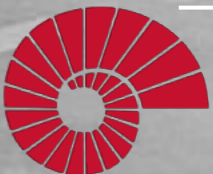


COMP201

Computer Systems & Programming

Lecture #17 – More Control Flow



KOÇ
UNIVERSITY

Aykut Erdem // Koç University // Spring 2025

Good news, everyone!

- Labs continue this week!





**Please rate your experience in the
midterm exam. The hardness of the
questions is**



**Please rate your experience in the
midterm exam. The duration of the exam
is**

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?

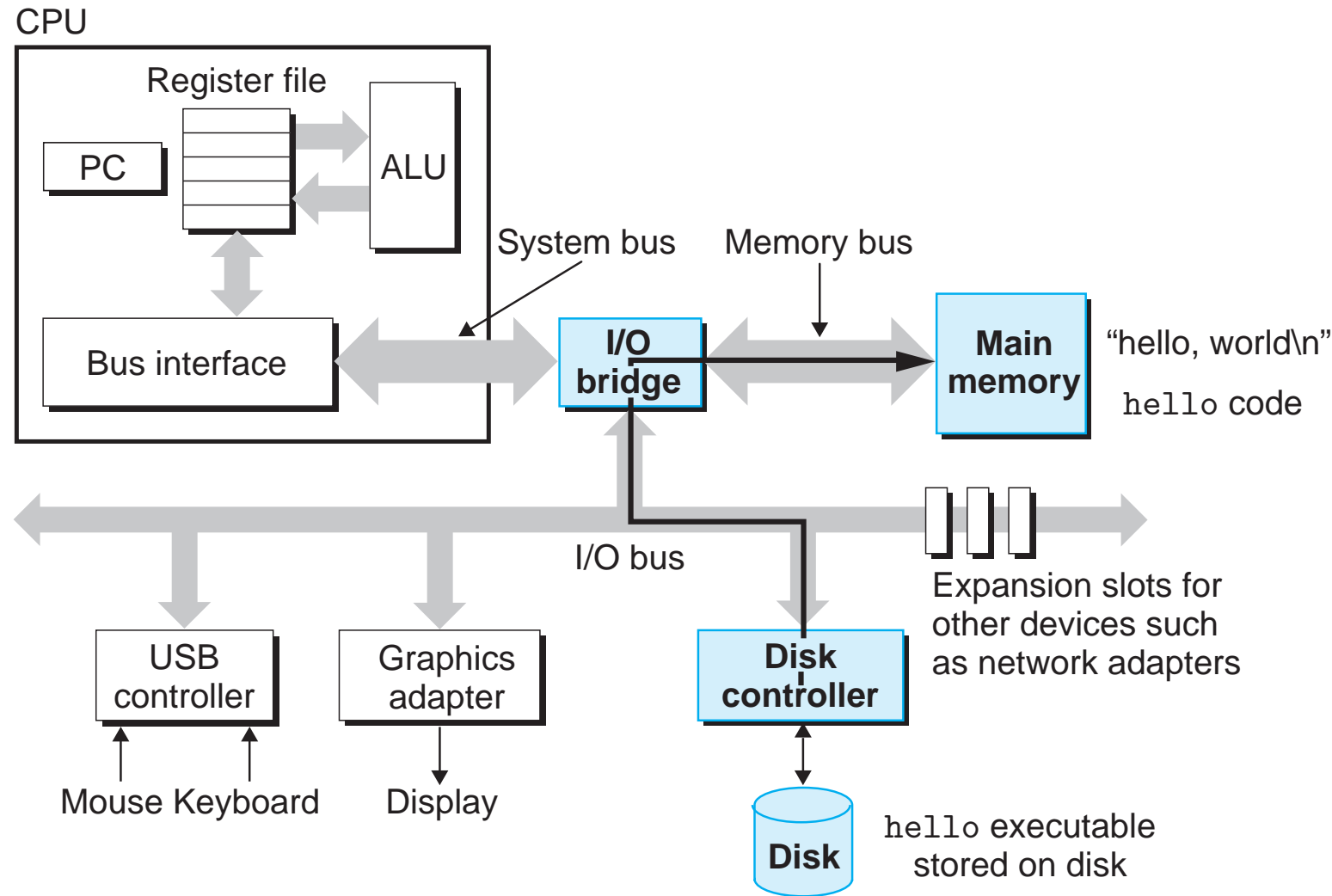
Answer:

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

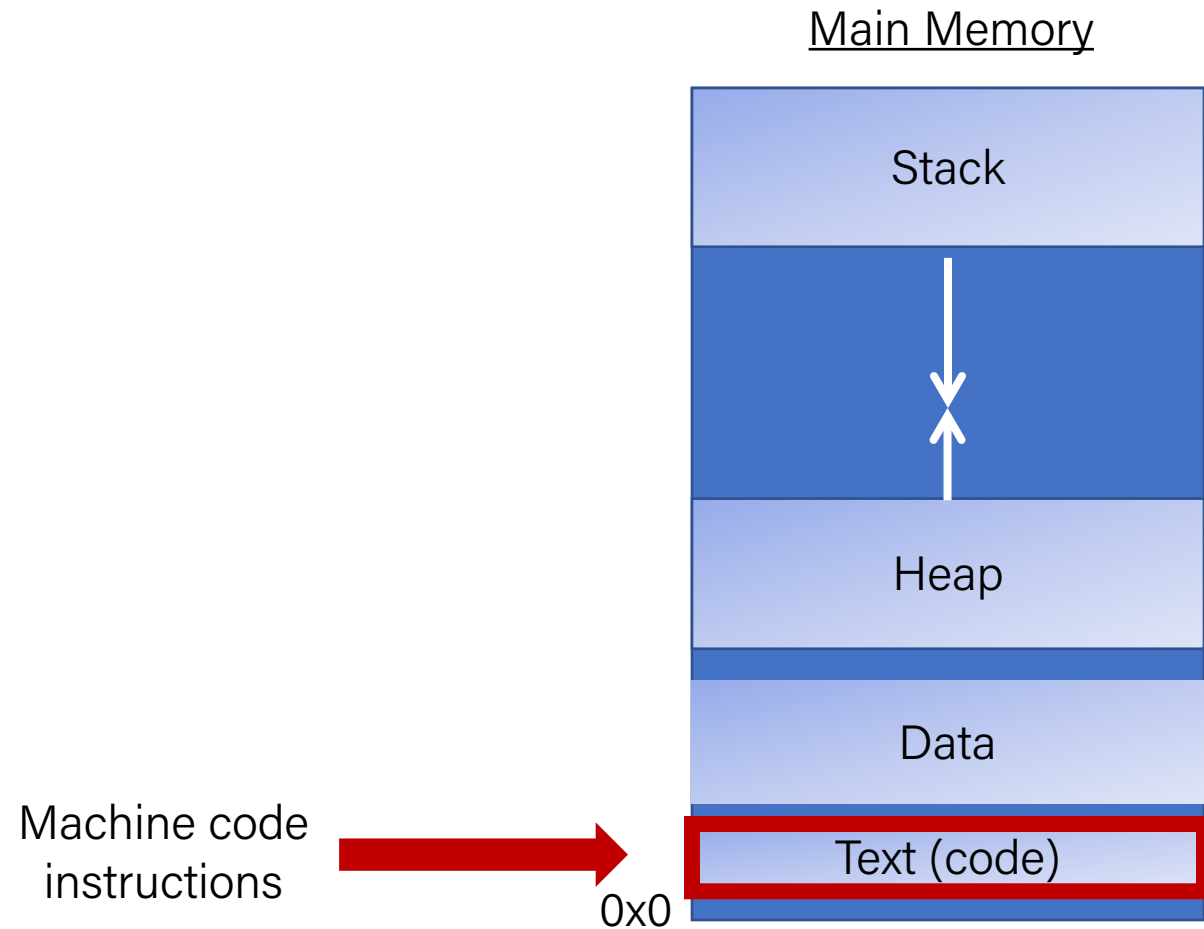
| | |
|--------|----|
| 4004fd | fa |
| 4004fc | eb |
| 4004fb | 01 |
| 4004fa | fc |
| 4004f9 | 45 |
| 4004f8 | 83 |
| 4004f7 | 00 |
| 4004f6 | 00 |
| 4004f5 | 00 |
| 4004f4 | 00 |
| 4004f3 | fc |
| 4004f2 | 45 |
| 4004f1 | c7 |
| 4004f0 | e5 |
| 4004ef | 89 |
| 4004ee | 48 |
| 4004ed | 55 |



Recap: Instructions Are Just Bytes!



Recap: Instructions Are Just Bytes!



Recap: %rip



00000000004004ed <loop>:

4004ed: 55

4004ee: 48 89 e5

4004f1: c7 45 fc 00 00 00 00

4004f8: 83 45 fc 01

4004fc: eb fa

push %rbp
mov %rsp,%rbp
movl \$0x0,-0x4(%rbp)
addl \$0x1,-0x4(%rbp)
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.

0x4004ed

%rip



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

$S2 \& S1 \neq 0$, so don't jump



Exercise 2: Conditional jump

00000000004004d6 <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



Exercise 2: Conditional jump

00000000004004d6 <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



Exercise 2: Conditional jump

00000000004004d6 <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



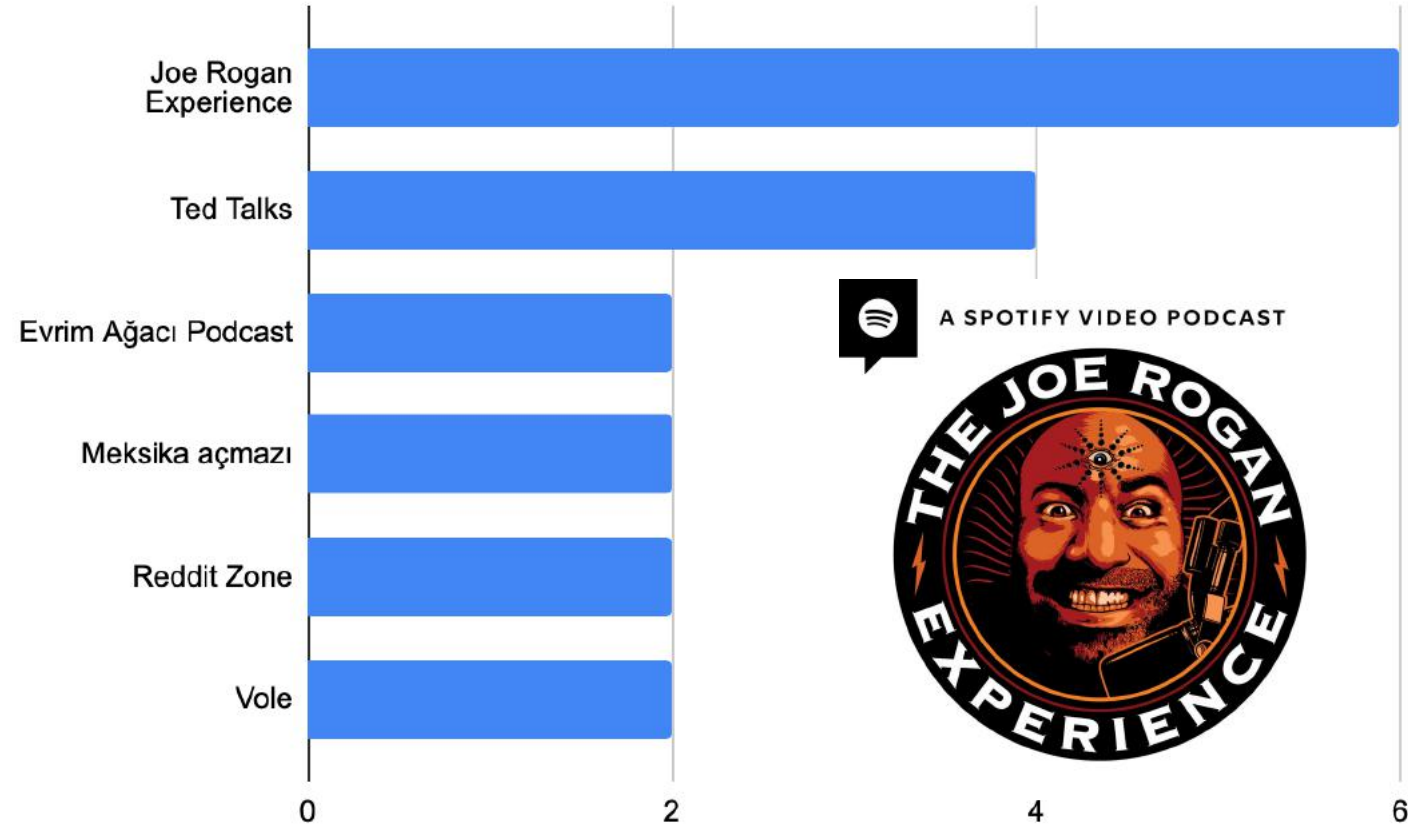
Plan for Today

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

Disclaimer: Slides for this lecture were borrowed from
—Nick Troccoli's Stanford CS107 class

Results of the Previous Attendance Question

Name one podcast
you are listening to
now.



Attendance Question

What's the most
overrated invention of
all time?*



*suggested by Ahmet Ertuğrul Sevinç

Lecture Plan

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

Practice: Fill In The Blank

```
int if_then(int param1) {  
    if ( _____ ) {  
        _____ ;  
    }  
  
    return _____ ;  
}
```

```
000000000004004d6 <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 ;  
}
```

```
000000000004004d6 <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

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

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

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

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

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++;  
    }  
}
```

| | | | |
|----------------------|--------|------|--------------------|
| 0x000000000000400570 | <+0>: | mov | \$0x0,%eax |
| 0x000000000000400575 | <+5>: | jmp | 0x40057a <loop+10> |
| 0x000000000000400577 | <+7>: | add | \$0x1,%eax |
| 0x00000000000040057a | <+10>: | cmp | \$0x63,%eax |
| 0x00000000000040057d | <+13>: | jle | 0x400577 <loop+7> |
| 0x00000000000040057f | <+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>:

0x0000000000400575 <+5>:

0x0000000000400577 <+7>:

0x000000000040057a <+10>:

0x000000000040057d <+13>:

0x000000000040057f <+15>:

mov \$0x0,%eax

jmp 0x40057a <loop+10>

add \$0x1,%eax

cmp \$0x63,%eax

jle 0x400577 <loop+7>

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 `j1` instructions doing?
(`j1`: jump less; signed <)

00000000004005b6 <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 <=) |

cmove: Conditional move

cmove **src,dst** conditionally moves data in **src** to data in **dst**.

- Move **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  
cmovege %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 |
|-------------|---------|---|
| cmovz 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 | cmovnl | 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;  
}
```

signed_division:

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

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

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:

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: “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”

```
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)?

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*