18-600: Recitation #4
Exploits (Attack Lab)

September 19th, 2017

Announcements

- Some students have triggered the bomb multiple times
  - Use breakpoints for explode_bomb()
- Attack lab will be released on Sep. 19, 11:59 PT
  - Optional, score doesn't count towards the final grade
  - Available throughout the semester
  - Concepts will be covered in the exam

Agenda

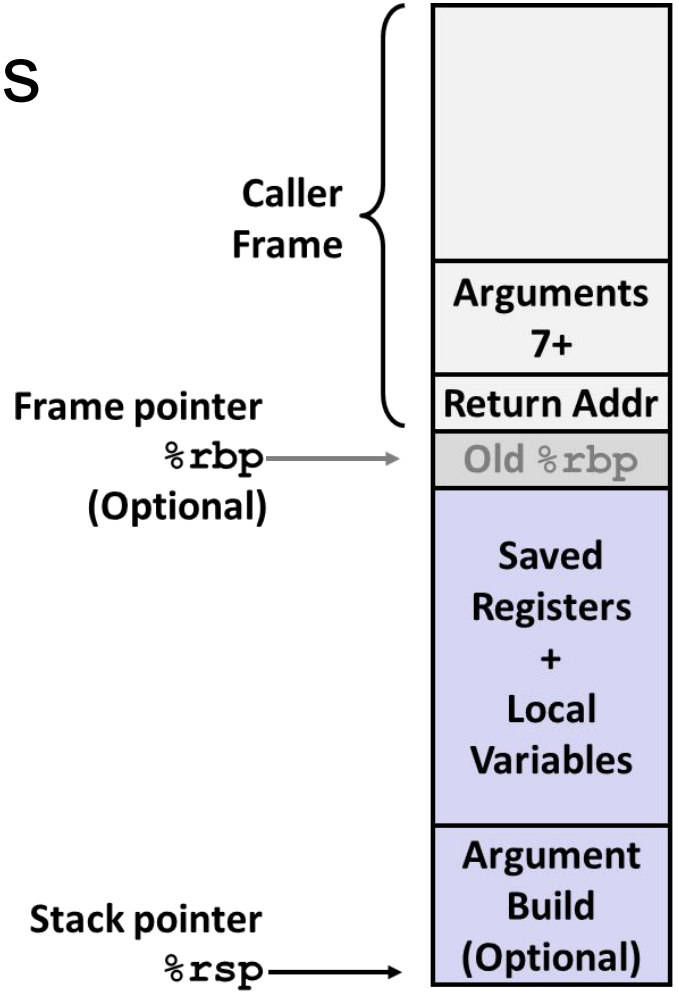
- Recap x86-64 Assembly
- Buffer Overflow Attack
- Return Oriented Programming Attack

Recap: x86-64: Register Conventions

- Arguments passed in registers: `%rdi, %rsi, %rdx, %rcx, %r8, %r9`
- Return value: `%rax`
- Callee-saved: `%rbx, %r12, %r13, %r14, %rbp, %rsp`
- Caller-saved: `%rdi, %rsi, %rdx, %rcx, %r8, %r9, %rax, %r10, %r11`
- Stack pointer: `%rsp`
- Instruction pointer: `%rip`

Recap: x86-64: Stack Frames

- Every function call has its own **stack frame**.
- Think of a frame as a workspace for each call.
  - Local variables
  - Callee and Caller-saved registers
  - Optional arguments for a function call



Recap: x86-64: Function Call Setup

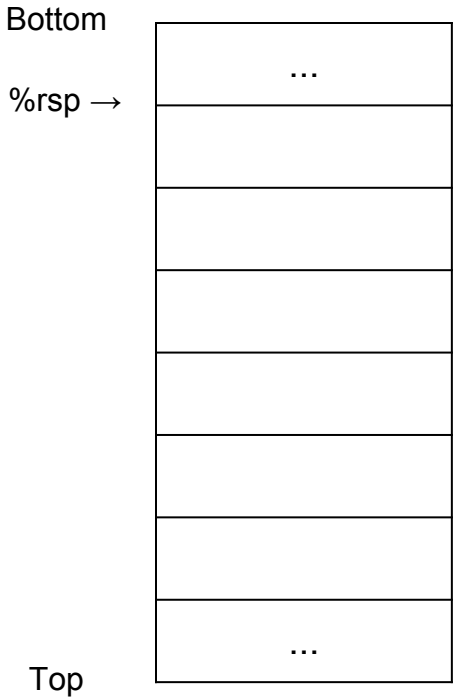
Caller:

- Allocates stack frame large enough for saved registers, optional arguments
- Save any caller-saved registers in frame
- Save any optional arguments (in **reverse order**) in frame
- `call foo`: push `%rip` to stack, jump to label `foo`

Callee:

- Push any callee-saved registers, decrease `%rsp` to make room for new frame

Recap: x86-64: Function Call Setup



%rip

0x18600

Caller-saved Registers:

%rdi

0x1234

%rsi

0x5678

Callee-saved Registers:

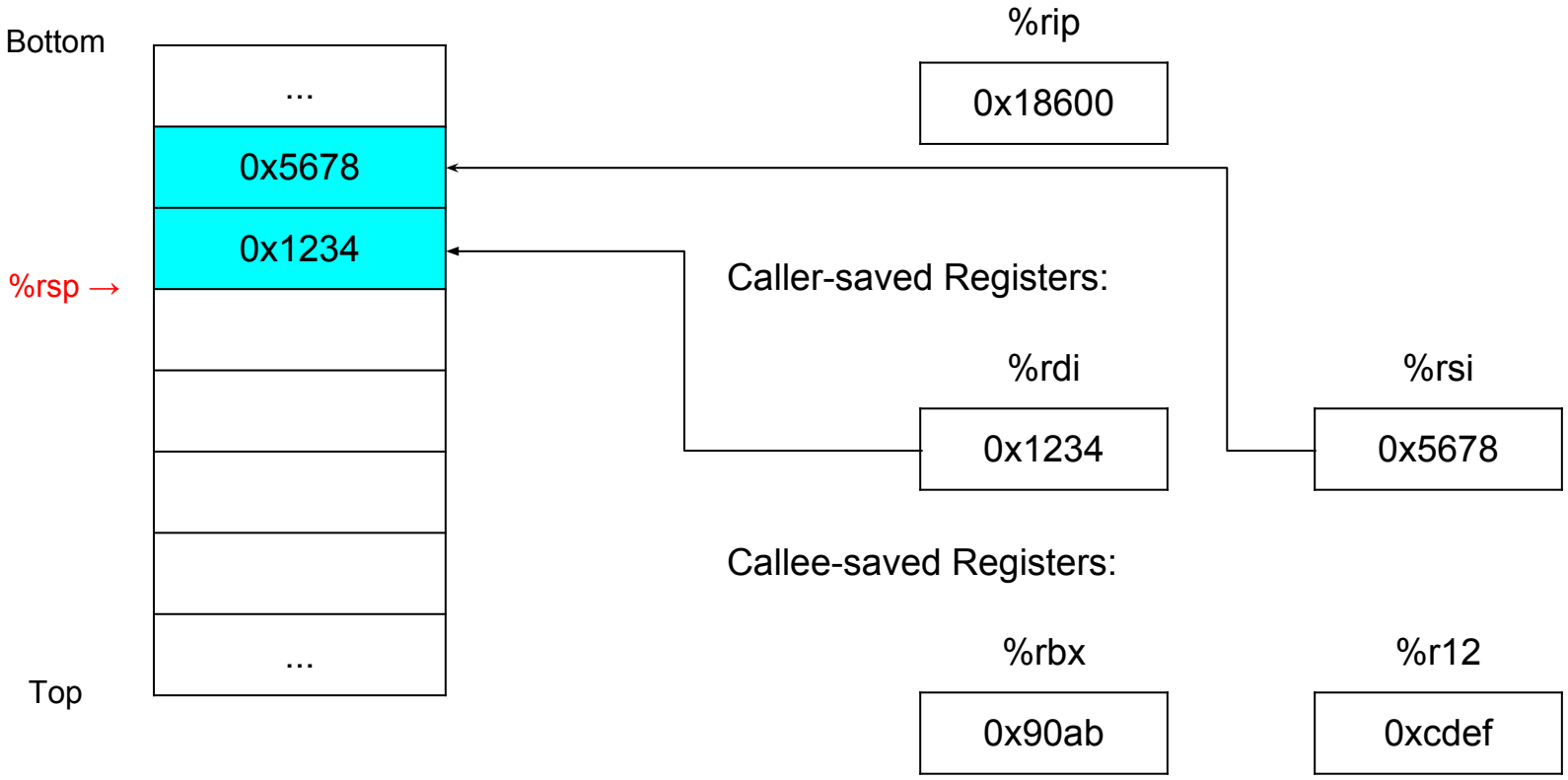
%rbx

0x90ab

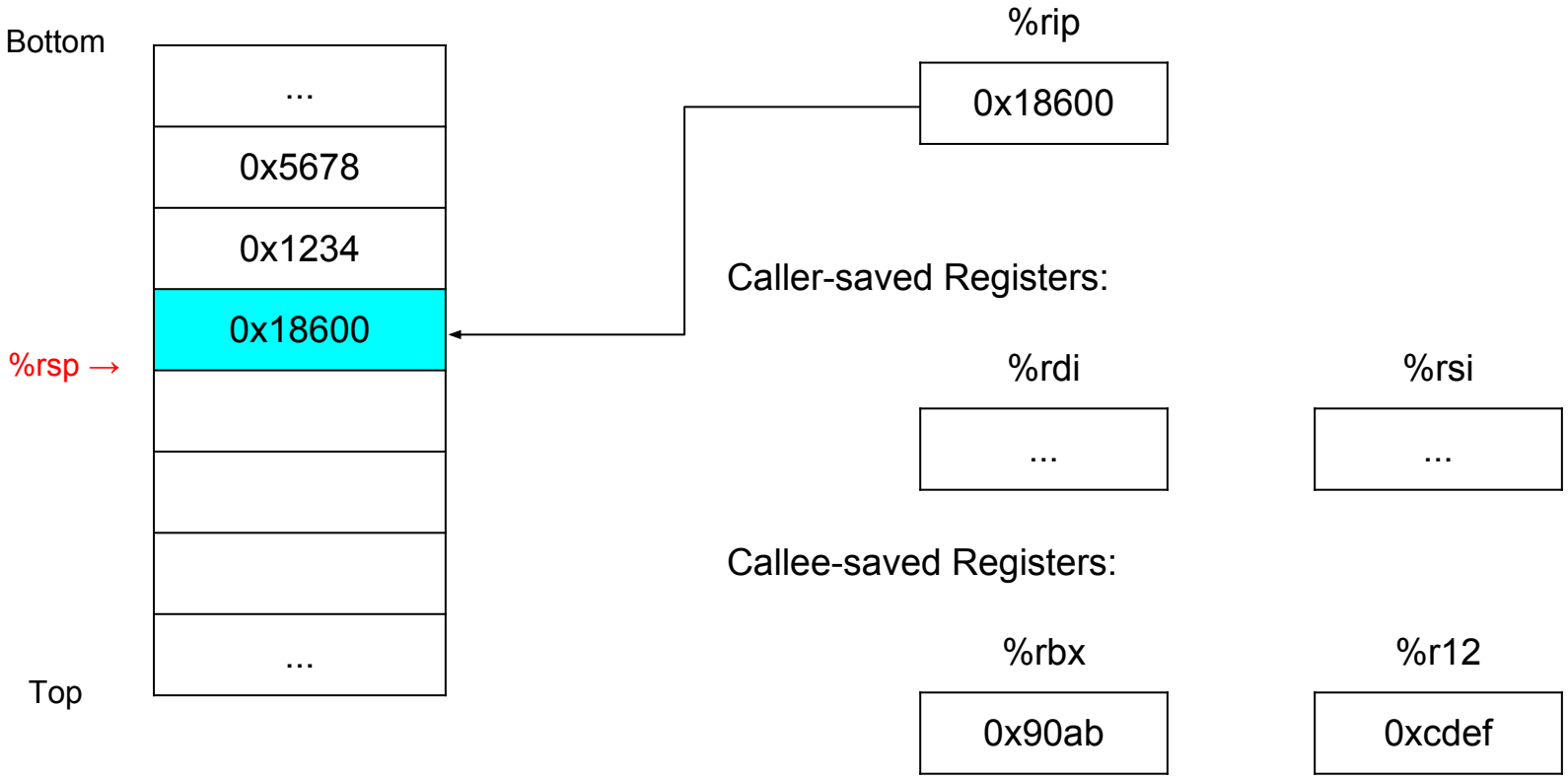
%r12

0xcdef

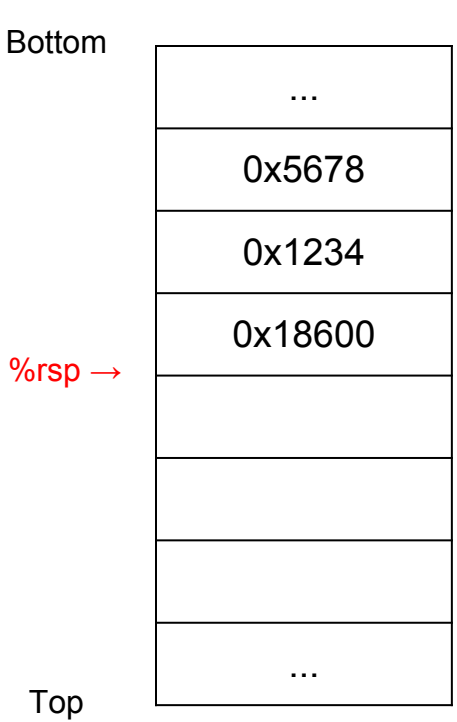
Recap: x86-64: Function Call Setup



Recap: x86-64: Function Call Setup



Recap: x86-64: Function Call Setup



%rip

0x15213

Caller-saved Registers:

%rdi

...

%rsi

...

Callee-saved Registers:

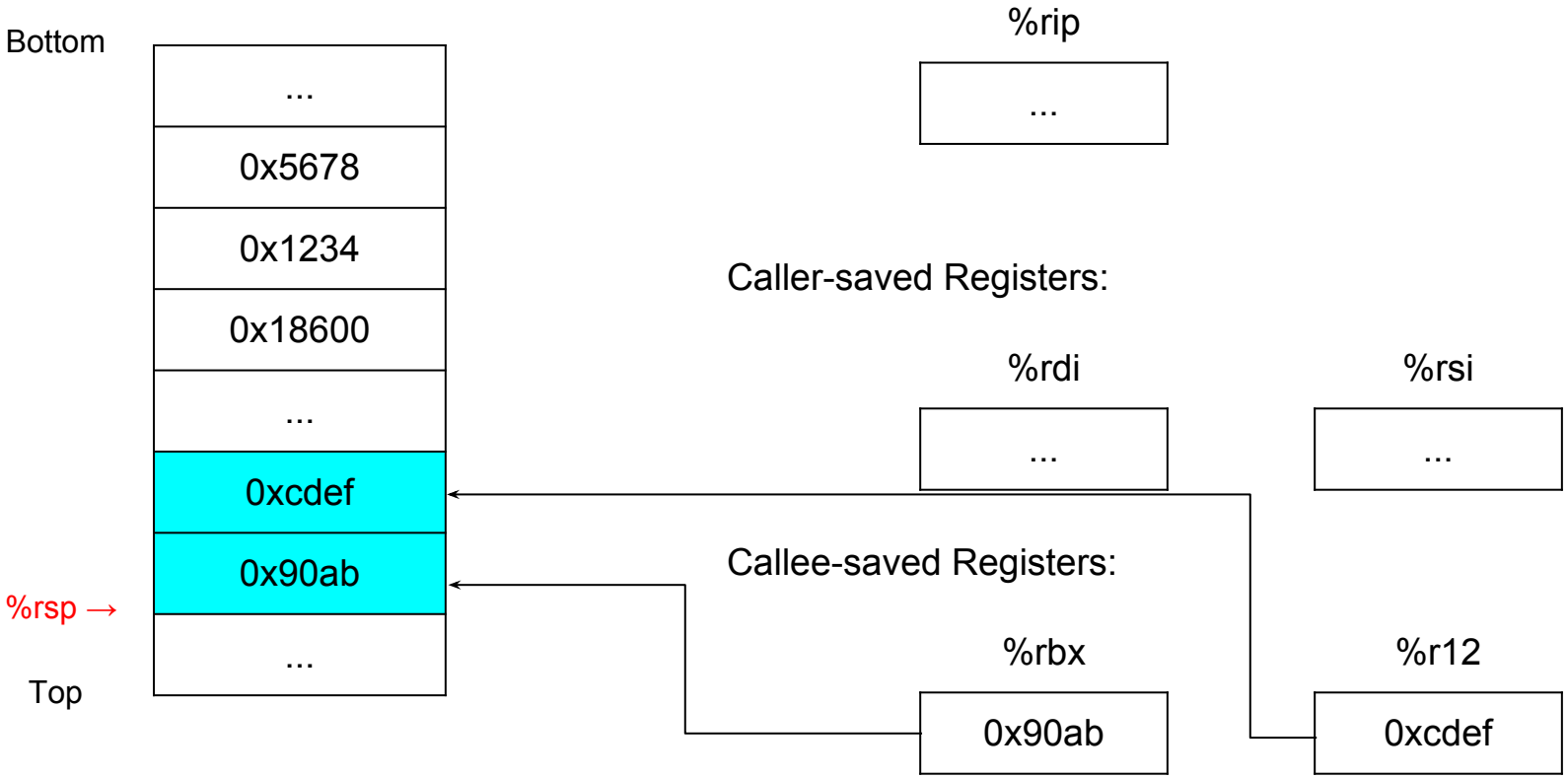
%rbx

0x90ab

%r12

0xcdef

Recap: x86-64: Function Call Setup

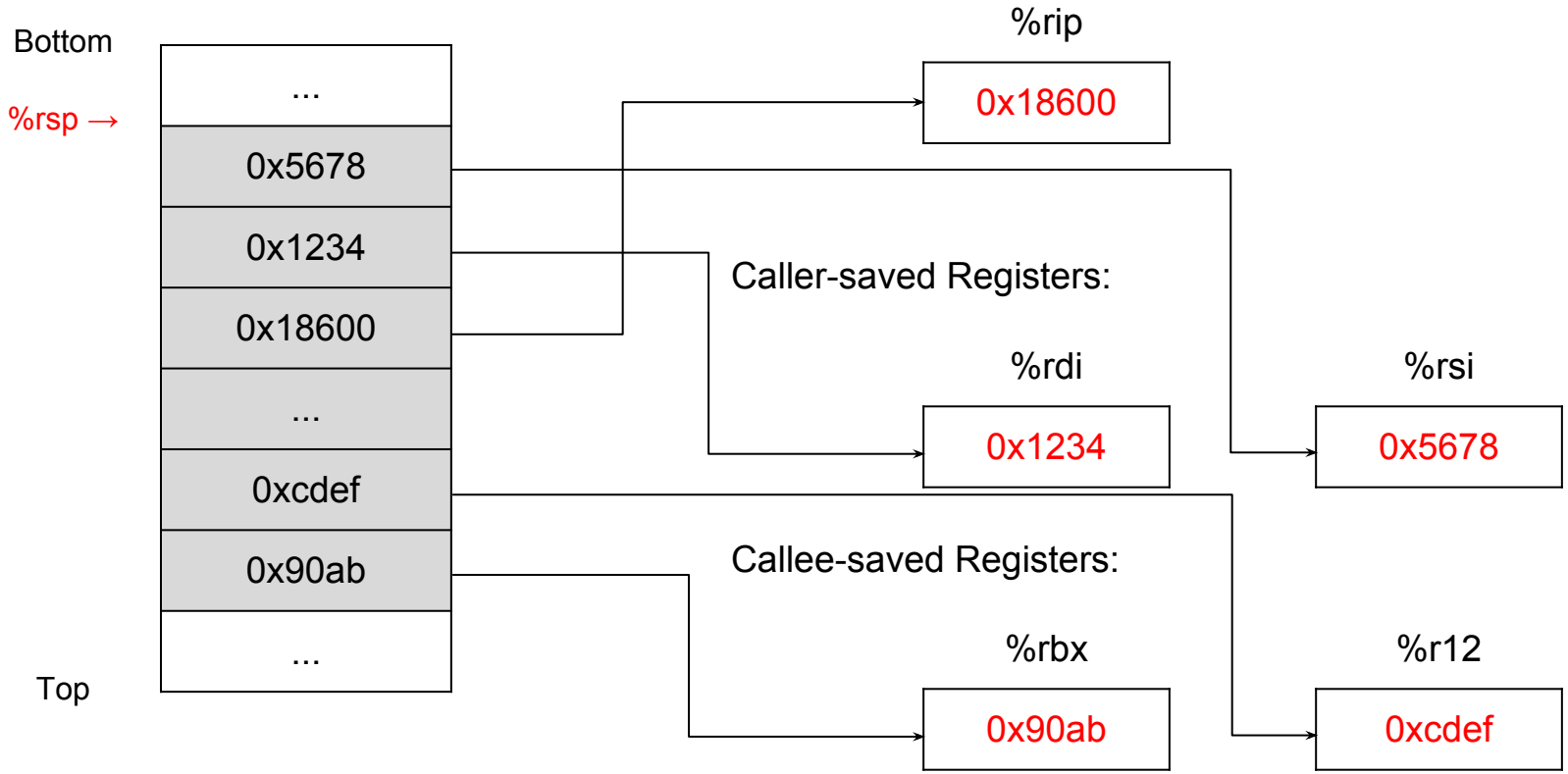


Recap: x86-64: Function Call Return

Callee:

- Increase `%rsp`, pop any callee-saved registers (in **reverse order**), execute `ret: pop %rip`

Recap: x86-64: Function Call Setup



Control Hijacking

Buffer Overflow

- Exploit x86-64 by overwriting the stack
- Overflow a buffer, overwrite return address
- Execute injected code

Strcpy Vulnerability

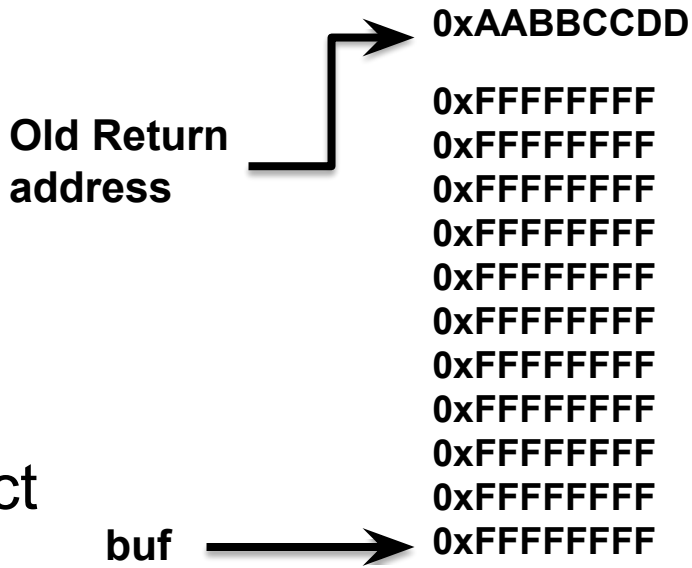
```
int main(int argc, char *argv[]){
    foo(argv[1]);
    ...
}

void foo(char *input){
    char buf[32];
    ...
    strcpy (buf, input);
    return;
}
```

What is the potential issue with this program?

Buffer Overflows

- Exploit *strcpy vulnerability* to overwrite important info on stack
- When this function returns, where will it begin executing?
  - Recall

    ```
    ret:pop %rip
    ```
- What if we want to inject new code to execute?



Generating Byte Codes

- Use **gcc** and **objdump** to generate byte codes for assembly instruction sequences

```
mov     $0x497284,%edi
mov     $0x3b,%eax
syscall
```

exploit.s

```
gcc -c -o exploit.o exploit.s
            &
objdump -d exploit.o > exploit.txt
```


Values in little endian

```
0:   bf 84 72 49 00      mov     $0x497284,%edi
5:   b8 3b 00 00 00      mov     $0x3b,%eax
10:  0f 05               syscall
```

exploit.txt

Buffer Overflows

- Exploit *strcpy vulnerability* to overwrite important info on stack
- When this function returns, where will it begin executing?
  - Recall

    `ret:pop %rip`
- What if we want to inject new code to execute?

Advanced Control Flow Hijacking

- What if the stack addresses are randomized at runtime, so that buf is always in a different place?
  - Potential solution: “nop” slide
- What if a “canary” or secret value has been placed at the end of the buffer, so that the program knows when it has been tampered with?
  - Potential solution: get canary value when generated, to fool checks
- Non-executable memory, e.g. DEP/NX
  - Potential solution: return oriented programming, no code on stack required!

Return Oriented Programming

Overview

- Utilize return-oriented programming to execute arbitrary code
  - Useful when stack is non-executable or randomized
- Find gadgets, string together to form injected code

Key Advice

- Use mixture of pop & mov instructions + constants to perform specific task

ROP Example

- Draw a stack diagram and ROP exploit to **pop a value 0xBBBBBBBB into %rbx** and **move it into %rax**

```
void foo(char *input){
    char buf[32];
    ...
    strcpy (buf, input);
    return;
}
```

Gadgets:

address$_1$: mov %rbx, %rax; ret

address$_2$: pop %rbx; ret

Inspired by content created by Professor David Brumley

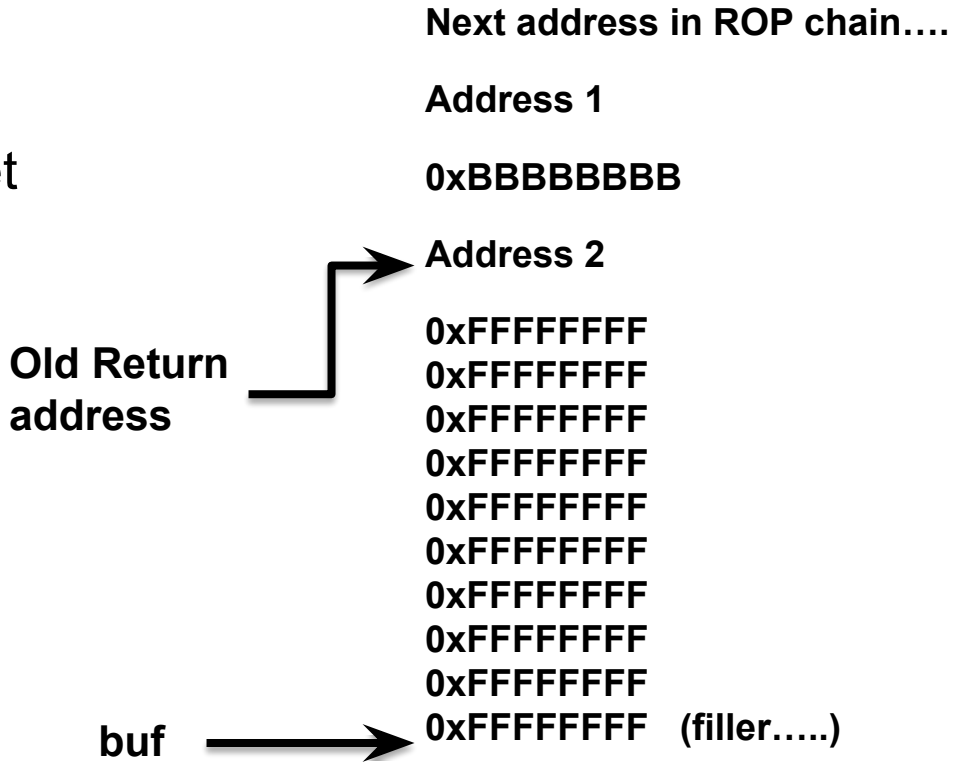
ROP Example: Solution

Gadgets:

Address 1: mov %rbx, %rax; ret

Address 2: pop %rbx; ret

```
void foo(char *input){
    char buf[32];
    ...
    strcpy (buf, input);
    return;
}
```



Looking for Gadgets

- How to identify useful gadgets in your code

```
000000000000013b <some_glibc_fn1>:
 13b:   55                  push   %rbp
 13c:   48 89 e5            mov    %rsp,%rbp
 13f:   48 89 7d f8         mov    %rdi,-0x8(%rbp)
 143:   48 8b 45 f8         mov    -0x8(%rbp),%rax
 147:   c7 00 48 89 e3      mov    %rbp,%rsp
 14c:   5d                  pop    %rbp
 14d:   c3                  ret
```

```
000000000000007c <some_glibc_fn2>:
  7c:   55                  push   %rbp
  7d:   48 89 e5            mov    %rsp,%rbp
  80:   48 89 7d f8         mov    %rdi,-0x8(%rbp)
  84:   48 8b 45 f8         mov    -0x8(%rbp),%rax
  88:   c7 00 c2 6a 30 58   movl   $0x58306ac2,(%rax)
  8e:   5d                  pop    %rbp
  8f:   c3                  ret
```

```
00000000000000b4 <setval_341>:
  b4:   55                  push   %rbp
  b5:   48 89 e5            mov    %rsp,%rbp
  b8:   48 89 7d f8         mov    %rdi,-0x8(%rbp)
  bc:   48 8b 45 f8         mov    -0x8(%rbp),%rax
  c0:   c7 00 cf 08 89 e0   movl   $0xe08908cf,(%rax)
  c6:   5d                  pop    %rbp
  c7:   c3                  ret
```

```
89 e0 : movl %esp, %eax
5d:     pop %rbp
c3:     ret
```

A. Encodings of `movq` instructions

`movq` *S*, *D*

Source *S*	Destination *D*							
	%rax	%rcx	%rdx	%rbx	%rsp	%rbp	%rsi	%rdi
%rax	48 89 c0	48 89 c1	48 89 c2	48 89 c3	48 89 c4	48 89 c5	48 89 c6	48 89 c7
%rcx	48 89 c8	48 89 c9	48 89 ca	48 89 cb	48 89 cc	48 89 cd	48 89 ce	48 89 cf
%rdx	48 89 d0	48 89 d1	48 89 d2	48 89 d3	48 89 d4	48 89 d5	48 89 d6	48 89 d7
%rbx	48 89 d8	48 89 d9	48 89 da	48 89 db	48 89 dc	48 89 dd	48 89 de	48 89 df
%rsp	48 89 e0	48 89 e1	48 89 e2	48 89 e3	48 89 e4	48 89 e5	48 89 e6	48 89 e7
%rbp	48 89 e8	48 89 e9	48 89 ea	48 89 eb	48 89 ec	48 89 ed	48 89 ee	48 89 ef
%rsi	48 89 f0	48 89 f1	48 89 f2	48 89 f3	48 89 f4	48 89 f5	48 89 f6	48 89 f7
%rdi	48 89 f8	48 89 f9	48 89 fa	48 89 fb	48 89 fc	48 89 fd	48 89 fe	48 89 ff

B. Encodings of `popq` instructions

Operation	Register *R*							
	%rax	%rcx	%rdx	%rbx	%rsp	%rbp	%rsi	%rdi
popq *R*	58	59	5a	5b	5c	5d	5e	5f

C. Encodings of `movl` instructions

`movl` *S*, *D*

Source *S*	Destination *D*							
	%eax	%ecx	%edx	%ebx	%esp	%ebp	%esi	%edi
%eax	89 c0	89 c1	89 c2	89 c3	89 c4	89 c5	89 c6	89 c7
%ecx	89 c8	89 c9	89 ca	89 cb	89 cc	89 cd	89 ce	89 cf
%edx	89 d0	89 d1	89 d2	89 d3	89 d4	89 d5	89 d6	89 d7
%ebx	89 d8	89 d9	89 da	89 db	89 dc	89 dd	89 de	89 df
%esp	89 e0	89 e1	89 e2	89 e3	89 e4	89 e5	89 e6	89 e7
%ebp	89 e8	89 e9	89 ea	89 eb	89 ec	89 ed	89 ee	89 ef
%esi	89 f0	89 f1	89 f2	89 f3	89 f4	89 f5	89 f6	89 f7
%edi	89 f8	89 f9	89 fa	89 fb	89 fc	89 fd	89 fe	89 ff

D. Encodings of 2-byte functional nop instructions

Operation	Register *R*			
	%al	%cl	%dl	%bl
andb *R*, *R*	20 c0	20 c9	20 d2	20 db
orb *R*, *R*	08 c0	08 c9	08 d2	08 db
cmpb *R*, *R*	38 c0	38 c9	38 d2	38 db
testb *R*, *R*	84 c0	84 c9	84 d2	84 db

Figure 3: Byte encodings of instructions. All values are shown in hexadecimal.

Summary

- Attack lab is posted for fun on Autolab
- TAs will be *very pleased* if you attempt it
- We expect you to be familiar with this content at a high level

Questions?