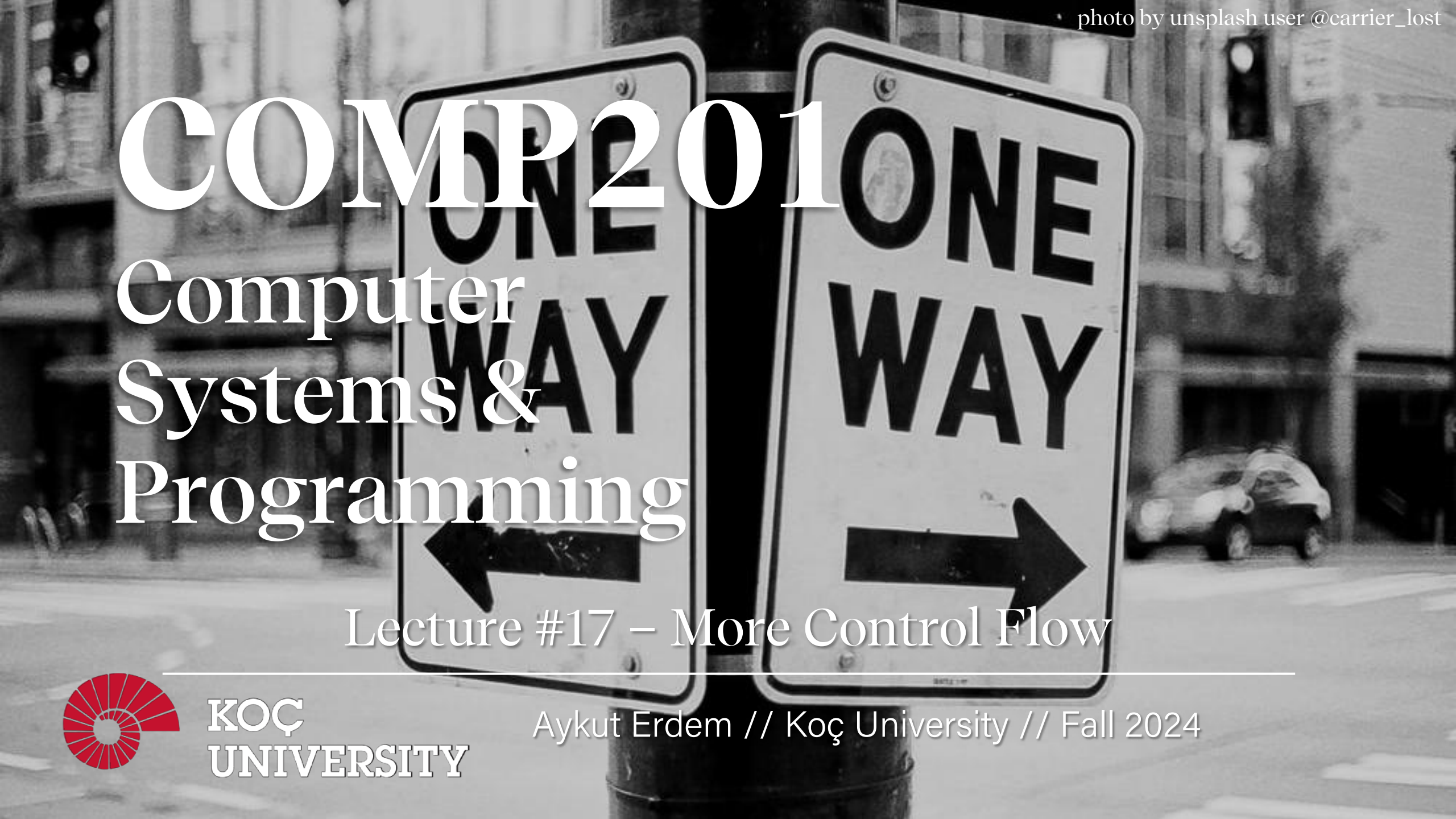



photo by unsplash user @carrier_lost

# COMP201

# Computer Systems & Programming

## Lecture #17 – More Control Flow

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Fall 2024

# Recap

- Assembly Execution and `%rip`
- Control Flow Mechanics
  - Condition Codes
  - Assembly Instructions

# Recap: Executing Instructions

So far:

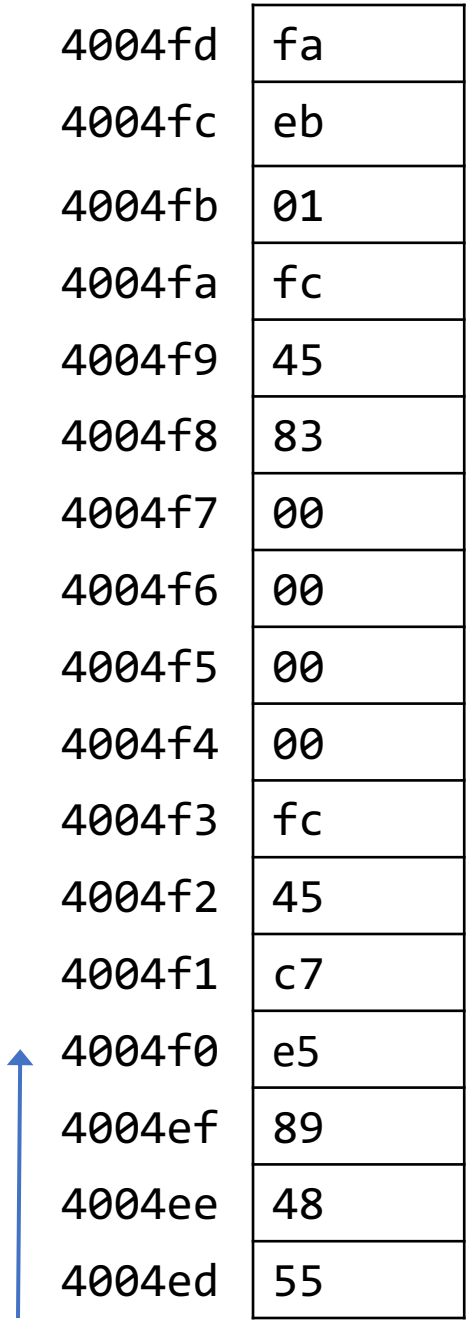
- Program values can be stored in memory or registers.
- Assembly instructions read/write values back and forth between registers (on the CPU) and memory.
- Assembly instructions are also stored in memory.

Last time:

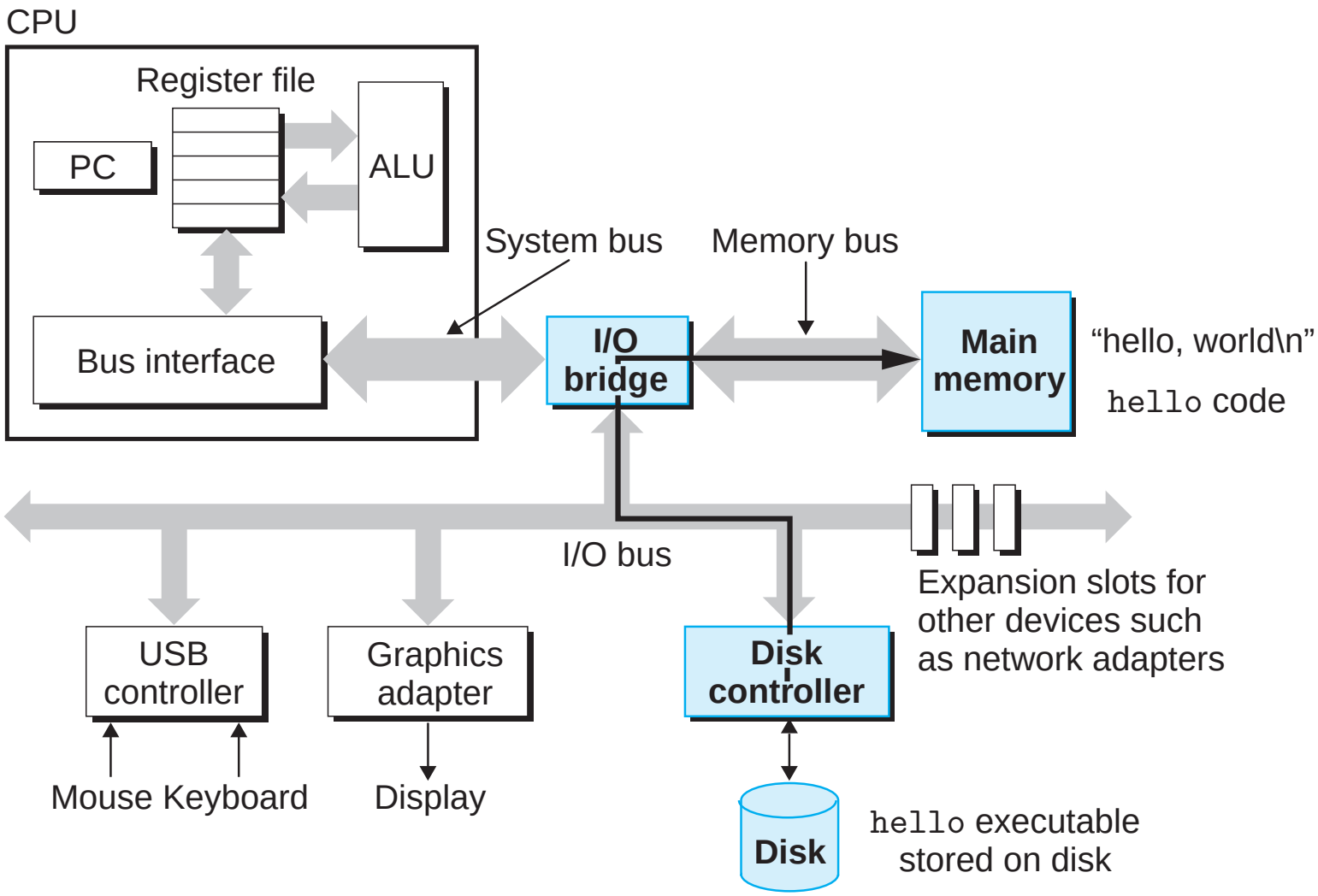
- **Who controls the instructions?**
  How do we know what to do now or next?

Answer:

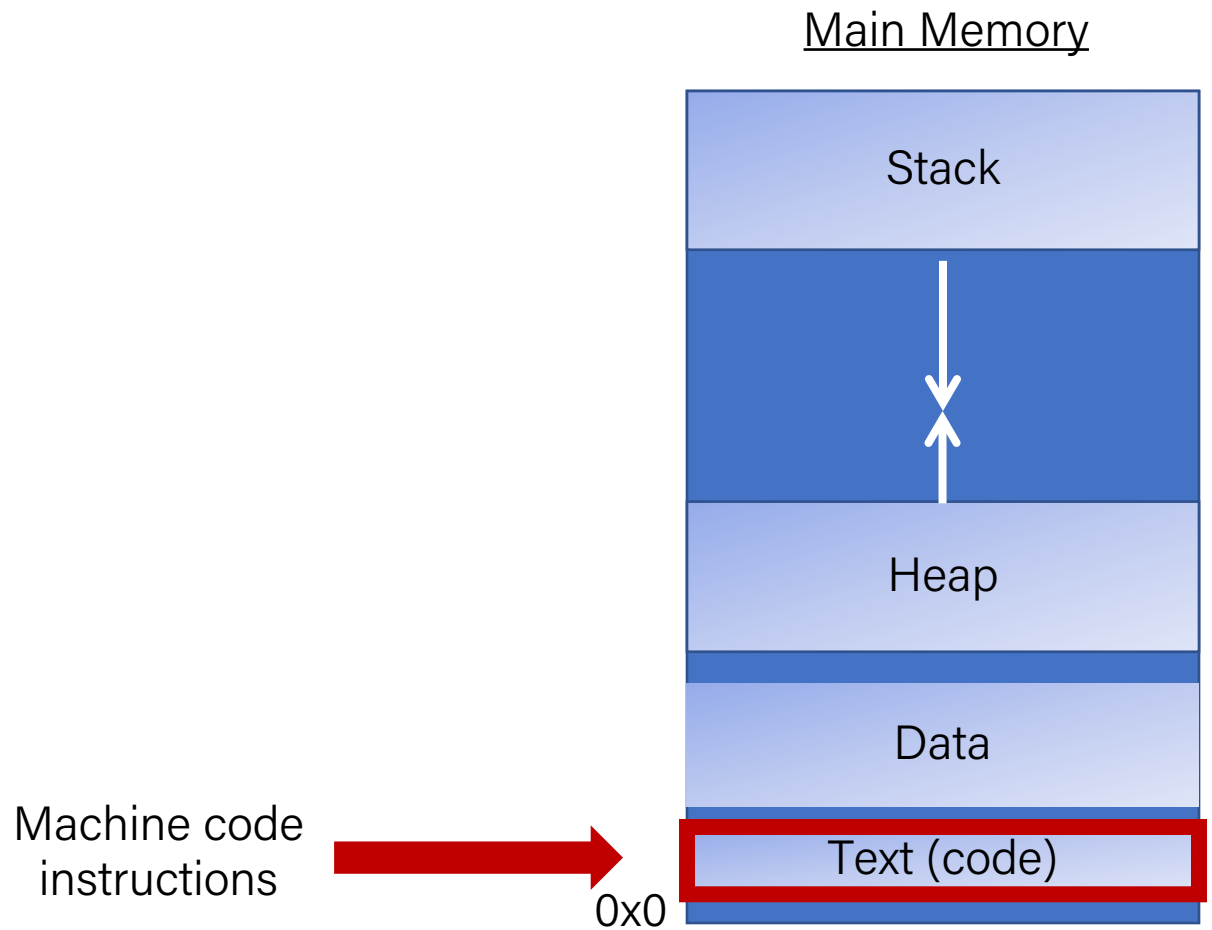
- The **program counter** (PC), `%rip`.



# Recap: Instructions Are Just Bytes!



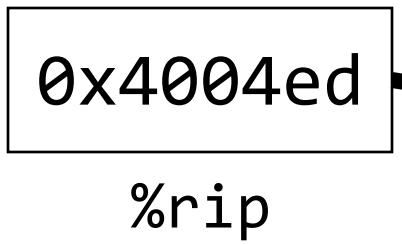
# Recap: Instructions Are Just Bytes!



# Recap: %rip

```
0000000004004ed <loop>:
4004ed: 55                              push   %rbp
4004ee: 48 89 e5                        mov    %rsp,%rbp
4004f1: c7 45 fc 00 00 00 00            movl   $0x0,-0x4(%rbp)
4004f8: 83 45 fc 01                     addl   $0x1,-0x4(%rbp)
4004fc: eb fa                           jmp    4004f8 <loop+0xb>
```

The **program counter** (PC), known as `%rip` in x86-64, stores the address in memory of the ***next instruction*** to be executed.




| | |
|---|---|
| 4004fd | fa |
| 4004fc | eb |
| 4004fb | 01 |
| 4004fa | fc |
| 4004f9 | 45 |
| 4004f8 | 83 |
| 4004f7 | 00 |
| 4004f6 | 00 |
| 4004f5 | 00 |
| 4004f4 | 00 |
| 4004f3 | fc |
| 4004f2 | 45 |
| 4004f1 | c7 |
| 4004f0 | e5 |
| 4004ef | 89 |
| 4004ee | 48 |
| 4004ed | 55 |

# Recap: `jmp`

The **`jmp`** instruction jumps to another instruction in the assembly code ("Unconditional Jump").

```
jmp Label       (Direct Jump)
jmp *Operand    (Indirect Jump)
```

The destination can be hardcoded into the instruction (direct jump):

```
jmp 404f8 <loop+0xb>  # jump to instruction at 0x404f8
```

The destination can also be one of the usual operand forms (indirect jump):

```
jmp *%rax     # jump to instruction at address in %rax
```

# Recap: Control

```
if (x > y) {
    // a
} else {
    // b
}
```

In Assembly:

1. **Calculate the condition result**
2. **Based on the result, go to a or b**

# Recap: Conditional Jumps

There are also variants of **`jmp`** that jump only if certain conditions are true ("Conditional Jump"). The jump location for these must be hardcoded into the instruction.

| Instruction | Synonym | Set Condition |
|---|---|---|
| `je` *`Label`* | `jz` | Equal / zero |
| `jne` *`Label`* | `jnz` | Not equal / not zero |
| `js` *`Label`* | | Negative |
| `jns` *`Label`* | | Nonnegative |
| `jg` *`Label`* | `jnle` | Greater (signed >) |
| `jge` *`Label`* | `jnl` | Greater or equal (signed >=) |
| `jl` *`Label`* | `jnge` | Less (signed <) |
| `jle` *`Label`* | `jng` | Less or equal (signed <=) |
| `ja` *`Label`* | `jnbe` | Above (unsigned >) |
| `jae` *`Label`* | `jnb` | Above or equal (unsigned >=) |
| `jb` *`Label`* | `jnae` | Below (unsigned <) |
| `jbe` *`Label`* | `jna` | Below or equal (unsigned <=) |

# Recap: Condition Codes

Alongside normal registers, the CPU also has single-bit *condition code* registers. They store the results of the most recent arithmetic or logical operation.

Most common condition codes:

- **CF:** Carry flag. The most recent operation generated a carry out of the most significant bit. Used to detect overflow for unsigned operations.
- **ZF:** Zero flag. The most recent operation yielded zero.
- **SF:** Sign flag. The most recent operation yielded a negative value.
- **OF:** Overflow flag. The most recent operation caused a two's-complement overflow-either negative or positive.

# Recap: Setting Condition Codes

The **`cmp`** instruction is like the subtraction instruction, but it does not store the result anywhere. It just sets condition codes. (**Note** the operand order!)

`CMP S1, S2` `S2 - S1`

| Instruction | Description |
|---|---|
| `cmpb` | Compare byte |
| `cmpw` | Compare word |
| `cmpl` | Compare double word |
| `cmpq` | Compare quad word |

# Recap: Setting Condition Codes

The **`test`** instruction is like **`cmp`**, but for AND. It does not store the & result anywhere. It just sets condition codes.

```
TEST S1, S2          S2 & S1
```

| Instruction | Description |
|---|---|
| `testb` | Test byte |
| `testw` | Test word |
| `testl` | Test double word |
| `testq` | Test quad word |

**Cool trick:** if we pass the same value for both operands, we can check the sign of that value using the **Sign Flag** and **Zero Flag** condition codes!

# Exercise 1: Conditional jump

```
je target
```

jump if ZF is 1

Let %edi store 0x10. Will we jump in the following cases? %edi 0x10

1.
```
cmp $0x10,%edi
je  40056f
add  $0x1,%edi
```

S2 - S1 == 0, so jump

# Exercise 1: Conditional jump

```
je target
```

jump if ZF is 1

Let %edi store 0x10. Will we jump in the following cases? %edi 0x10

1.
```
cmp $0x10,%edi
je  40056f
add  $0x1,%edi
```

S2 - S1 == 0, so jump

2.
```
test $0x10,%edi
je   40056f
add  $0x1,%edi
```

S2 & S1 != 0, so don't jump

# Exercise 2: Conditional jump

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```
0000000004004d6 <if_then>:
  4004d6:   83 ff 06    cmp    $0x6,%edi
  4004d9:   75 03       jne    4004de <if_then+0x8>
  400rdb:   83 c7 01    add    $0x1,%edi
  4004de:   8d 04 3f    lea    (%rdi,%rdi,1),%eax
  4004e1:   c3          retq
```

%edi `0x5`

1. What is the value of `%rip` after executing the `jne` instruction?
   A. `4004d9`
   B. `4004db`
   C. `4004de`
   D. Other

slido

Please download and install the Slido app on all computers you use

# What is the value of %rip after executing the jne instruction?

ⓘ Start presenting to display the poll results on this slide.

# Exercise 2: Conditional jump

slido

```
0000000004004d6 <if_then>:
  4004d6:   83 ff 06    cmp    $0x6,%edi
  4004d9:   75 03       jne    4004de <if_then+0x8>
  400rdb:   83 c7 01    add    $0x1,%edi
  4004de:   8d 04 3f    lea    (%rdi,%rdi,1),%eax
  4004e1:   c3          retq
```

`%edi` `0x5`

1. What is the value of `%rip` after executing the `jne` instruction?
   - A. `4004d9`
   - B. `4004db`
   - C. `4004de`
   - D. Other

2. What is the value of `%eax` when we hit the `retq` instruction?
   - A. `4004e1`
   - B. `0x2`
   - C. `0xa`
   - D. `0xc`
   - E. Other

slido

Please download and install the Slido app on all computers you use

# What is the value of %eax when we hit the retq instruction?

ⓘ Start presenting to display the poll results on this slide.

# Exercise 2: Conditional jump

slido

```
0000000004004d6 <if_then>:
  4004d6:   83 ff 06    cmp    $0x6,%edi
  4004d9:   75 03       jne    4004de <if_then+0x8>
  400rdb:   83 c7 01    add    $0x1,%edi
  4004de:   8d 04 3f    lea    (%rdi,%rdi,1),%eax
  4004e1:   c3          retq
```

%edi **0x5**

1. What is the value of `%rip` after executing the `jne` instruction?
   - A. `4004d9`
   - B. `4004db`
   - C. `4004de`
   - D. Other

2. What is the value of `%eax` when we hit the `retq` instruction?
   - A. `4004e1`
   - B. `0x2`
   - C. `0xa`
   - D. `0xc`
   - E. Other

# Plan for Today

- If statements
- Loops
- Other Instructions That Depend On Condition Codes

**Disclaimer:** Slides for this lecture were borrowed from

—Nick Troccoli's Stanford CS107 class

# Lecture Plan

- If statements
- Loops
- Other Instructions That Depend On Condition Codes

# Practice: Fill In The Blank

```
int if_then(int param1) {
  if ( __________ ) {
      __________ ;
  }

  return __________ ;
}
```

```
00000000004004d6 <if_then>:
  4004d6:    cmp  $0x6,%edi
  4004d9:    jne  4004de
  4004db:    add  $0x1,%edi
  4004de:    lea  (%rdi,%rdi,1),%eax
  4004e1:    retq
```

# Practice: Fill In The Blank

```
int if_then(int param1) {
  if (param1 == 6 ) {
        param1++;
  }

  return  param1 * 2;
}
```

```
0000000004004d6 <if_then>:
  4004d6:    cmp  $0x6,%edi
  4004d9:    jne  4004de
  4004db:    add  $0x1,%edi
  4004de:    lea  (%rdi,%rdi,1),%eax
  4004e1:    retq
```

# Practice: Fill In The Blank

If-Else In C

```
if (__________) {
    __________;
} else {
    __________;
}

__________;
```

If-Else In Assembly pseudocode

```
Test
Jump to else-body if test fails
If-body
Jump to past else-body
Else-body
Past else body
```

# Practice: Fill In The Blank

slido

If-Else In C

```
if ( _____ ) {
    _____;
} else {
    _____;
}
_____;
```

```
400552 <+0>:  cmp  $0x3,%edi
400555 <+3>:  jle  0x40055e <if_else+12>
400557 <+5>:  mov  $0xa,%eax
40055c <+10>: jmp  0x400563 <if_else+17>
40055e <+12>: mov  $0x0,%eax
400563 <+17>: add  $0x1,%eax
```

If-Else In Assembly pseudocode

```
Test
Jump to else-body if test fails
If-body
Jump to past else-body
Else-body
Past else body
```

# Practice: Fill In The Blank

slido

If-Else In C

```
if (  arg > 3   ) {
    _________;
} else {
    _________;
}
_____;
```

```
400552 <+0>:  cmp  $0x3,%edi
400555 <+3>:  jle  0x40055e <if_else+12>
400557 <+5>:  mov  $0xa,%eax
40055c <+10>: jmp  0x400563 <if_else+17>
40055e <+12>: mov  $0x0,%eax
400563 <+17>: add  $0x1,%eax
```

If-Else In Assembly pseudocode

```
Test
Jump to else-body if test fails
If-body
Jump to past else-body
Else-body
Past else body
```

# Practice: Fill In The Blank

slido

If-Else In C

```
if (  arg > 3   ) {
     ret = 10;
} else {
     _________;
}
_____;
```

```
400552 <+0>:  cmp  $0x3,%edi
400555 <+3>:  jle  0x40055e <if_else+12>
400557 <+5>:  mov  $0xa,%eax
40055c <+10>: jmp  0x400563 <if_else+17>
40055e <+12>: mov  $0x0,%eax
400563 <+17>: add  $0x1,%eax
```

If-Else In Assembly pseudocode

```
Test
Jump to else-body if test fails
If-body
Jump to past else-body
Else-body
Past else body
```

# Practice: Fill In The Blank

slido

If-Else In C

```
if (  arg > 3   ) {
     ret = 10;
} else {
     ret = 0;
}
_____;
```

```
400552 <+0>:   cmp   $0x3,%edi
400555 <+3>:   jle   0x40055e <if_else+12>
400557 <+5>:   mov   $0xa,%eax
40055c <+10>:  jmp   0x400563 <if_else+17>
40055e <+12>:  mov   $0x0,%eax
400563 <+17>:  add   $0x1,%eax
```

If-Else In Assembly pseudocode

```
Test
Jump to else-body if test fails
If-body
Jump to past else-body
Else-body
Past else body
```

# Practice: Fill In The Blank

slido

If-Else In C

```
if (  arg > 3   ) {
     ret = 10;
} else {
     ret = 0;
}
ret++;
```

```
400552 <+0>:   cmp   $0x3,%edi
400555 <+3>:   jle   0x40055e <if_else+12>
400557 <+5>:   mov   $0xa,%eax
40055c <+10>:  jmp   0x400563 <if_else+17>
40055e <+12>:  mov   $0x0,%eax
400563 <+17>:  add   $0x1,%eax
```

If-Else In Assembly pseudocode

```
Test
Jump to else-body if test fails
If-body
Jump to past else-body
Else-body
Past else body
```

# Lecture Plan

- If statements (cont'd.)
- Loops
  - While loops
  - For loops
- Other Instructions That Depend On Condition Codes

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:    mov    $0x0,%eax
0x0000000000400575 <+5>:    jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:    add    $0x1,%eax
0x000000000040057a <+10>:   cmp    $0x63,%eax
0x000000000040057d <+13>:   jle    0x400577 <loop+7>
0x000000000040057f <+15>:   repz retq
```

Set `%eax` (`i`) to 0.

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

Jump to another instruction.

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

Compare `%eax` (`i`) to 0x63 (99) by calculating `%eax` – 0x63. This is 0 – 99 = -99, so it sets the Sign Flag to 1.

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

**`jle`** means “jump if less than or equal”. This jumps if **`%eax`** <= 0x63. The flags indicate this is true, so we jump.

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

Add 1 to %eax (i).

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

Compare `%eax` (`i`) to 0x63 (99) by calculating `%eax` – 0x63. This is 1 – 99 = -98, so it sets the Sign Flag to 1.

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

**`jle`** means "jump if less than or equal". This jumps if **`%eax`** <= 0x63. The flags indicate this is true, so we jump.

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

We continue in this pattern until we do not make this conditional jump. When will that be?

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

We will stop looping when this comparison says that **%eax** – 0x63 > 0!

# Loops and Control Flow

```
void loop() {
    int i = 0;
    while (i < 100) {
        i++;
    }
}
```

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

Then, we return from the function.

# Common While Loop Construction

C

```
while (test) {
      body
}
```

Assembly

```
Jump to test
Body
Test
Jump to body if success
```

**From Previous Slide:**

```
0x0000000000400570 <+0>:     mov    $0x0,%eax
0x0000000000400575 <+5>:     jmp    0x40057a <loop+10>
0x0000000000400577 <+7>:     add    $0x1,%eax
0x000000000040057a <+10>:    cmp    $0x63,%eax
0x000000000040057d <+13>:    jle    0x400577 <loop+7>
0x000000000040057f <+15>:    repz retq
```

# Lecture Plan

- Loops
  - While loops
  - For loops
- Other Instructions That Depend On Condition Codes

# Common While Loop Construction

**C For loop**

```
for (init; test; update) {
      body
}
```

**C Equivalent While Loop**

```
init
while(test) {
     body
     update
}
```

**Assembly pseudocode**

```
Init
Jump to test
Body
Update
Test
Jump to body if success
```

`for` loops and `while` loops are treated (essentially) the same when compiled down to assembly.

# Back to Our First Assembly

```
int sum_array(int arr[], int nelems) {
    int sum = 0;
    for (int i = 0; i < nelems; i++) {
        sum += arr[i];
    }
    return sum;
}
```

1. Which register is C code's `sum`?
2. Which register is C code's `i`?
3. Which assembly instruction is C code's `sum += arr[i]`?
4. What are the **`cmp`** and **`jl`** instructions doing?
   (**`jl`**: jump less; signed <)

```
0000000004005b6 <sum_array>:
  4005b6:       mov    $0x0,%edx
  4005bb<+5>:   mov    $0x0,%eax
  4005c0<+10>:  jmp    4005cb <sum_array+21>
  4005c2<+12>:  movslq %edx,%rcx
  4005c5<+15>:  add    (%rdi,%rcx,4),%eax
  4005c8<+18>:  add    $0x1,%edx
  4005cb<+21>:  cmp    %esi,%edx
  4005cd<+23>:  jl     4005c2 <sum_array+12>
  4005cf<+25>:  repz retq
```

# Lecture Plan

- If Statements
- Loops
- Other Instructions That Depend On Condition Codes

# Condition Code-Dependent Instructions

There are three common instruction types that use condition codes:

- **`jmp`** instructions conditionally jump to a different next instruction
- **`set`** instructions conditionally set a byte to 0 or 1
- new versions of **`mov`** instructions conditionally move data

# `set`: Read condition codes

**`set`** instructions conditionally set a byte to 0 or 1.

- Reads current state of flags
- Destination is a single-byte register (e.g., `%al`) or single-byte memory location
- Does not perturb other bytes of register
- Typically followed by `movzbl` to zero those bytes

```
int small(int x) {
    return x < 16;
}
```

```
cmp $0xf,%edi
setle %al
movzbl %al, %eax
retq
```

# `set`: Read condition codes

| Instruction | Synonym | Set Condition (1 if true, 0 if false) |
|---|---|---|
| `sete D` | `setz` | Equal / zero |
| `setne D` | `setnz` | Not equal / not zero |
| `sets D` | | Negative |
| `setns D` | | Nonnegative |
| `setg D` | `setnle` | Greater (signed >) |
| `setge D` | `setnl` | Greater or equal (signed >=) |
| `setl D` | `setnge` | Less (signed <) |
| `setle D` | `setng` | Less or equal (signed <=) |
| `seta D` | `setnbe` | Above (unsigned >) |
| `setae D` | `setnb` | Above or equal (unsigned >=) |
| `setb D` | `setnae` | Below (unsigned <) |
| `setbe D` | `setna` | Below or equal (unsigned <=) |

# `cmov`: Conditional move

**`cmovx src,dst`** conditionally moves data in `src` to data in `dst`.

- Mov `src` to `dst` if condition `x` holds; no change otherwise
- `src` is memory address/register, `dst` is register
- May be more efficient than branch (i.e., jump)
- Often seen with C ternary operator: `result = test ? then: else;`

```
int max(int x, int y) {
    return x > y ? x : y;
}
```

```
cmp     %edi,%esi
mov     %edi, %eax
cmovge  %esi, %eax
retq
```

# Ternary Operator

The ternary operator is a shorthand for using if/else to evaluate to a value.

**`condition ? expressionIfTrue : expressionIfFalse`**

```
int x;
if (argc > 1) {
    x = 50;
} else {
    x = 0;
}

// equivalent to
int x = argc > 1 ? 50 : 0;
```

# cmov: Conditional move

| Instruction | Synonym | Move Condition |
|---|---|---|
| `cmove S,R` | `cmovz` | Equal / zero (ZF = 1) |
| `cmovne S,R` | `cmovnz` | Not equal / not zero (ZF = 0) |
| `cmovs S,R` | | Negative (SF = 1) |
| `cmovns S,R` | | Nonnegative (SF = 0) |
| `cmovg S,R` | `cmovnle` | Greater (signed >) (SF = 0 and SF = OF) |
| `cmovge S,R` | `cmovnl` | Greater or equal (signed >=) (SF = OF) |
| `cmovl S,R` | `cmovnge` | Less (signed <) (SF != OF) |
| `cmovle S,R` | `cmovng` | Less or equal (signed <=) (ZF = 1 or SF! = OF) |
| `cmova S,R` | `cmovnbe` | Above (unsigned >) (CF = 0 and ZF = 0) |
| `cmovae S,R` | `cmovnb` | Above or equal (unsigned >=) (CF = 0) |
| `cmovb S,R` | `cmovnae` | Below (unsigned <) (CF = 1) |
| `cmovbe S,R` | `cmovna` | Below or equal (unsigned <=) (CF = 1 or ZF = 1) |

# Practice: Conditional Move

```
int signed_division(int x) {
    return x / 4;
}
```

---

-14/4 should yield -3 rather than -4
(See Sec. 2.3.7)

```
signed_division:
  leal 3(%rdi), %eax
  testl %edi, %edi
  cmovns %edi, %eax
  sarl $2, %eax
  ret
```

Put x + 3 into %eax (add appropriate bias, $2^2$-1)

To see whether x is negative, zero, or positive

If x is positive, put x into %eax

Divide %eax by 4

# Extra Practice

# Practice: Fill In The Blank

*Note: .L2/.L3 are "labels" that make jumps easier to read.*

**C Code**

```
long loop(long a, long b) {
    long result = _______;
    while (_________) {
      result = _____________;
      a = _________;
    }
    return result;
}
```

**Common while loop construction:**

Jump to test
Body
Test
Jump to body if success

**What does this assembly code translate to?**

```
// a in %rdi, b in %rsi
loop:
    movl $1, %eax
    jmp .L2
.L3
    leaq (%rdi,%rsi), %rdx
    imulq %rdx, %rax
    addq $1, %rdi
.L2
    cmpq %rsi, %rdi
    jl .L3
rep; ret
```

# Practice: Fill In The Blank

*Note: .L2/.L3 are "labels" that make jumps easier to read.*

**C Code**

```
long loop(long a, long b) {
    long result = ____1____;
    while (__ a < b __) {
      result = result*(a+b);
      a = __ a + 1 __;
    }
    return result;
}
```

**Common while loop construction:**

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Jump to body if success

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    leaq (%rdi,%rsi), %rdx
    imulq %rdx, %rax
    addq $1, %rdi
.L2
    cmpq %rsi, %rdi
    jl .L3
rep; ret
```

# Practice: “Escape Room”

```
escapeRoom:
  leal (%rdi,%rdi), %eax
  cmpl $5, %eax
  jg .L3
  cmpl $1, %edi
  jne .L4
  movl $1, %eax
  ret
.L3:
  movl $1, %eax
  ret
.L4:
  movl $0, %eax
  ret
```

What must be passed to the `escapeRoom` function such that it returns true (1) and not false (0)?

# Practice: “Escape Room”

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  ret
.L4:
  movl $0, %eax
  ret
```

What must be passed to the `escapeRoom` function such that it returns true (1) and not false (0)?

First param > 2 or == 1.

# Recap

- Assembly Execution and `%rip`
- Control Flow Mechanics
  - Condition Codes
  - Assembly Instructions
- If statements
- Loops
  - While loops
  - For loops
- Other Instructions That Depend On Condition Codes

**Next time:** *Function calls in assembly*