15-213 Recitation
Attack Lab

Your TAs

Tuesday, June 2nd

Poll: Midterm Review Session

https://forms.gle/PK56ZGLLWhtwuEyF6

Reminders

- **`bomblab`** was due yesterday (June 1)
- **`attacklab`** has been released, and is due on ***June 9***

Agenda

- Review: Structs and Alignment
- Stacks
- Calling Procedures, Stack Frames
- Endianness
- Intro to Attack Lab
- Activity!

Review: `structs`

Alignment Requirements

- Badly aligned data can harm performance:
  - May need multiple memory accesses instead of just one.
- *Primitive* types have pre-determined alignments:
  - **`char`** = 1 byte
  - **`short`** = 2 bytes
  - **`int`** = 4 bytes
  - **`long`** = 8 bytes
  - **`double`** = 8 bytes
  - **`pointer`** = 8 bytes

Alignment : Compound Types

- Compound types:
  - Arrays
  - Structs
  - Unions
- Alignment rules for these types:
  1. Takes largest alignment requirement of its fields.
  2. Initial address and size must both be multiples of the alignment requirement.

Alignment Requirements: Example

```
double d;
```

- What is the alignment requirement for **d**?
  - *Primitive:* has pre-defined alignment requirement.
  - **Alignment: 8**
- What is its size?
  - **Size: 8 bytes**

Alignment Requirements: Example

```
struct y {
   double d;
}
```

- What is the alignment requirement for **`y`**?
  - **Rule (1):** struct alignment = max alignment of fields.
  - **Alignment: 8**
- What is its size?
  - **Size: 8 bytes**

Alignment Requirements: Example

```
struct y {
   short c;
   double d;
}
```

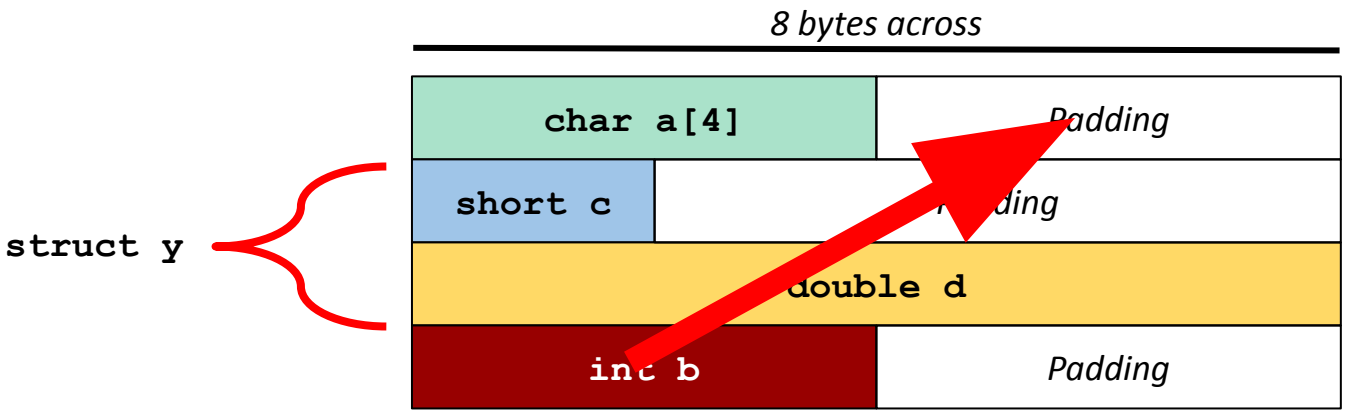
- What is the alignment requirement for **y**?
  - **Alignment: 8**
- What is its size?
  - **Rule (2):** have to add padding after **c** so that **d** is 8-byte aligned
  - **Size: 16 bytes**

Alignment Requirements: Example

```
struct x {
   char a[4];
   struct {
      short c;
      double d;
   } y;
   int b;
}
```

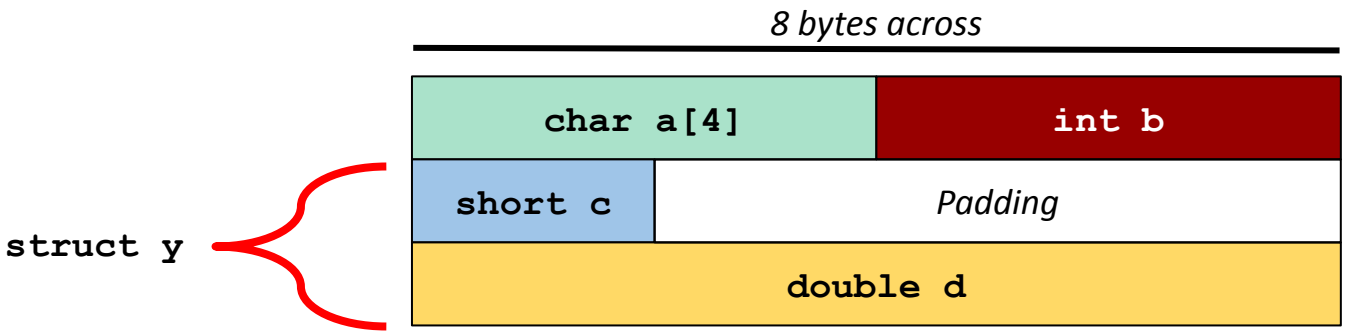
- What is the alignment requirement for **x**?
  - **Alignment: 8**
- What is its size?
  - Remember, the entire struct must also follow alignment rules
  - **Size: 32 bytes**

`structs`: Reordering Fields



- **`struct x`** takes up *32 bytes* to store *18 bytes* of data.
- Can we reorder the fields to do better?

`structs`: Reordering Fields



- **`struct x`** now takes up *24 bytes*!
- Compiler *cannot* do this optimization. It's up to the programmer (you!)
- *Note:* Can't move field into or out of **`y`** without also changing how you access those fields in your code.

Stacks

Manipulating the Stack

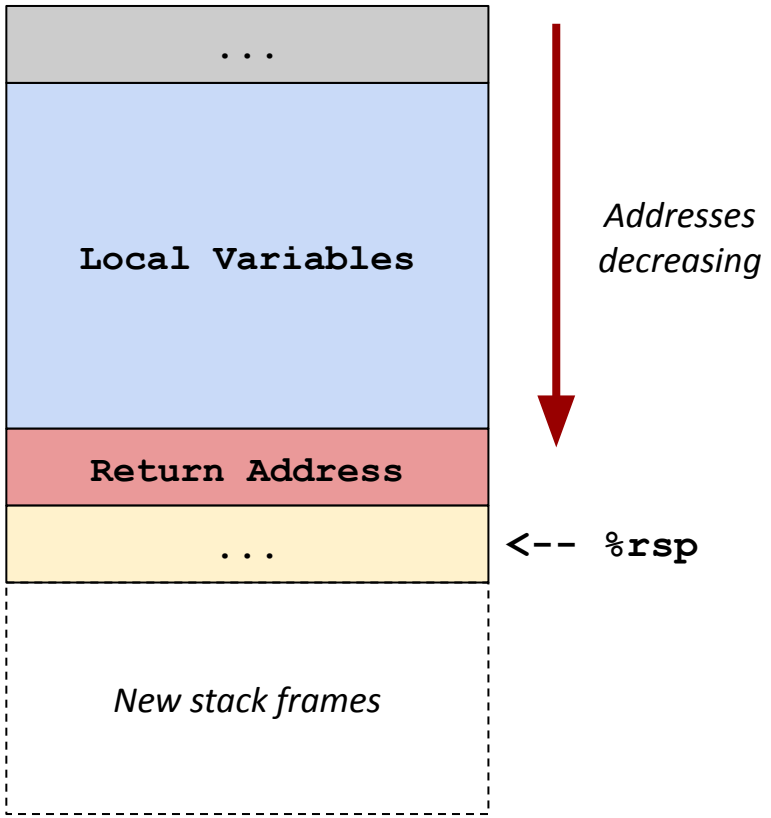
- Certain instructions ***grow*** the stack, and certain instructions ***shrink*** the stack:

Growing the stack	*Shrinking the stack*
`sub 0x38, %rsp`	`add 0x38, %rsp`
`push %rbp`	`pop %rbp`
`call`	`ret`

- But what does this look like in memory?

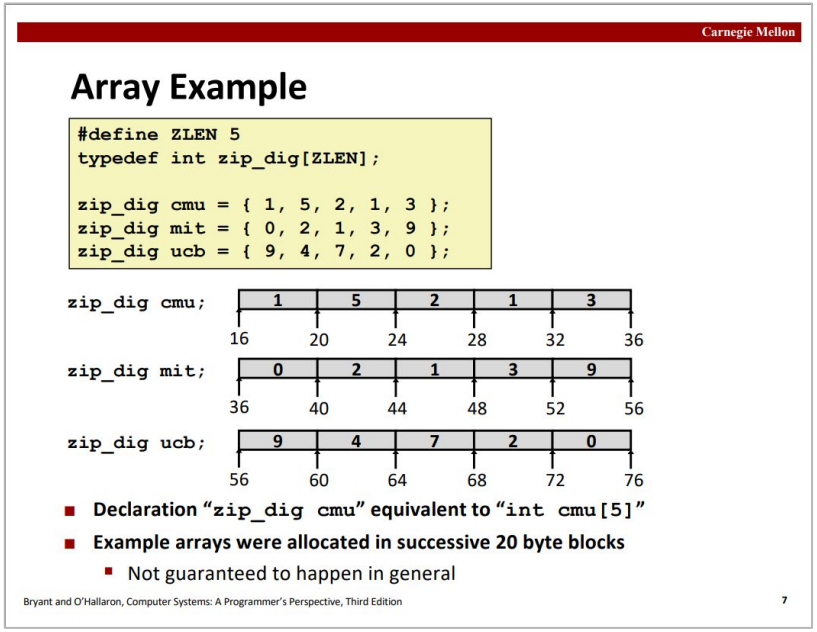
Which way does the stack grow?

- We say that the stack grows ***"down"*** because it grows towards ***lower addresses***:
  - e.g. **`sub 0x38, %rsp`**
- We will draw them this way in **`attacklab`** examples
  - But you can draw them in any way that makes sense to you!

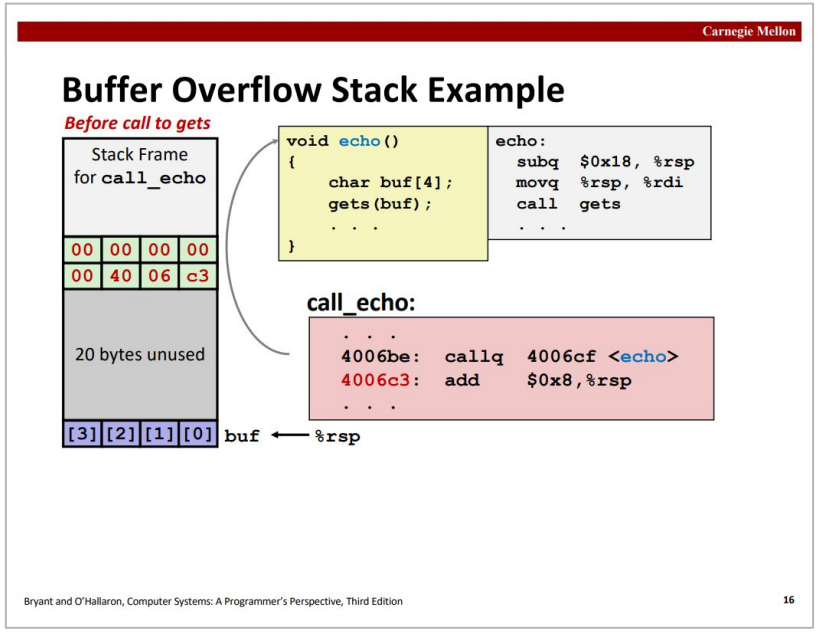


Drawing Memory

Conventional Memory Diagram



Stack Diagram



Addresses Increasing:

- **Towards the <u>right</u>**
- **Then <u>downwards</u>**

Addresses Increasing:

- **Towards the <u>left</u>**
- **Then <u>upwards</u>**

Calling Procedures, Stack Frames

Review: Calling Procedures

Procedure Call: **`call label`**

- Push *return address* onto the stack (so that we can pass control back to the caller!)
- Jump to **`label`**

Procedure Return: **`ret`**

- Pop address from stack
  - This is the address of the next instruction of the *caller*
- Jump to that address

Example

- Take a look at the following code snippet:

```
int outer_function() {
    int result = inner_function(1, 2, 3, 4, 5, 6, 7, 8, 9);

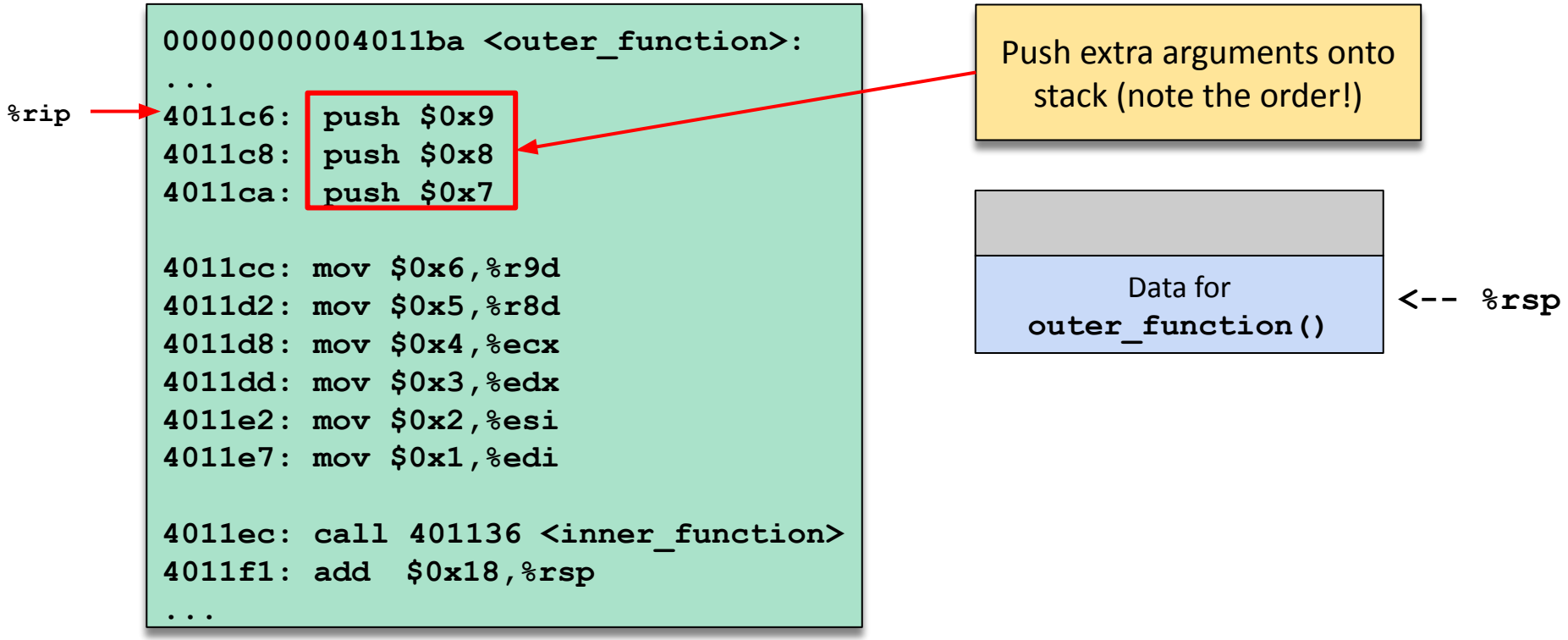
    return result + 1;
}
```

Lots of arguments!

- What would this look like in assembly? How would having many arguments affect the stack?

Example: `outer_function()`

- Here is the assembly for `outer_function`:



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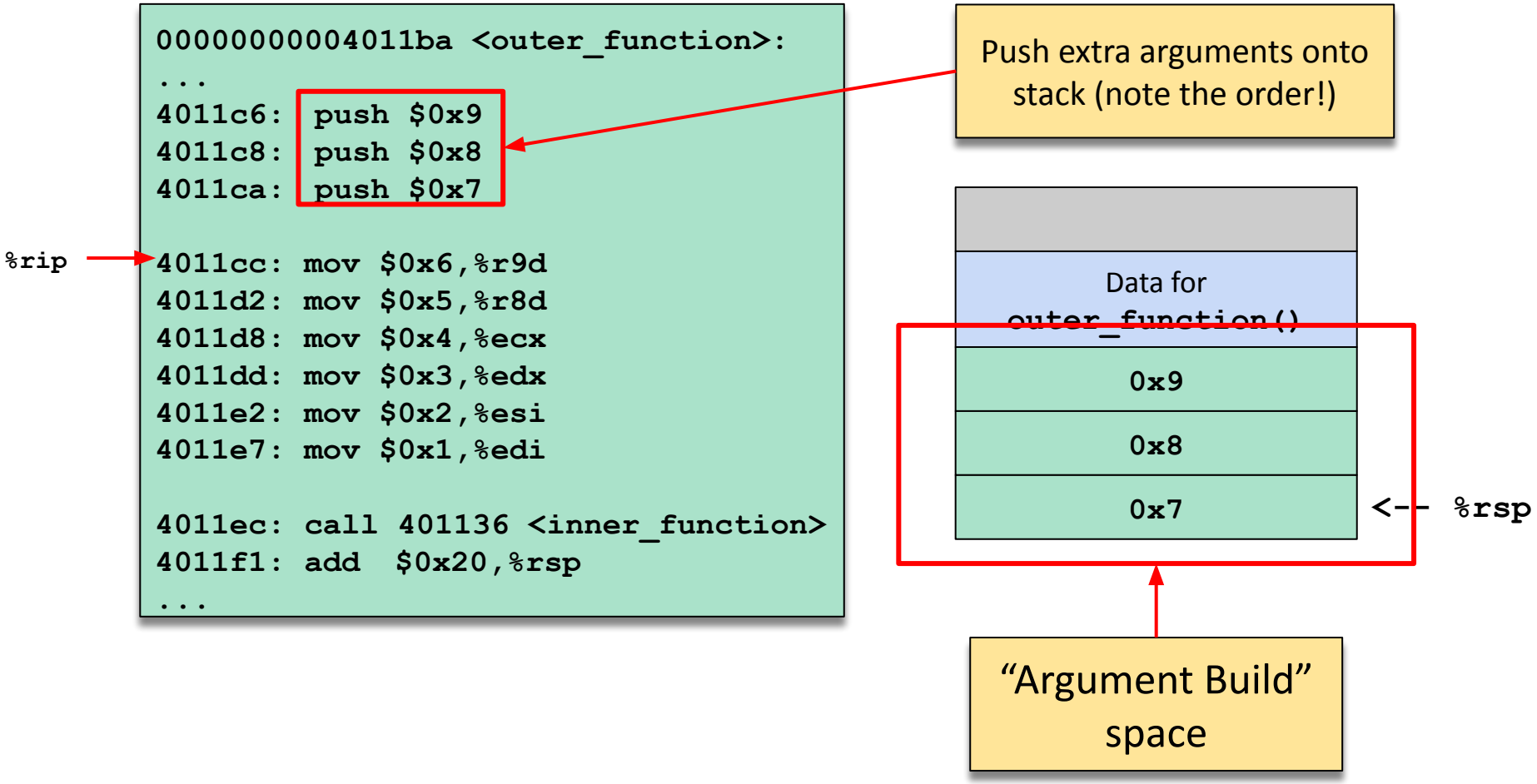

Example: `outer_function()`

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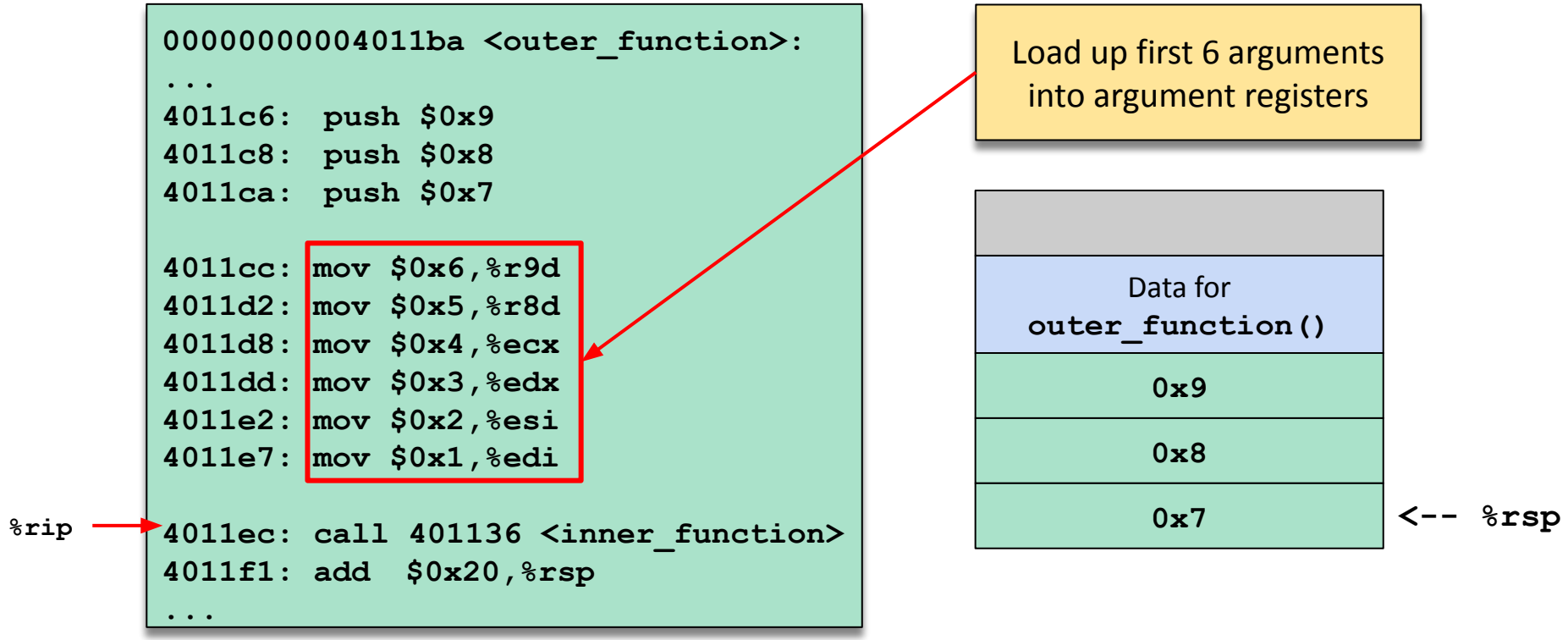


Example: `outer_function()`

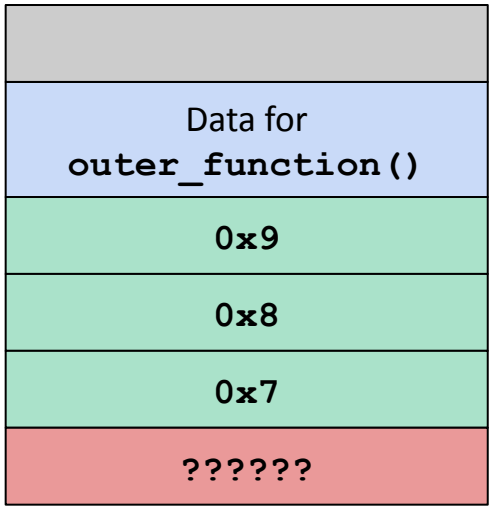
- Remember, **`call`** loads the return address onto the stack

```
00000000004011ba <outer_function>:
...
4011c6:  push $0x9
4011c8:  push $0x8
4011ca:  push $0x7

4011cc: mov $0x6,%r9d
4011d2: mov $0x5,%r8d
4011d8: mov $0x4,%ecx
4011dd: mov $0x3,%edx
4011e2: mov $0x2,%esi
4011e7: mov $0x1,%edi

4011ec: call 401136 <inner_function>
4011f1: add  $0x20,%rsp
...
```

Now we're ready to call!



Example: `outer_function()`

- What is the return address we should store? Let's inspect gdb to find out!

```
(gdb) x /4gx $rsp
0x7fffffffe3c8: 0x00000000004011f1      0x0000000000000007
0x7fffffffe3d8: 0x0000000000000008      0x0000000000000009
```

- Where does this value come from?

```
4011ec: call 401136 <inner_function>
4011f1: add $0x20,%rsp
...
```

- It's the address of the instruction we want to jump to after completing the call to **`inner_function`**

Example: `outer_function()`

- State of our program before starting **`inner_function`**

```
00000000004011ba <outer_function>:
...
4011c6:  push $0x9
4011c8:  push $0x8
4011ca:  push $0x7

4011cc: mov $0x6,%r9d
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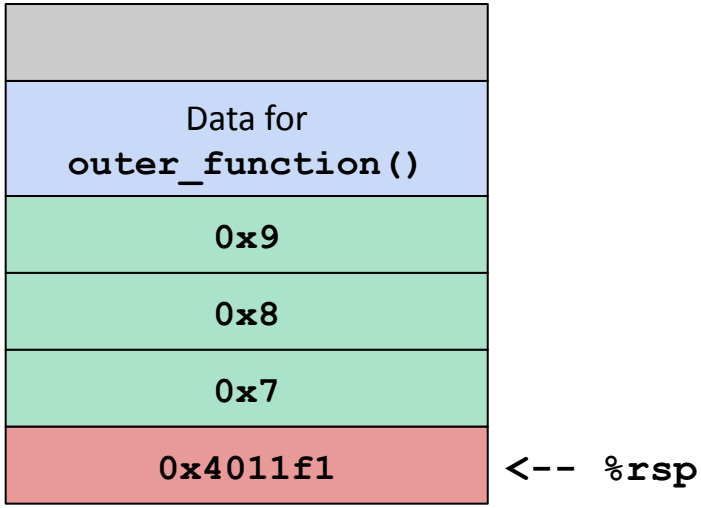
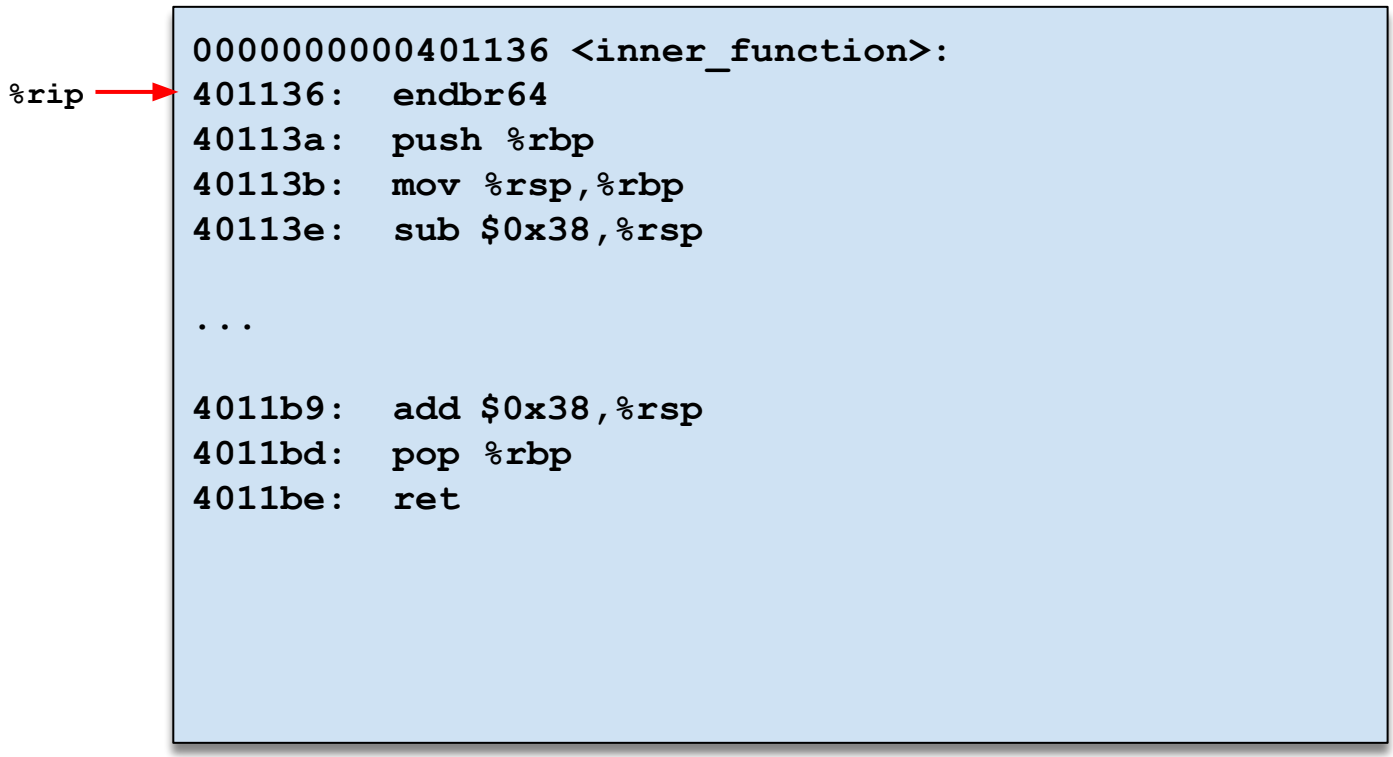


Pass control to **`inner_function()`**
=> Set **`%rip`** to **`0x401136`**

Example: `inner_function()`

- Here is the assembly for **`inner_function`**



Example: `inner_function()`

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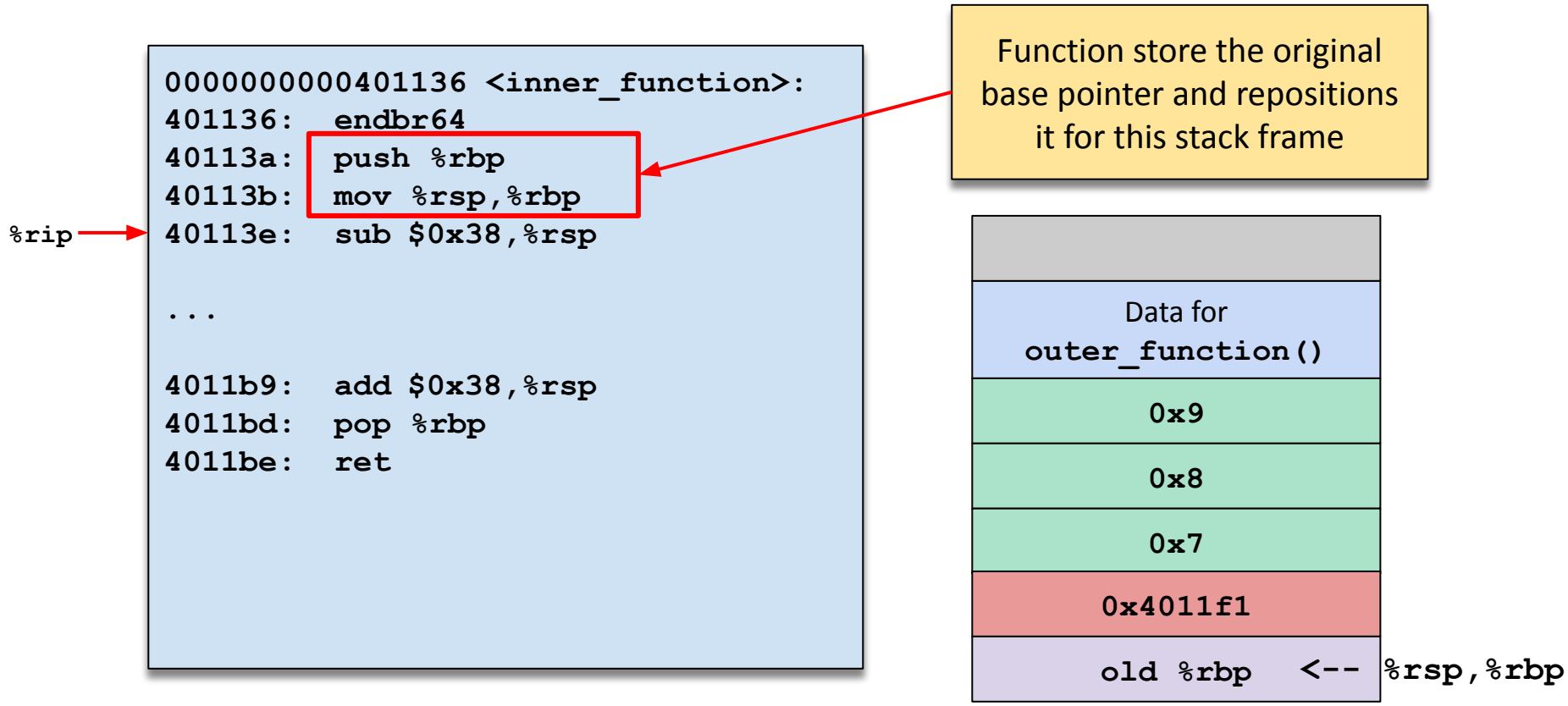


Example: `inner_function()`

- Here is the assembly for **`inner_function`**

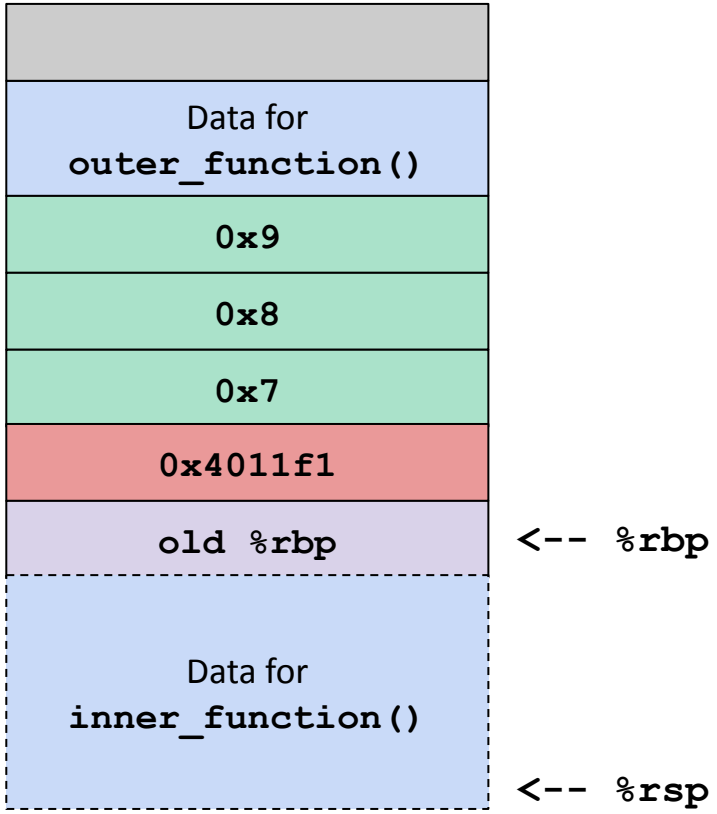
```
0000000000401136 <inner_function>:
401136:   endbr64
40113a:   push %rbp
40113b:   mov %rsp,%rbp
40113e:   sub $0x38,%rsp

...

4011b9:   add $0x38,%rsp
4011bd:   pop %rbp
4011be:   ret
```

%rip →

Function allocates any space it needs



Example: `inner_function()`

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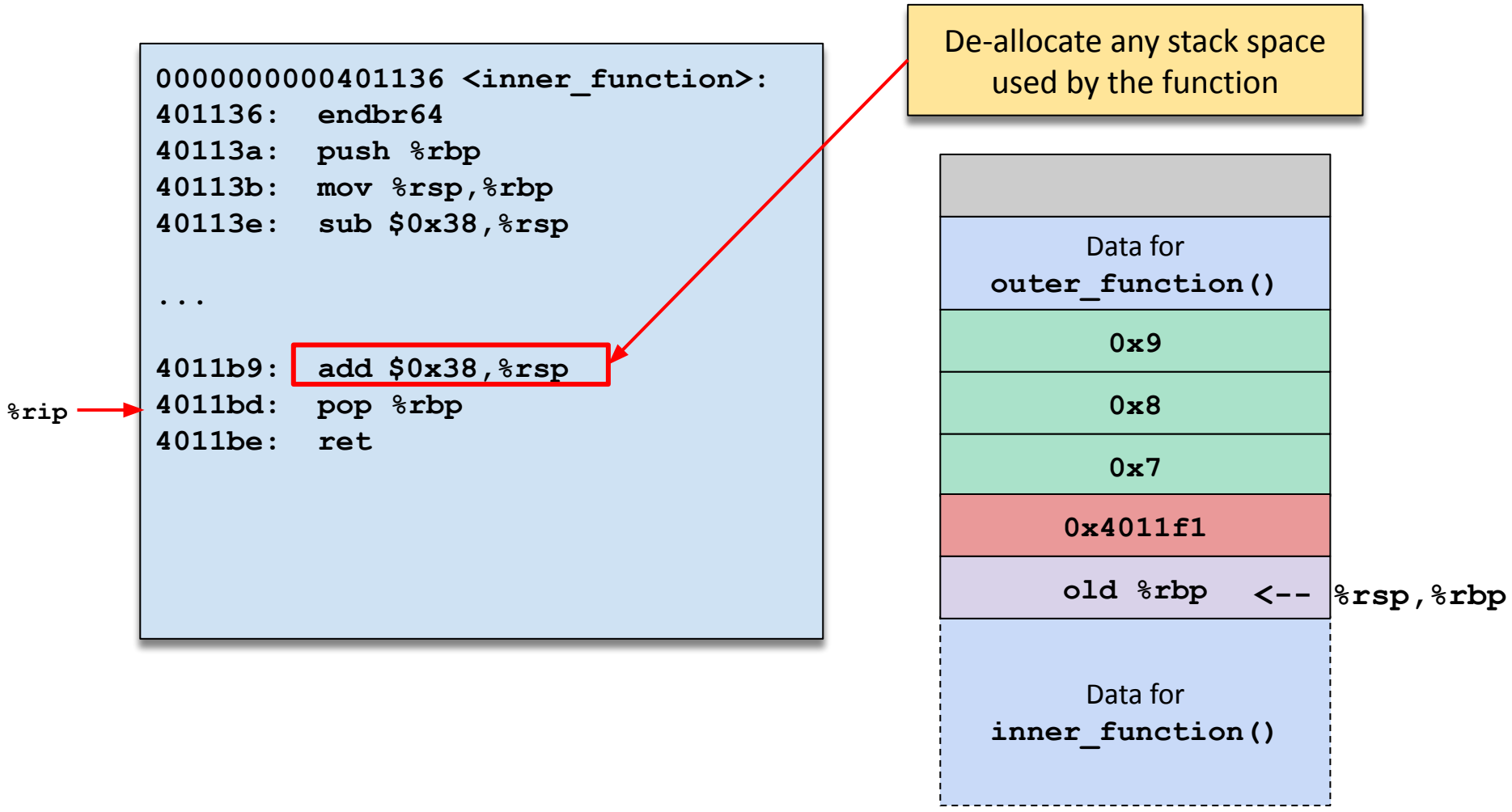

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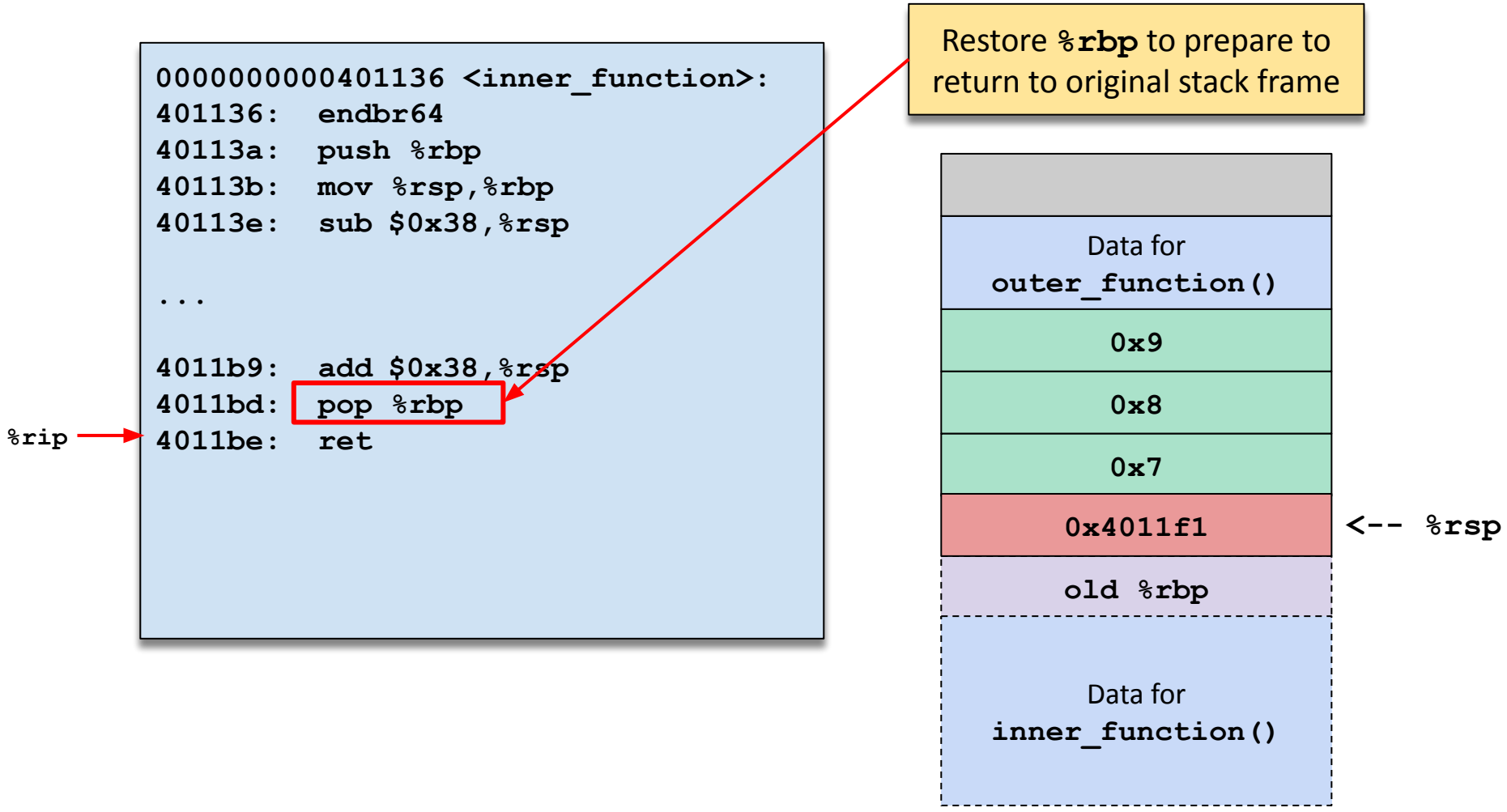

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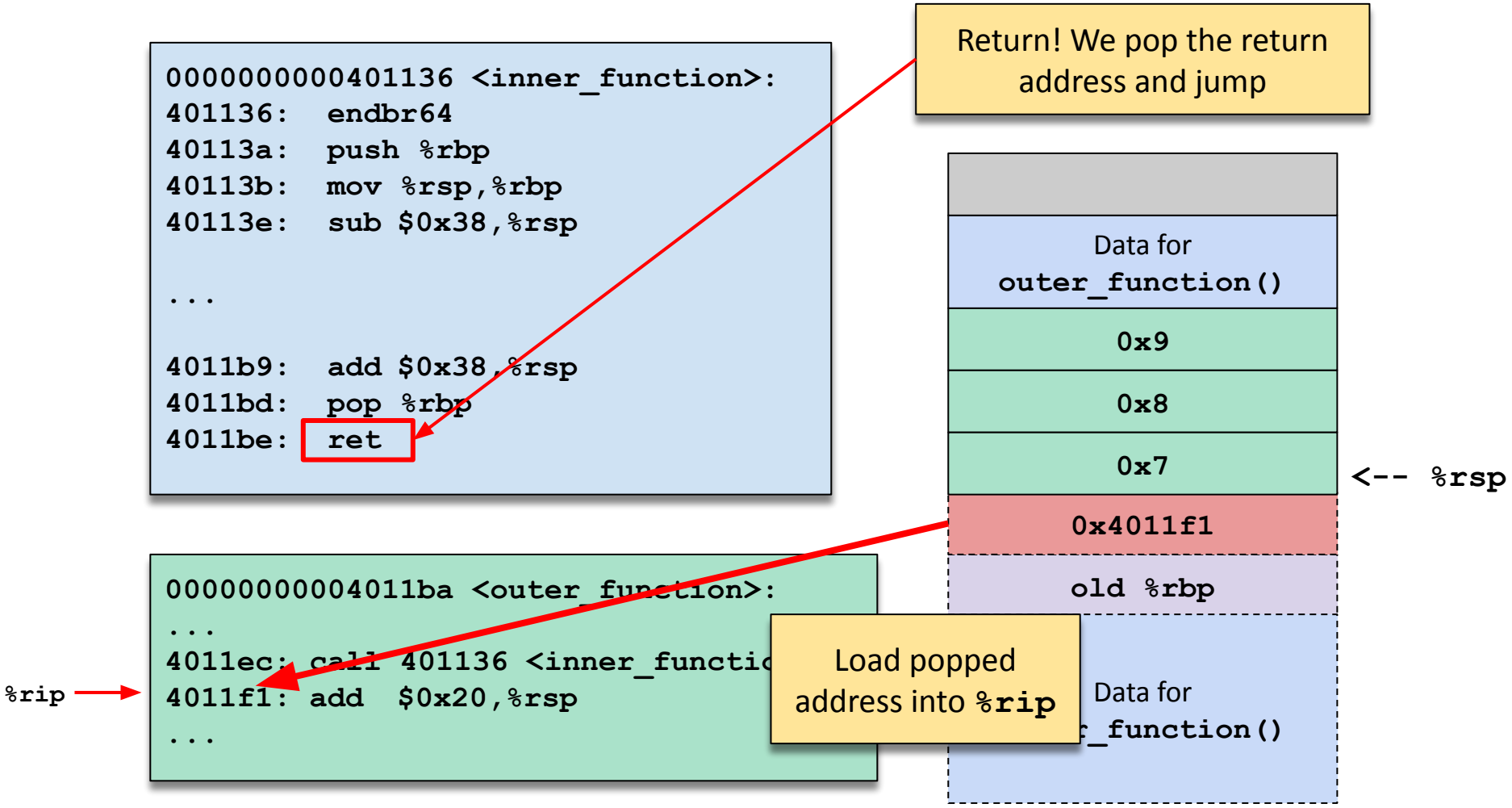


Endianness

Endianness

- Under the hood, we represent everything as a series of contiguous *bytes.*
- ***Endianness*** refers to how we order the ***bytes*** for **"simple"** types (integers and floats).

Endianness

- ***Little-Endian***:
  - *Least* significant byte is stored at the *lowest* address.
  - Shark Machines are Little-Endian.
  - Assume everything in this class is **little-endian** unless otherwise stated.
- ***Big-Endian***:
  - *Most* significant byte is stored at the *lowest* address.

32-bit integer

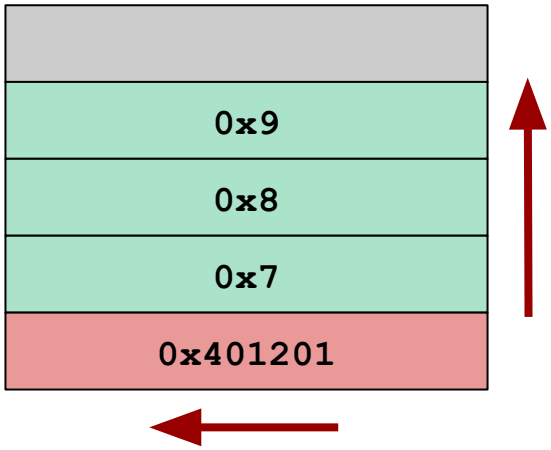
0x01020304

"Big end" "Little end"

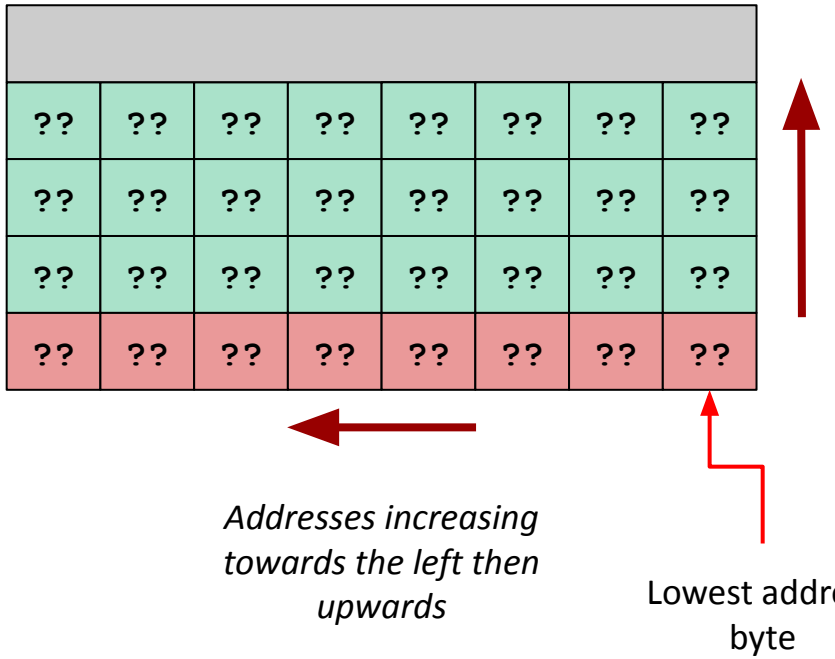
	Mem[0]	Mem[1]	Mem[2]	Mem[3]
Little-Endian	0x04	0x03	0x02	0x01
Big-endian	0x01	0x02	0x03	0x04

Endianness: Example

- Suppose we draw our diagram with addresses increasing towards the left, then upwards.
- How are the bytes ordered on a little endian machine?



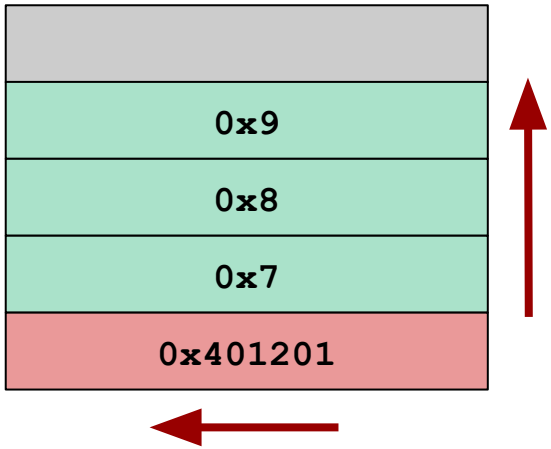
Addresses increasing towards the left then upwards

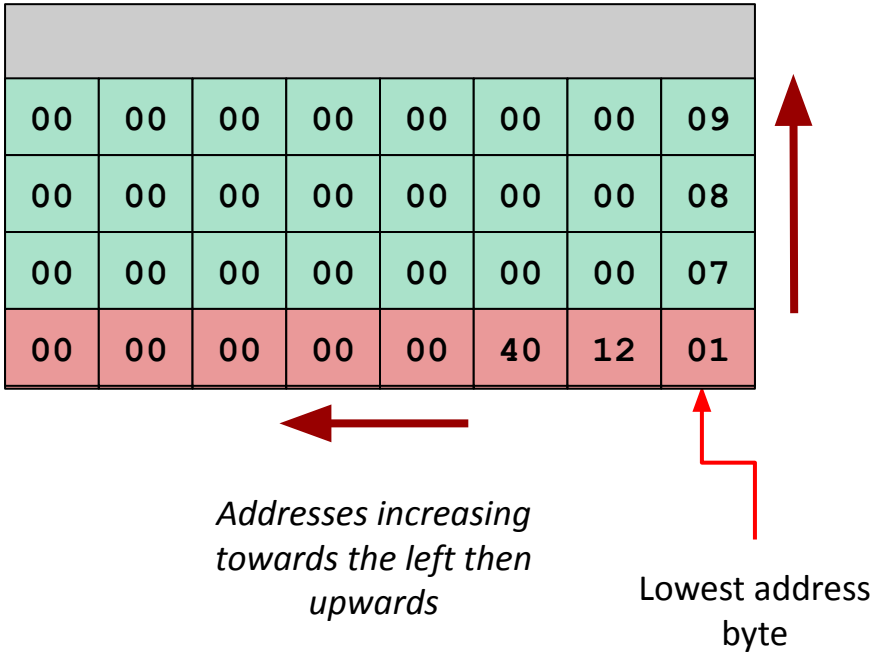


Addresses increasing towards the left then upwards

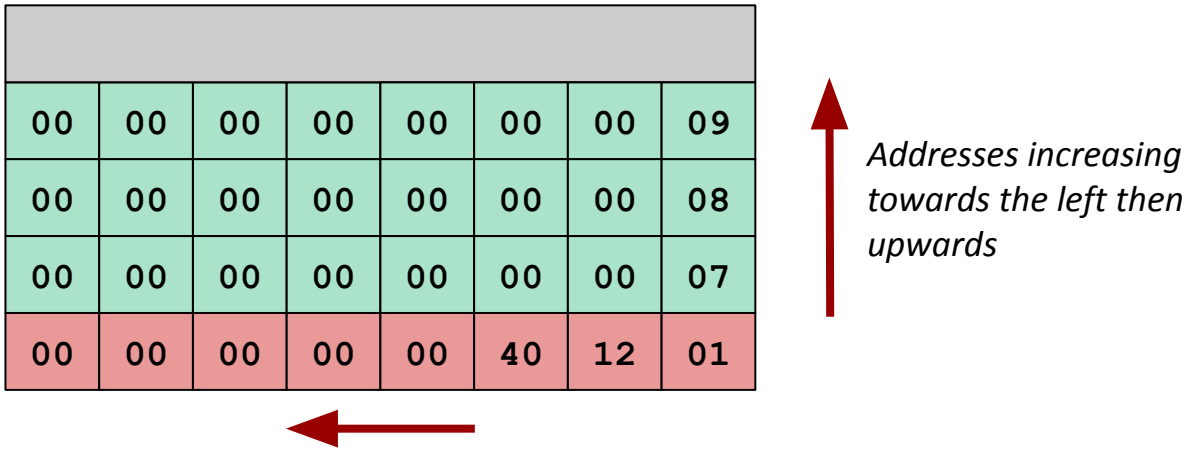
Lowest address byte

Endianness: Example





Endianness Example: Comparing with gdb




```
(gdb) x /32bx $rsp
0x7fffffffe3e8: 0x01 0x12 0x40 0x00 0x00 0x00 0x00 0x00
0x7fffffffe3f0: 0x07 0x00 0x00 0x00 0x00 0x00 0x00 0x00
0x7fffffffe3f8: 0x08 0x00 0x00 0x00 0x00 0x00 0x00 0x00
0x7fffffffe400: 0x09 0x00 0x00 0x00 0x00 0x00 0x00 0x00
```

Addresses increasing towards the right then downwards

- **gdb** draws its diagram with addresses increasing towards the right then downwards.
- Both diagrams are correct, and are still little-endian!

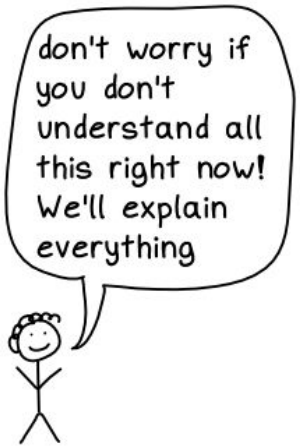
Julia Evans
@b0rk

8 bytes, many meanings

The same bytes can mean many different things. Here are 8 bytes and a bunch of things they could potentially mean:

Addresses increase towards the right

8 bytes →	63	6f	6d	70	75	74	65	72	
	c	o	m	p	u	t	e	r	8 ASCII characters
	99	111	109	112	117	116	101	114	8 8-bit integers
	28515		28781		29813		29285		4 unsigned 16-bit integers
	1886220131				1919251573				2 unsigned 32-bit integers
	8243122740717776739								1 unsigned 64-bit integer
	0x72657475706d6f63								a 64-bit pointer
	99.111.109.112				117.116.101.114				2 IPv4 addresses
	arpl WORD PTR [edi+0x6d],bp		jo 0x7a		je 0x6c		.byte 0x72		x86 machine code
	c	o	m	p	u	t	29285		6 ASCII characters + 1 16-bit integer
	2.93930e+29				4.54482e+30				2 32-bit floating point numbers
	1.144493e+243								1 64-bit floating point numbers
	rgba(99, 111, 109, 0.44)				rgba(117, 116, 101, 0.45)				2 RGBA colours



Attack Lab

Attack Lab: Overview

- Exploit vulnerabilities in target programs using the techniques you learned in lecture.
- Hijack their control flow and make them do something else!
- Targets do *not* explode like in **`bomblab`**.
- We'll get some practice right now!

Activity

Activity 1

- Download this week's handout from the *Schedule* page.
- For now:
  - Just open up the source code under **`src/activity.c`**.
  - We'll start by walking through the code together!

```
$ wget https://www.cs.cmu.edu/~213/activities/m26-rec4.tar
$ tar -xvf m26-rec4.tar
$ cd m26-rec4
```

Activity 1: `solve()`

src/activity.c

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

    Gets(buf);

    if (before == 0x3331323531)
        win(0x15213);
    if (after == 0x3331323831)
        win(0x18213);
}
```

- Assume **`before`** and **`after`** are stored on the stack.
- Is there any way for **`solve()`** to call **`win()`**?
- Based on what you learned in lecture, are there any vulnerabilities we can exploit here?

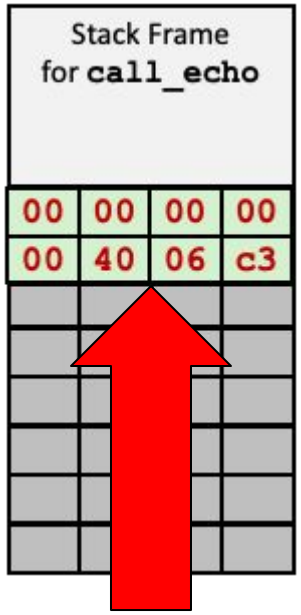
Recall: Unsafe Functions

- C standard library functions like **`gets()`** and **`strcpy()`** write to buffers, but have no length checks!
  - Enables *buffer overflow* attacks.

```
int echo() {
    char buf[4];
    gets(buf);
    ...
    return ...;
}
```

```
echo:
  subq   $0x18, %rsp
  movq   %rsp, %rdi
  call   gets
  . . .
```

Compiler making space for buffer + a little bit of padding



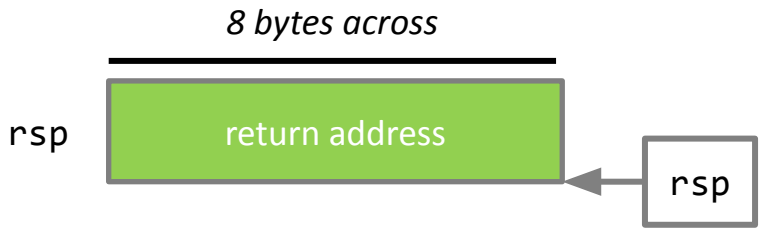
Can overwrite anything before the buffer!

Activity 1: Back to `solve()`

- Let's see if we can find a similar vulnerability in **`solve()`** by looking at the assembly!
- Source code and assembly code are both reproduced on the back of the handout.
- Draw a stack diagram to see if you can answer the following:
  - What does the stack frame look like?
  - Where is the saved return address?
  - Where do we store **`buf`**, **`before`**, and **`after`** in relation to each other?

Activity 1: Stack diagram

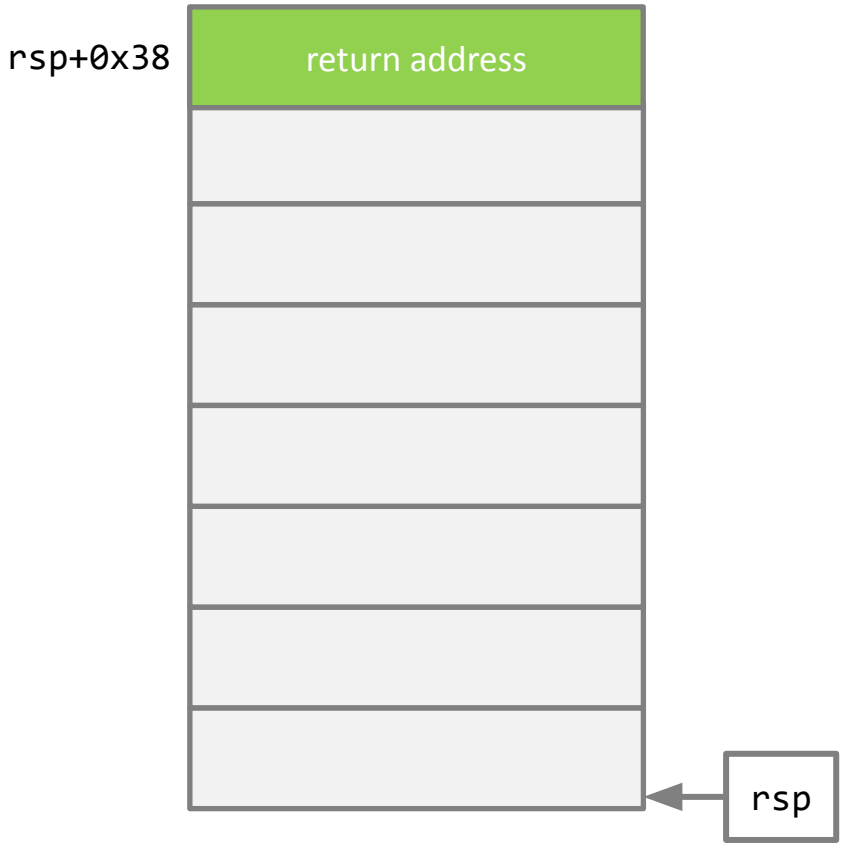
```
=> 0x4006b5 <+0>: sub    $0x38,%rsp
```



Addresses increase towards the top of the slide

Activity 1: Stack diagram

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



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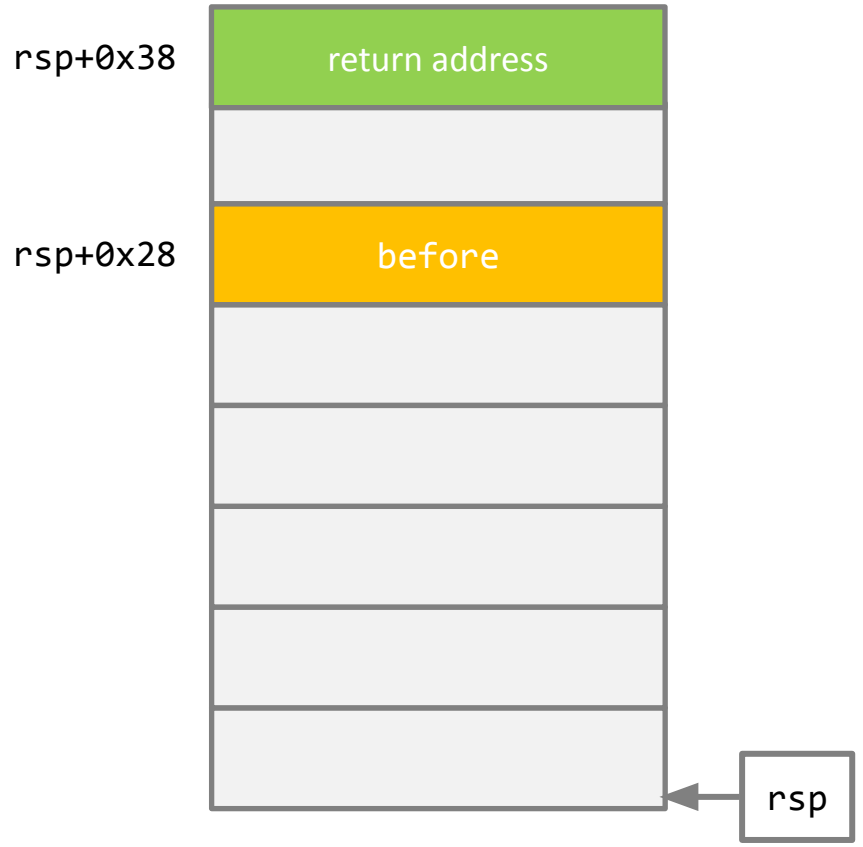
Activity 1: Stack diagram

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



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Activity 1: Stack diagram

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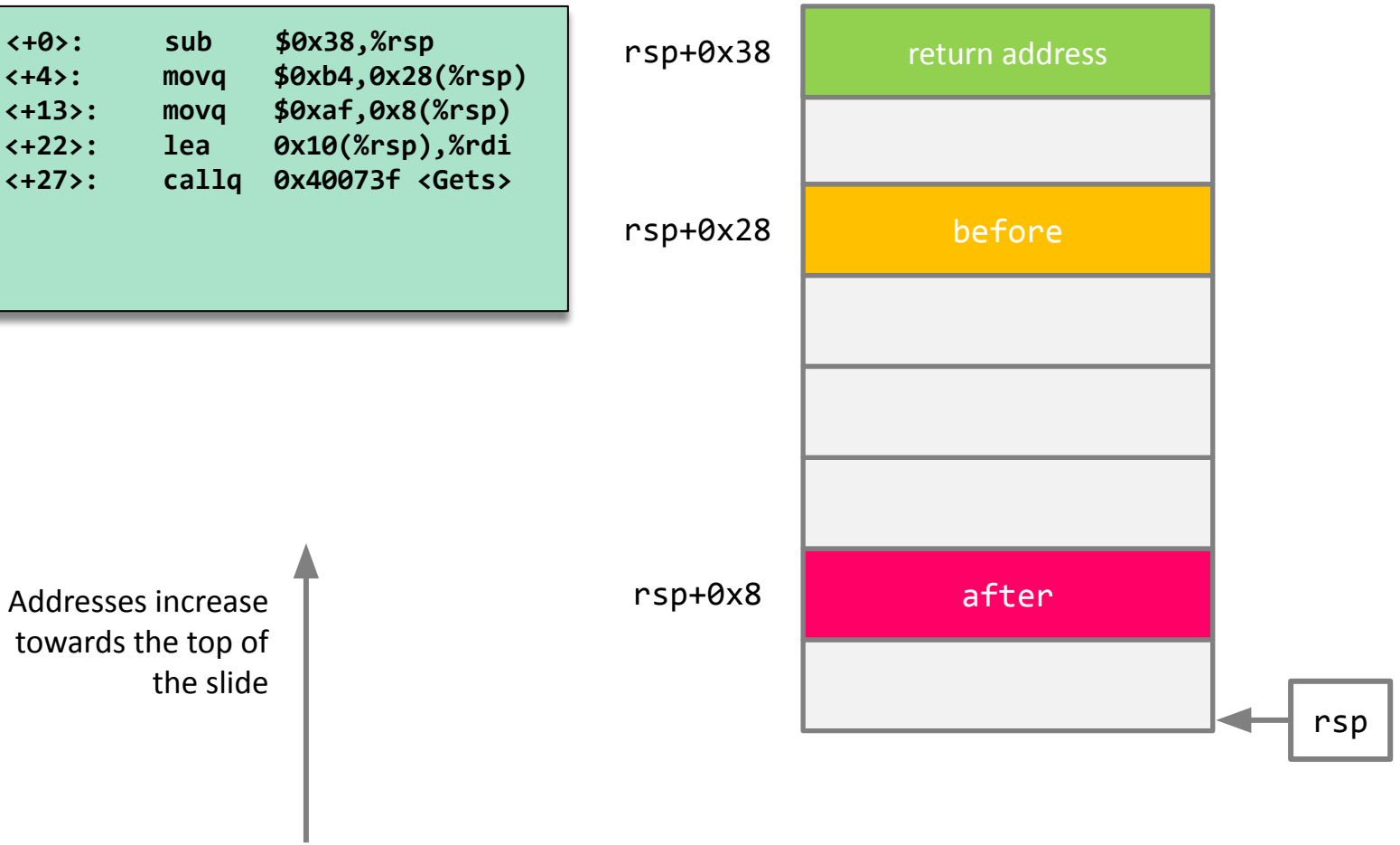
   0x4006b9 <+4>:     movq   $0xb4,0x28(%rsp)
   0x4006c2 <+13>:    movq   $0xaf,0x8(%rsp)
   0x4006cb <+22>:    lea    0x10(%rsp),%rdi
=> 0x4006d0 <+27>:    callq  0x40073f <Gets>
```



Activity 1: Stack diagram

```
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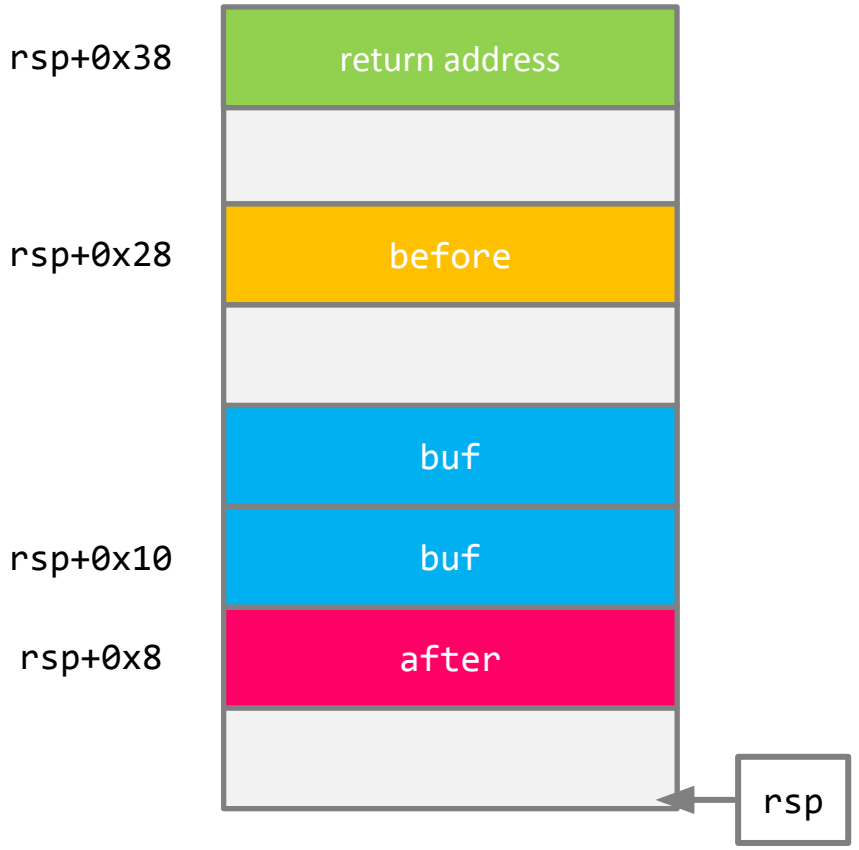
    0x4006b9 <+4>:     movq   $0xb4,0x28(%rsp)
    0x4006c2 <+13>:    movq   $0xaf,0x8(%rsp)
    0x4006cb <+22>:    lea    0x10(%rsp),%rdi
    0x4006d0 <+27>:    callq  0x40073f <Gets>
=> 0x4006d5 <+32>:    mov    0x28(%rsp),%rdx
```



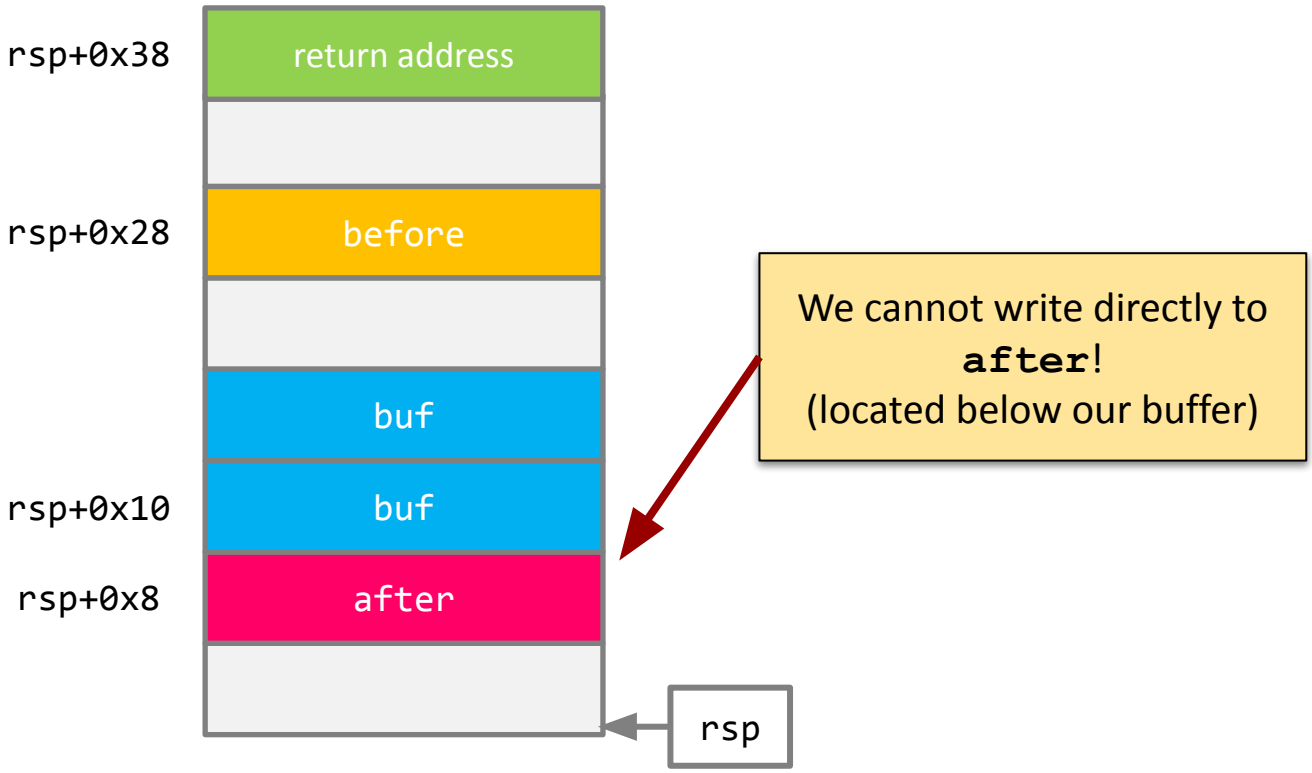
Addresses increase towards the top of the slide

Activity 1: Exploitation

- Goal: call **`win(0x15213)`**
- Take a few minutes to craft an exploit string!
- Crafting an exploit:
  - **`gets()`** stops reading once it sees a newline.
  - Will ***not*** stop reading when it sees a null terminator.

Activity 2

- Objective: call **`win(0x18213)`**
- How is activity 2 different from activity 1?

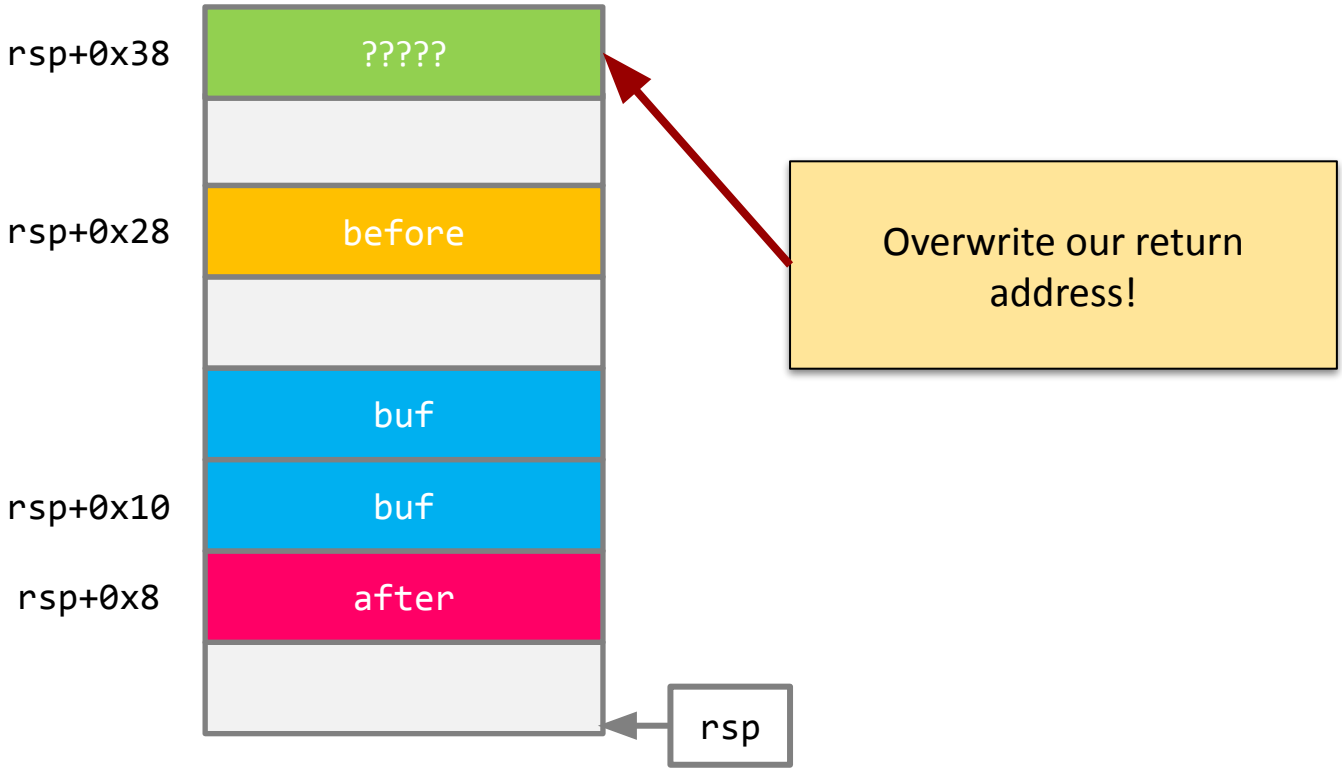


Activity 2: Exploitation

- If we cannot overwrite **`after`** in order to call **`win(0x18213)`**, what is another type of attack we can perform?
- *One possible solution:* Instead of setting local variables that result in calling **`win(0x18213)`**, we can jump to an instruction that directly calls **`win(0x18213)`**!

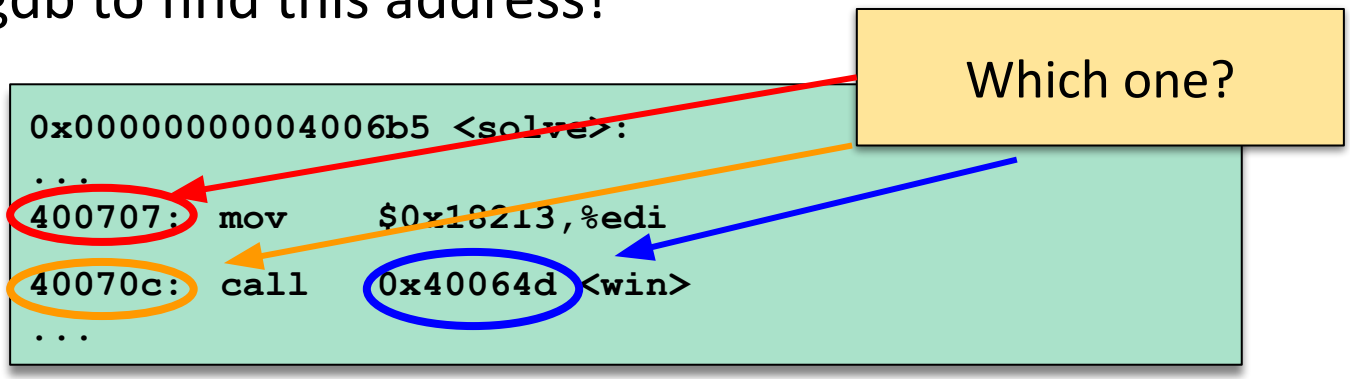
Activity 2

- Change the return address:



Activity 2: Reflection

- What address should we place in our return address?
- Use gdb to find this address!



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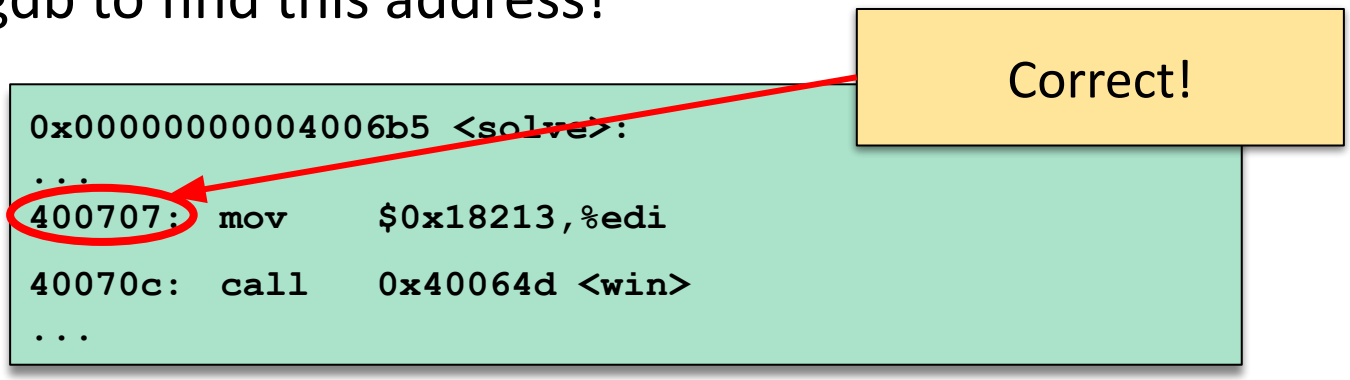
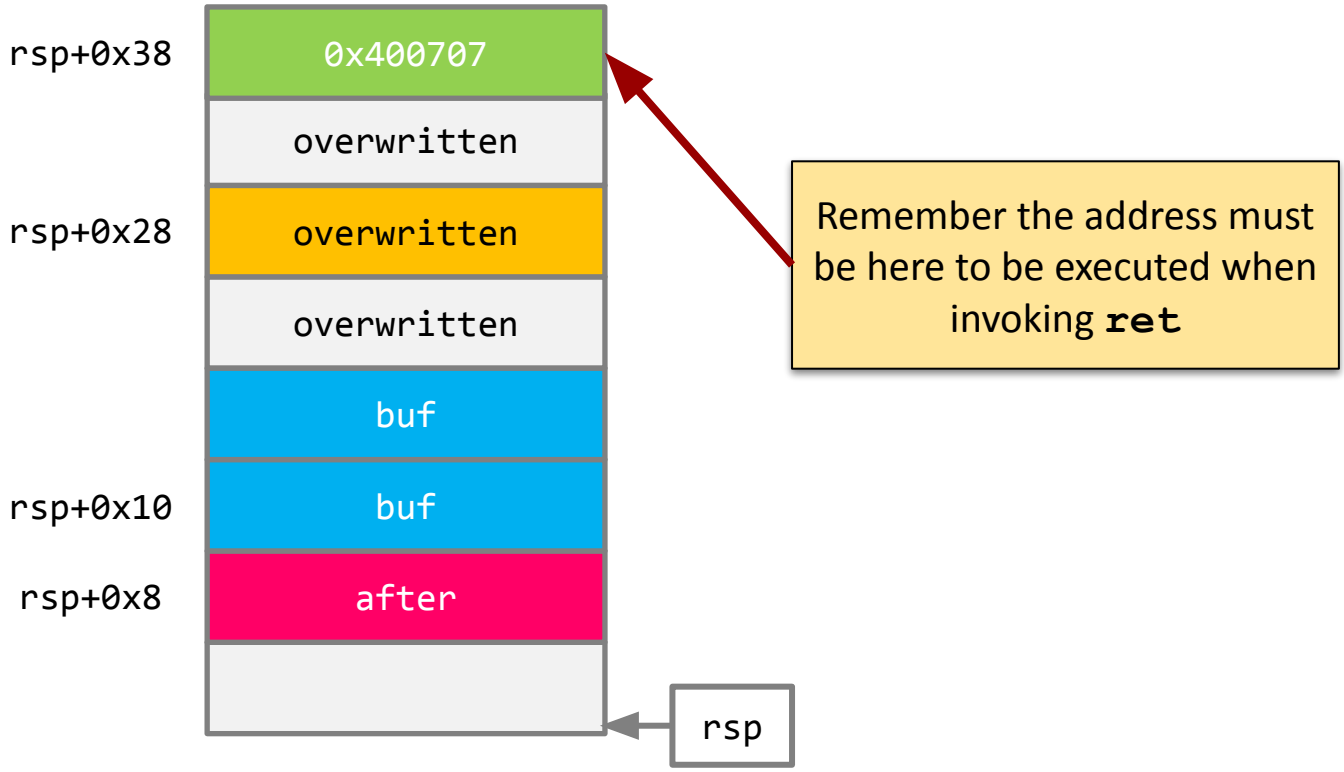
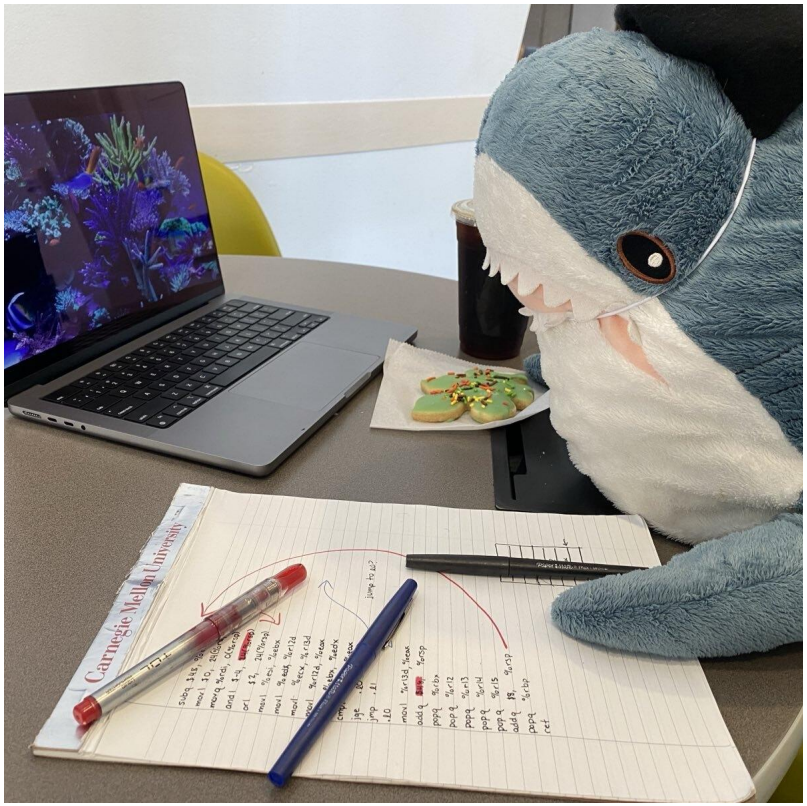


- Remember that we can't just call **`win()`**, we need to ensure that the first argument is set to **`0x18213`**.

Activity 2

- We write this address onto our stack:





The End