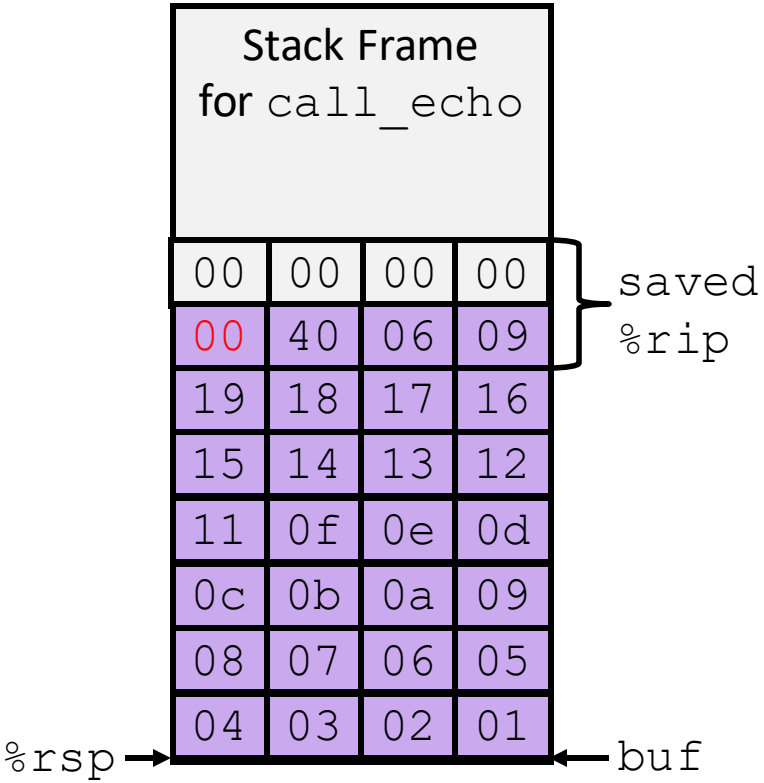
# Lecture 9: Buffer Overflows (cont'd)

CS 105 Fall 2024

# Review: Buffer Overflow Attack

- Idea: overwrite return address with address of instruction you want to execute next
  - If a string: use padding to fill up space between array and saved rip

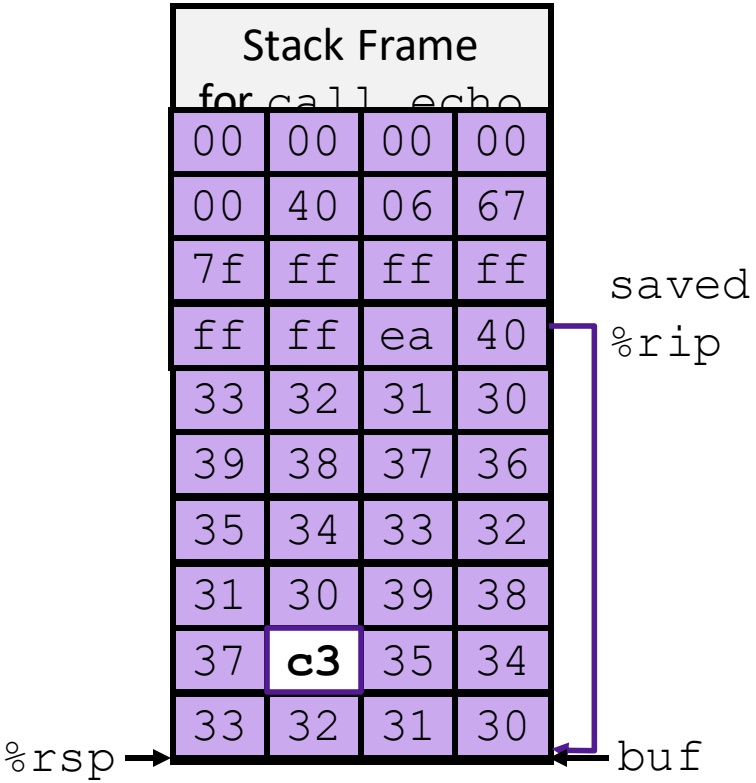



```
/* Echo Line */
void echo()
{
    char buf[4];
    gets(buf);
    puts(buf);
}
```

```
echo:
  subq  $0x18, %rsp
  movq  %rsp, %rdi
  call  gets
  call puts
  addq  $0x18, %rsp
  ret
```

# Code Injection

- Idea: fill the buffer with bytes that will be interpreted as code
- Overwrite the return address with address of the beginning of the buffer




```
/* Echo Line */
void echo()
{
    char buf[4];
    gets(buf);
    puts(buf);
}
```

```
echo:
  subq  $18, %rsp
  movq  %rsp, %rdi
  call  gets
  call puts
  addq  $18, %rsp
  ret
```

# Exercise: Code Injection

- Construct an input string that will cause this program to print 47.

```
int x = 13;

void echo(){
  char buf[12];
  gets(buf);
  puts(buf);
}

int main(int argc, char ** argv){
  printf("Enter a string: ");
  echo();
  printf("%d\n", x);
  return 0;
}
```

# Exercise: Code In

- Construct an input string th
  print 47.

```
int x = 13;

void echo(){
  char buf[12];
  gets(buf);
  puts(buf);
}

int main(int argc, char ** argv){
  printf("Enter a string: ");
  echo();
  printf("%d\n", x);
  return 0;
}
```

Assume `%rsp == 0x7fffffffe168` at the beginning of `echo`

```
echo:
   0x400616 <+0>:   sub    $0x18,%rsp
   0x40061a <+4>:   lea    0x4(%rsp),%rax
   0x40061f <+9>:   mov    %rax,%rdi
   0x400622 <+12>:  mov    $0x0,%eax
   0x400627 <+17>:  callq  0x400520 <gets>
   0x40062c <+22>:  lea    0x4(%rsp),%rax
   0x400631 <+27>:  mov    %rax,%rdi
   0x400634 <+30>:  callq  0x400500 <puts@>
   0x400639 <+35>:  nop
   0x40063a <+36>:  add    $0x18,%rsp
   0x40063e <+40>:  retq
main:
   0x40063f <+0>:   sub    $0x18,%rsp
   0x400643 <+4>:   mov    %edi,0xc(%rsp)
   0x400647 <+8>:   mov    %rsi,(%rsp)
   0x40064b <+12>:  mov    $0x400728,%edi
   0x400650 <+17>:  mov    $0x0,%eax
   0x400655 <+22>:  callq  0x400510 <printf>
   0x40065a <+27>:  mov    $0x0,%eax
   0x40065f <+32>:  callq  0x400616 <echo>
   0x400664 <+37>:  mov    0x601034,%eax
   0x40066a <+43>:  mov    %eax,%esi
   0x40066c <+45>:  mov    $0x400739,%edi
   0x400671 <+50>:  mov    $0x0,%eax
   0x400676 <+55>:  callq  0x400510 <printf>
   0x40067b <+60>:  mov    $0x0,%eax
   0x400680 <+65>:  add    $0x18,%rsp
   0x400684 <+69>:  retq
```

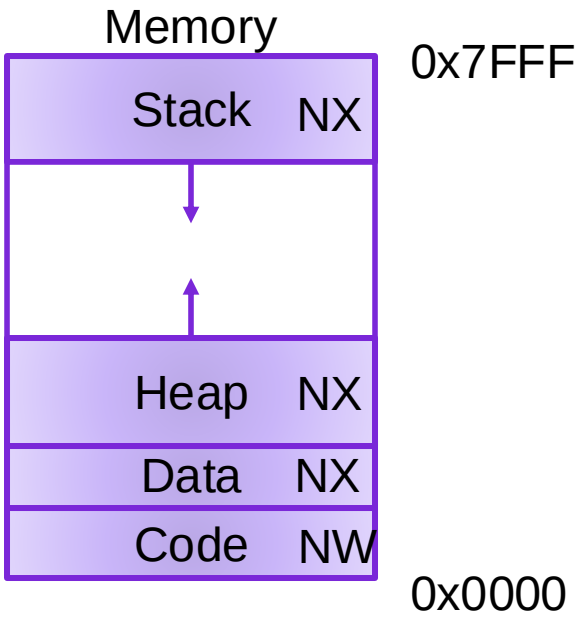
```
0000000000000000 <.text>:
   0:   48 c7 04 25 34 10 60 00 2f 00 00 00    movq   $0x2f,0x601034
   c:   c3                                     retq
```

# Defense #1: Bounds Checks

```
/* Echo Line */
void echo(){
  char buf[12];
  fgets(buf, 12, stdin);
  puts(buf);
}
```

- For example, use library routines that limit string lengths
  - **`fgets`** instead of **`gets`**
  - **`strncpy`** instead of **`strcpy`**
  - Don't use **`scanf`** with **`%s`** conversion specification (use **`fgets`** to read the string or use **`%ns`** where **`n`** is a suitable integer)
- Or use a high-level language

# Defense #2: Memory Tagging


GCC Implementation

- Now the default
- Can disable with **`-z execstack`**

# Code Reuse Attacks

- Key idea: execute instructions that already exist
- Defeats memory tagging defenses
- Examples:
  1. return to a function or line in the current program
  2. return to a library function (e.g., return-into-`libc`)
  3. return to some other instruction (return-oriented programming)

# Properties of x86 Assembly

- lots of instructions
- variable length instructions
- not word aligned
- dense instruction set

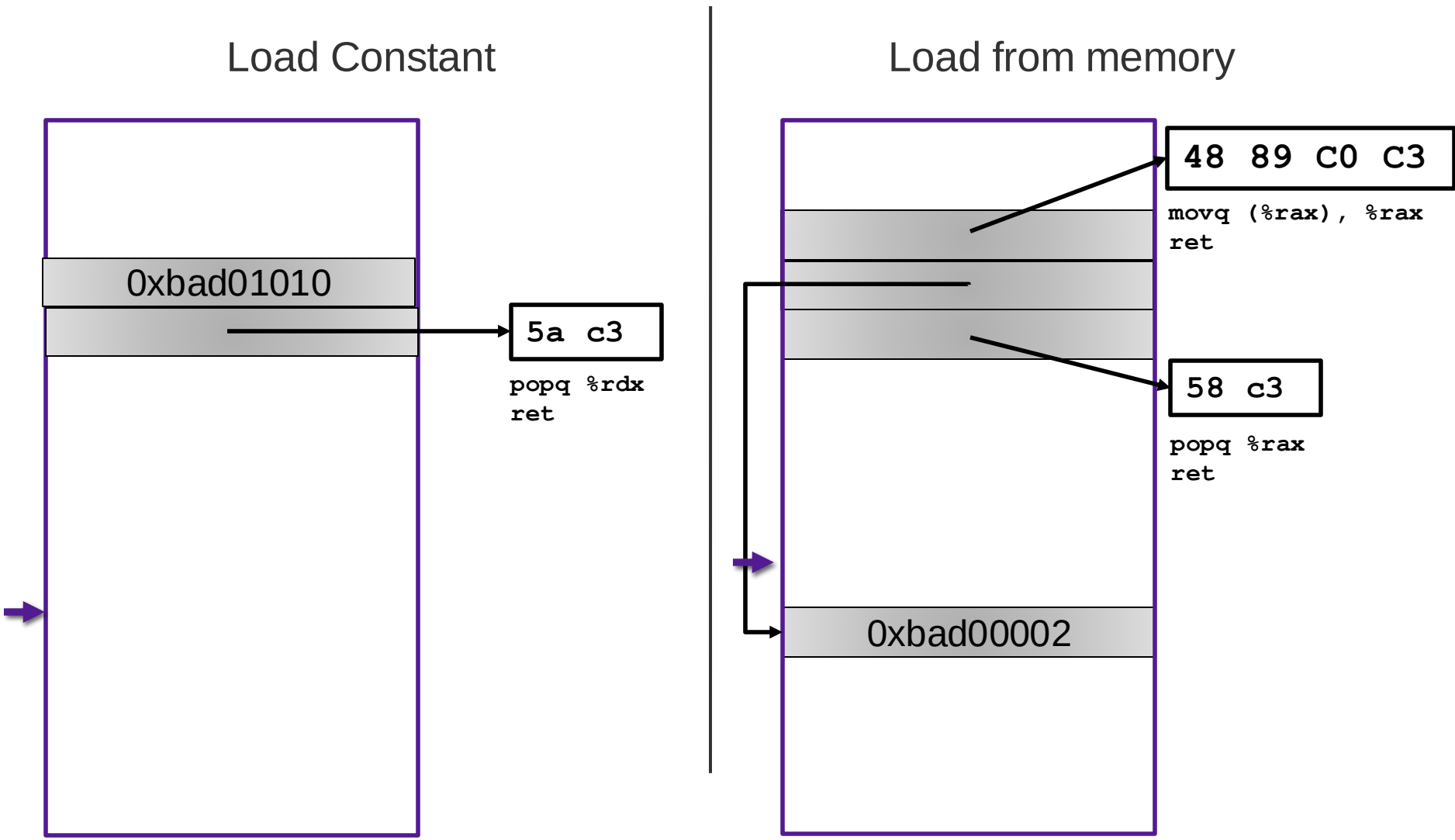
# Gadgets

```
void setval(unsigned* p) {
  *p = 3347663060u;
}
```

```
<setval>:
4004d9: c7 07 d4 48 89 c7   movl $0xc78948d4,(%rdi)
4004df: c3                  ret
```

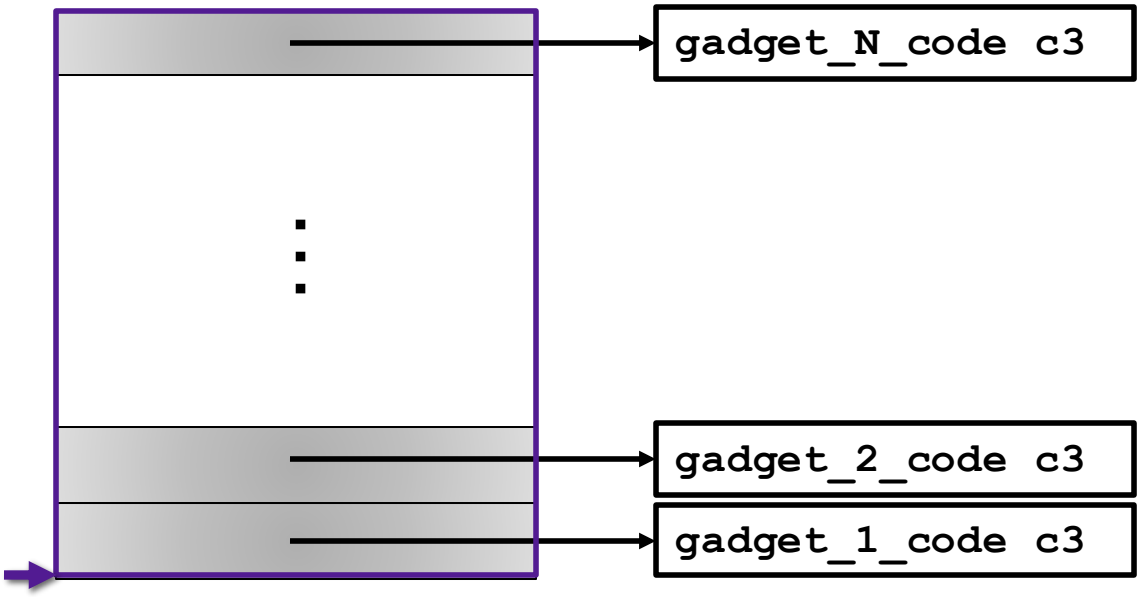
gadget address: `0x4004dc`
encodes: `movq %rax, %rdi`
`ret`
executes: `%rdi <- %rax`

# Example Gadgets



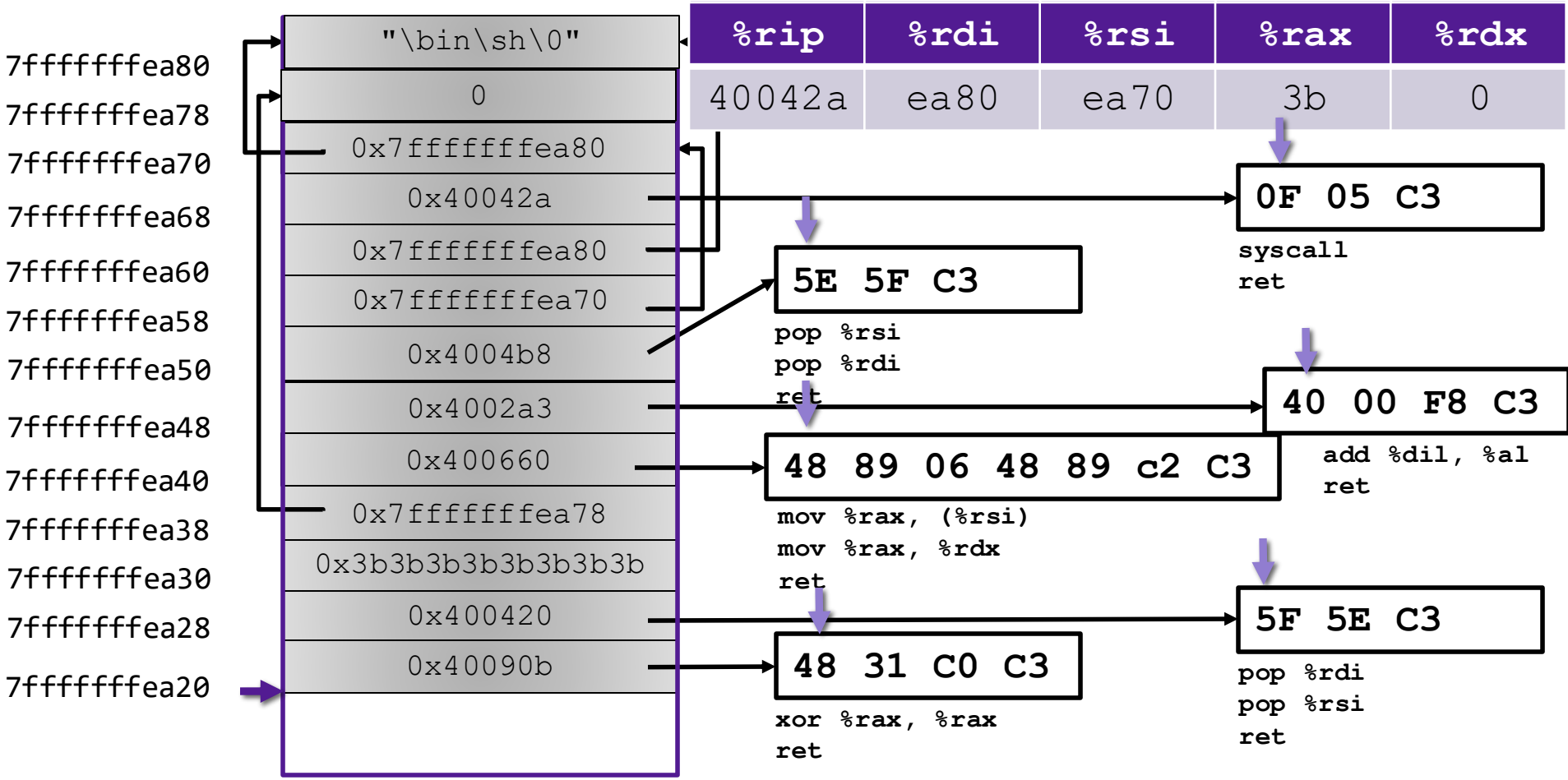
# Return-oriented Programming

# Return-oriented Programming



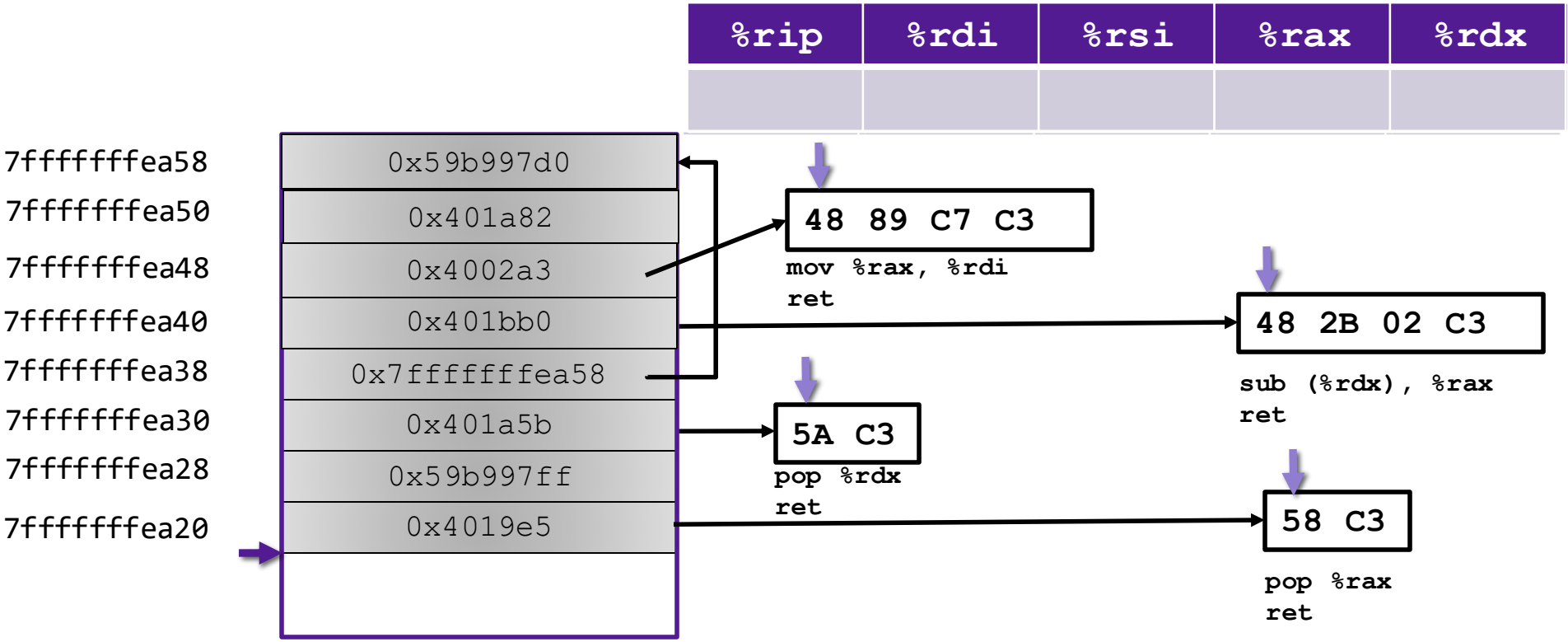

Final ret in each gadget sets pc (%rip) to beginning of next gadget code

# Return-Oriented Shellcode



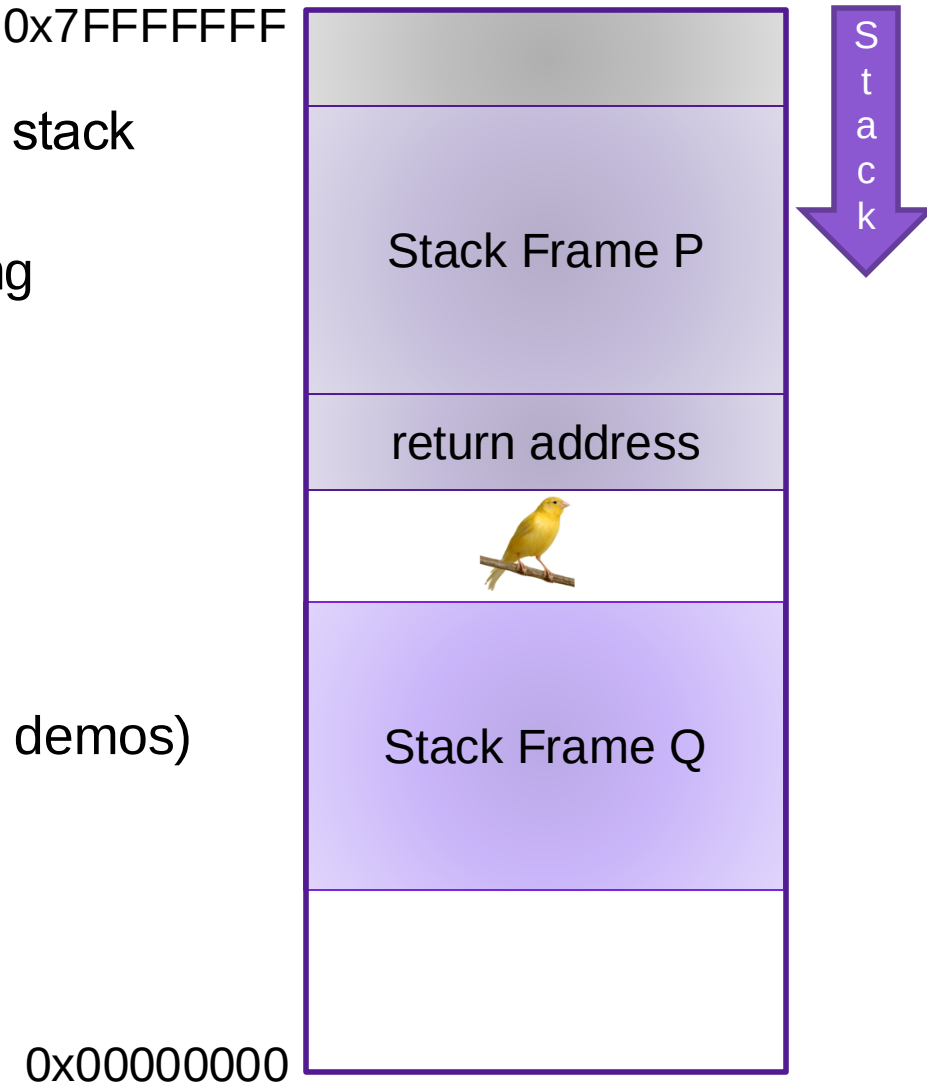
# Exercise: ROP

- What are the values in the registers when the function at address 0x401a82 starts executing?

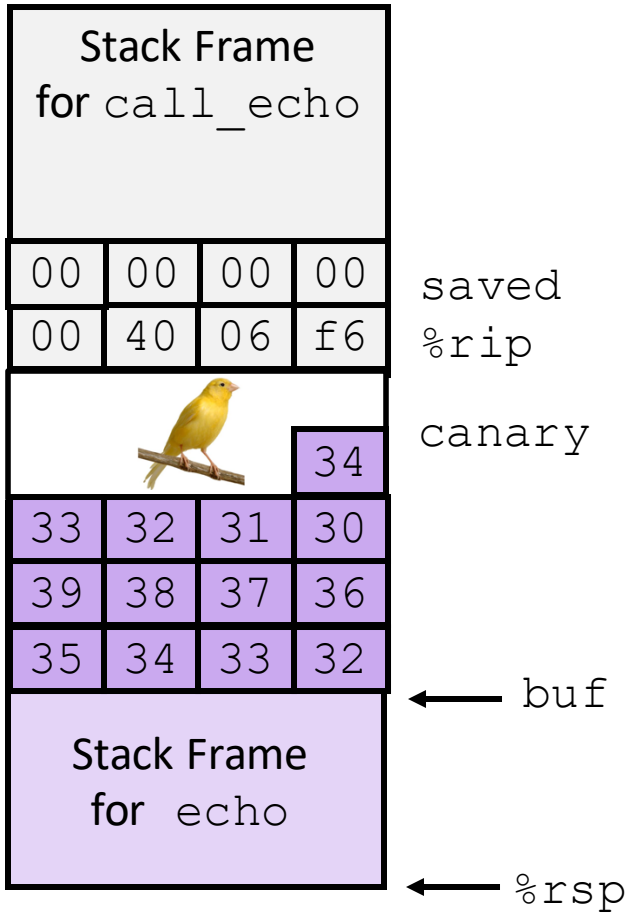


# Defense #3: Compiler checks

- Idea
  - Place special value (“canary”) on stack just beyond buffer
  - Check for corruption before exiting function
- GCC Implementation
  - `-fstack-protector`
  - Now the default (disabled in prior demos)



# Stack Canaries



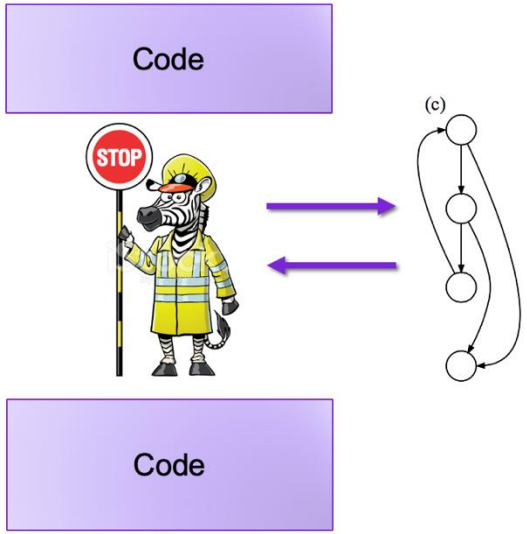

```
echo:
    sub     $0x28,%rsp
    mov     %fs:0x28,%rax
    mov     %rax,0x18(%rsp)
    xor     %eax,%eax
    lea     0xc(%rsp),%rax
    mov     %rax,%rdi
    mov     $0x0,%eax
    callq   0x400590 <gets>
    lea     0xc(%rsp),%rax
    mov     %rax,%rdi
    callq   0x400560 <puts>
    nop
    mov     0x18(%rsp),%rax
    xor     %fs:0x28,%rax
    je      0x4006cf <echo+73>
    callq   0x400570 <__stack_chk_fail>
    add     $0x28,%rsp
    retq
```

# Other Defenses

Address Space Layout Randomization

Gadget Elimination

Control Flow Integrity



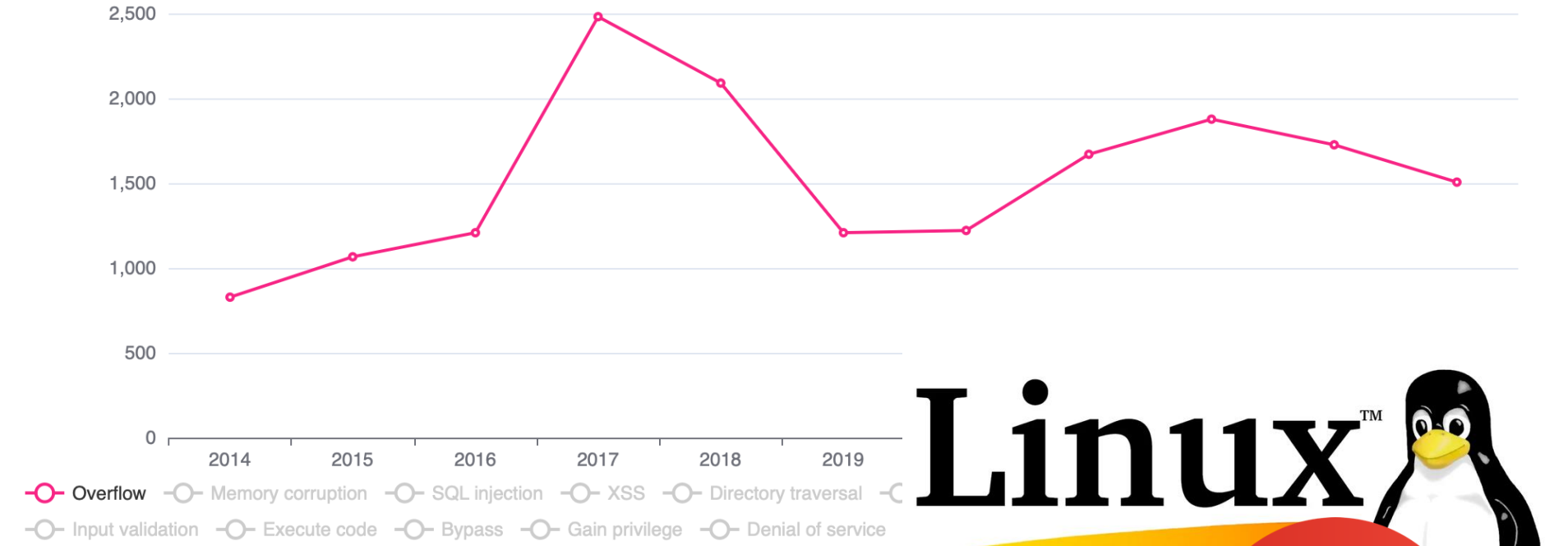
# The state of the world

Defenses:

- high-level languages
- Stack Canaries
- Memory tagging
- ASLR
- continuing research and development…

But all they aren't perfect!

# The state of the world




Linux™

Canon