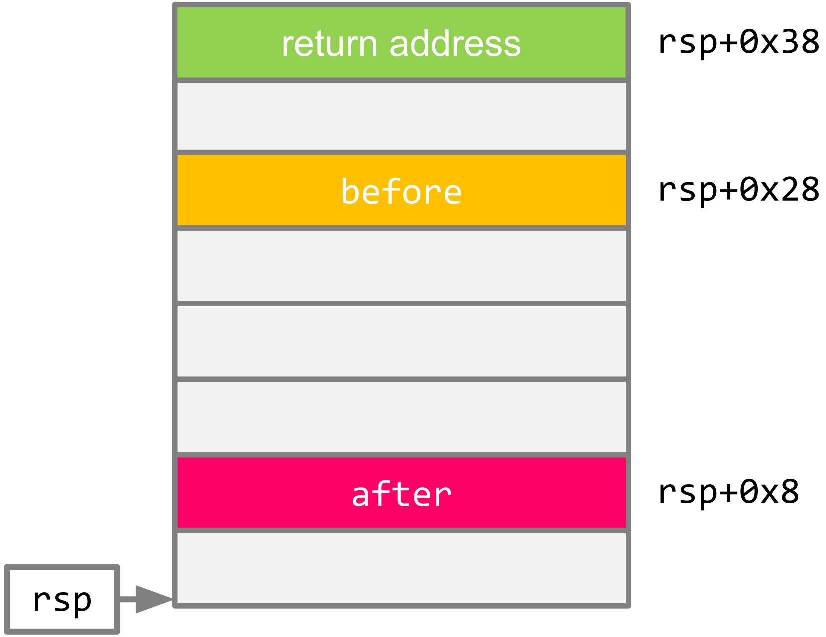
   0x4006b5 <+0>:     sub    $0x38,%rsp
   0x4006b9 <+4>:     movq   $0xb4,0x28(%rsp)
   0x4006c2 <+13>:    movq   $0xaf,0x8(%rsp)
   0x4006cb <+22>:    lea    0x10(%rsp),%rdi
=> 0x4006d0 <+27>:    callq  0x40073f <Gets>
```

Addresses increase towards the top of the slide



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=> 0x4006d5 <+32>:    mov    0x28(%rsp),%rdx
```
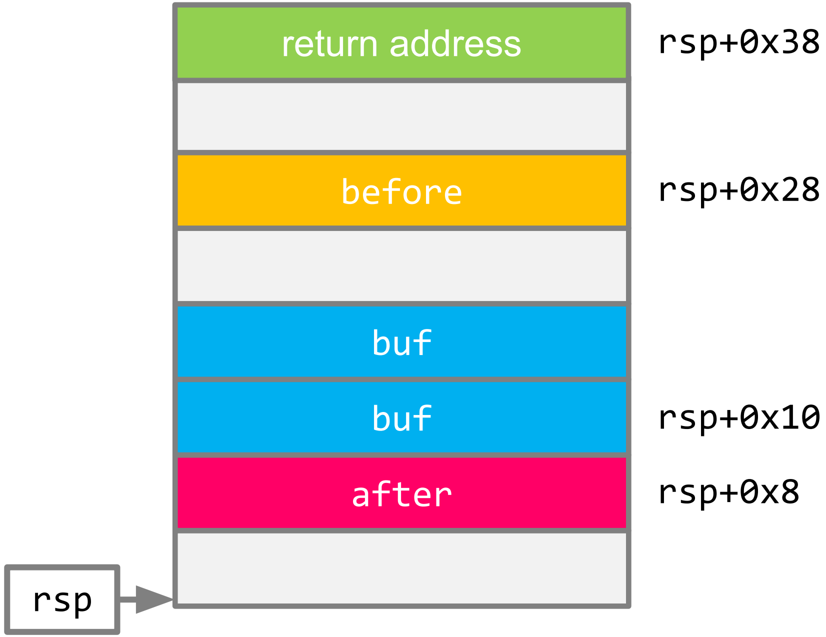

Addresses increase towards the top of the slide

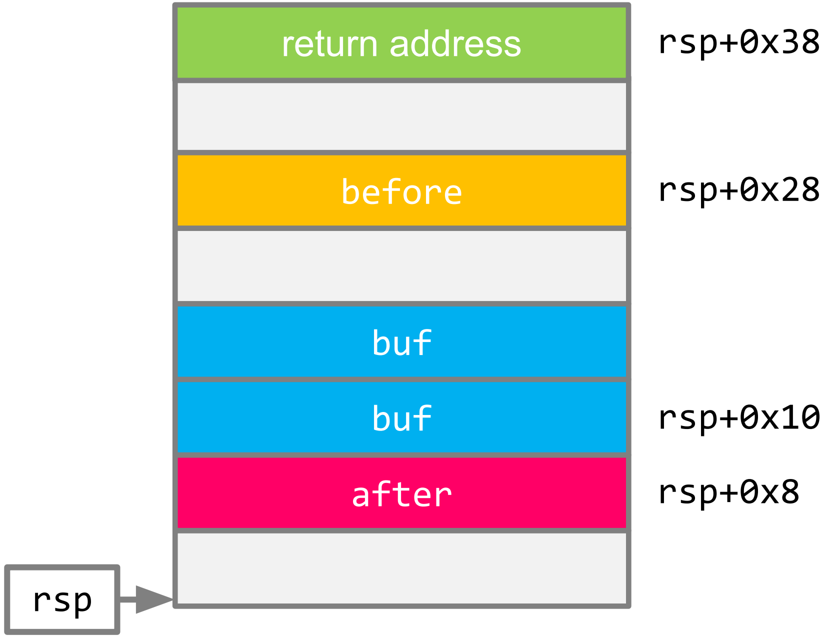


Part 1: Comparing with GDB output

Let's compare the stack diagram we drew with the actual values on the stack after `Gets()` returns.

```
   0x4006d0 <+27>:    callq  0x40073f <Gets>
=> 0x4006d5 <+32>:    mov    0x28(%rsp),%rdx
```

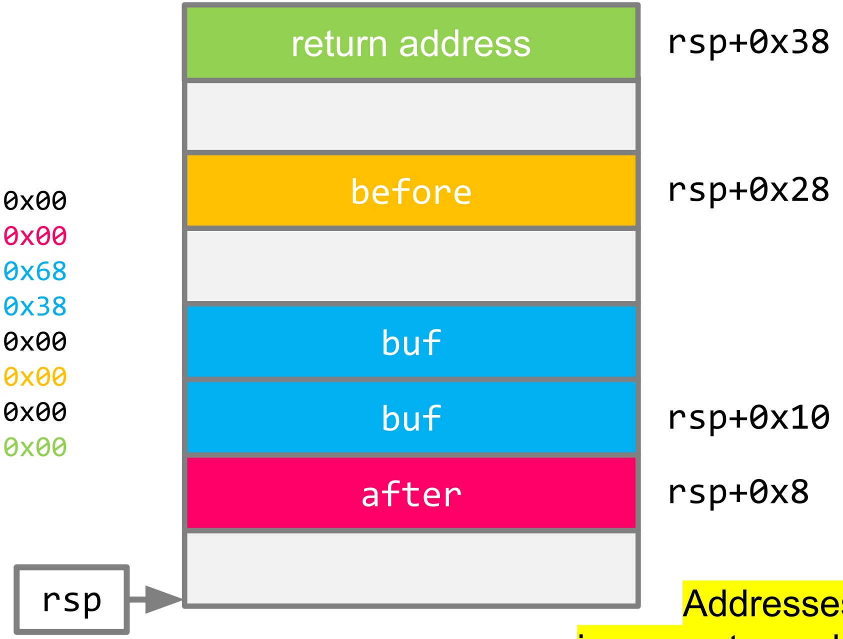
```
(gdb) break *0x4006d5
(gdb) run
Starting program: act1
abcdefgh12345678
(gdb) x/8gx $rsp
(gdb) x/64bx $rsp
```



Part 1: Comparing with GDB output

```
(gdb) x/8gx $rsp
0x602020:   0x0000000000000000    0x00000000000000af
0x602030:   0x6867666564636261    0x3837363534333231
0x602040:   0x0000000000000000    0x00000000000000b4
0x602050:   0x0000000000000000    0x0000000000400783

(gdb) x/64bx $rsp
0x602020:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0x602028:  0xaf  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0x602030:  0x61  0x62  0x63  0x64  0x65  0x66  0x67  0x68
0x602038:  0x31  0x32  0x33  0x34  0x35  0x36  0x37  0x38
0x602040:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0x602048:  0xb4  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0x602050:  0x00  0x00  0x00  0x00  0x00  0x00  0x00  0x00
0x602058:  0x83  0x07  0x40  0x00  0x00  0x00  0x00  0x00
```

Addresses increase towards **bottom of the slide**



Addresses increase towards **top of the slide**

Part 1: Exploitation

- Try to find an input string that wins 1 cookie!
  - What do we need to overwrite `before` with if we want to have `before == 0x3331323531`?
- Constructing an exploit
  - `gets()` stops reading once it sees a newline. In the buffer, it replaces the newline with a null terminator.
  - gets() does **not** stop reading at a null terminator.

Part 1: Recap

- Buffer overflows can **overwrite** parts of the stack frame, including other local variables
- Stack frames may include **padding**, so looking at the assembly is crucial to drawing a correct diagram
- GDB prints output starting at the **lowest** address, whereas our stack diagrams start at the **highest**

Procedure Calling Review

Call and return instructions

Which registers do callq and retq change?

`%rax`

`%rdi`

`%rsi`

`%rdx`

`%rcx`

`%r8`

`%r9`

`%r10`

`%r11`

`%rbx`

`%r12`

`%r13`

`%r14`

`%rbp`

`%rsp`

`%rip`

Call and return instructions

Which registers do callq and retq change?

`%rax`
`%rdi`
`%rsi`
`%rdx`
`%rcx`
`%r8`
`%r9`
`%r10`
`%r11`

`%rbx`
`%r12`
`%r13`
`%r14`
`%rbp`
`%rsp`
`%rip`

Stack/Procedure Review

```
0000000000400540 <multstore>:
  •
  •
=>400544: callq  400550 <mult2>
  400549: mov    %rax,(%rbx)
  •
  •
```

```
0000000000400550 <mult2>:
  400550:  mov    %rdi,%rax
  •
  •
  400557:  retq
```

```
0x130     •
0x128     •
0x120     •

%rsp   0x120

%rip   0x400544
```

Stack/Procedure Review

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0000000000400540 <multstore>:
  •
  •
=>400544: callq  400550 <mult2>
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  •
```

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  400550:  mov    %rdi,%rax
  •
  •
  400557:  retq
```

0x130

0x128

0x120

%rsp 0x120

%rip 0x400544

What happens next?

Stack/Procedure Review

```
0000000000400540 <multstore>:
  •
  •
  400544: callq  400550 <mult2>
  400549: mov    %rax,(%rbx)
  •
  •
```

```
0000000000400550 <mult2>:
=>400550:  mov    %rdi,%rax
  •
  •
  400557:  retq
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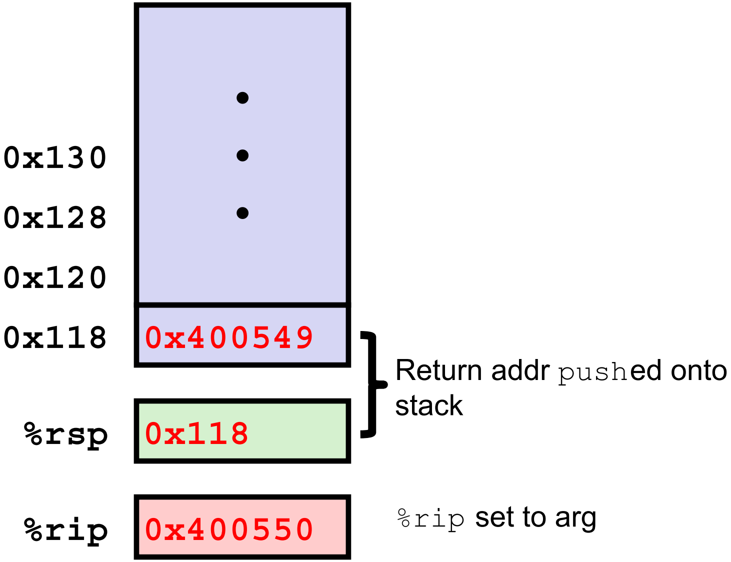

Stack/Procedure Review

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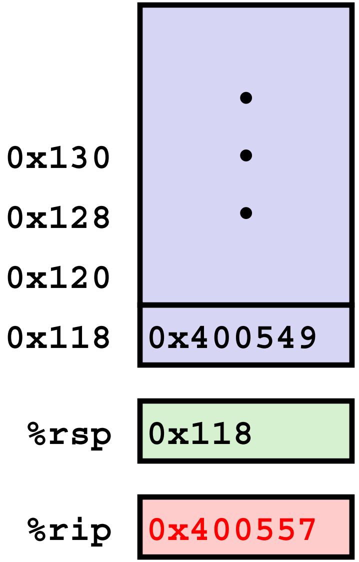

Stack/Procedure Review

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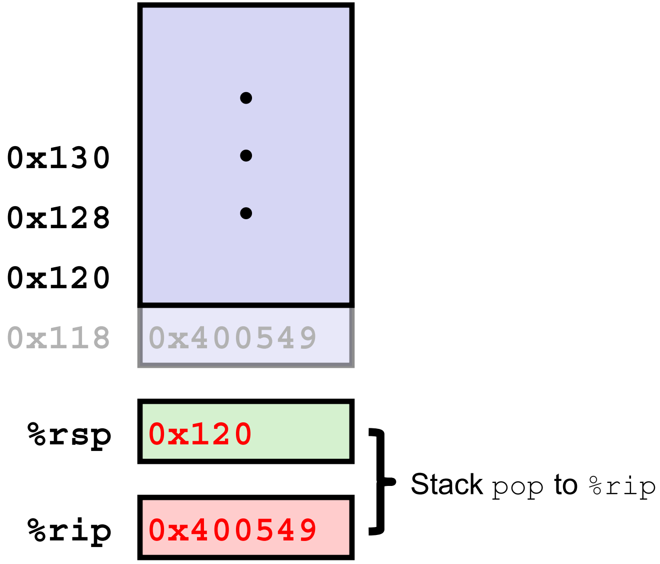
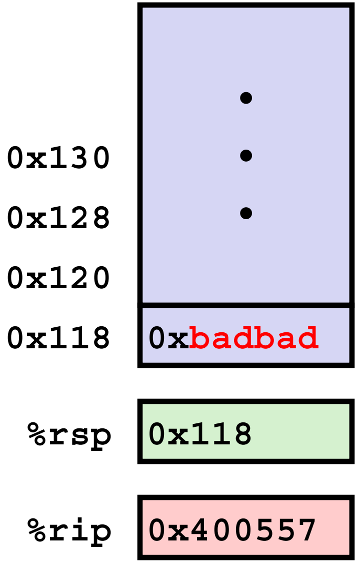


Let’s Rewind…

```
0000000000400540 <multstore>:
  •
  •
  400544: callq  400550 <mult2>
  400549: mov    %rax,(%rbx)
  •
  •
```

```
0000000000400550 <mult2>:
  400550:  mov    %rdi,%rax
  • ?????
  • ?????
=>400557:  retq
```



What if we mess up the return address?

Activity 2

Part 2: Exploitation

- Hijacking control flow
  - Is it possible to overwrite `after`? If not, what parts of the stack frame *can* we overwrite?
  - Is there anywhere we could jump to call `win(0x18213)`?
- Constructing an exploit

inputs/input2.txt

```
48 65 6c 6c 6f 20 31 35
32 31 33 21   # comment
```

→ **`make`** (runs `hex2raw`)

inputs/input2.bin

```
Hello 15213!
```

Part 2: Recap

- `retq` always jumps to the **saved return address**, which it pops off the stack (at `rsp`).
- **Overwriting** the saved return address on the stack allows us to "fool" `retq`, and transfer control to an arbitrary instruction.

Attack Lab Tools

- ```
  $ gcc -c test.s
  $ objdump -d test.o
  ```
  Compiles the assembly code in test.s, then shows the disassembled instructions along with the actual bytes.

- ```
  $ ./hex2raw < exploit.txt > exploit.bin
  ```
  Convert hex codes into raw binary strings to pass to targets.

- ```
  (gdb) display /12gx $rsp
  (gdb) display /2i $rip
  ```
  Displays 12 elements on the stack and the next 2 instructions to run
  GDB is also useful to for tracing to see if an exploit is working.
  ```

If you get stuck

- **Please read the writeup carefully.** Not everything will make sense on the first read-through.
- Other resources you can make use of:
  - CS:APP Chapter 3
  - Lecture slides and videos
  - x86-64 and GDB cheat sheets under Resources