# Computer Systems

CS107

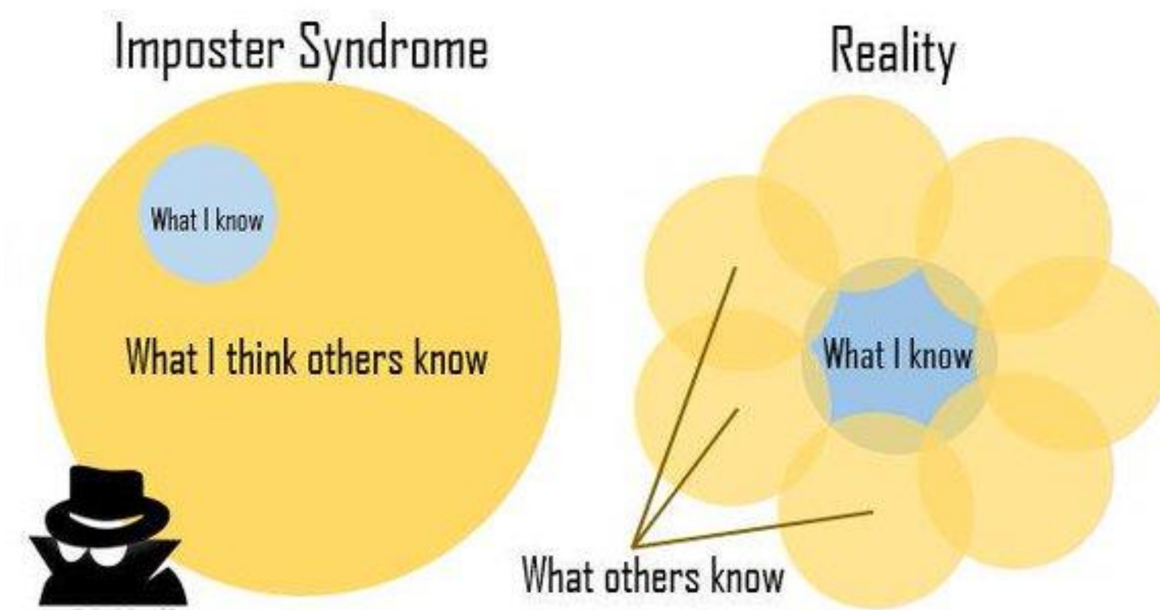
Cynthia Lee

## Today's Topics

LECTURE:

- › Pop quiz on floating point!
    - Just kidding.
- › New: Assembly code


Two friendly reminders:




# REMINDER:
# Everything is bits!

# Everything is bits!

- We’ve seen many data types so far:
  - › Integers:
    - char/short/int/long (encoding as unsigned or two’s complement signed)
  - › Letters/punctutation/etc:
    - char (ASCII encoding)
  - › Real numbers:
    - float/double (IEEE floating point encoding)
  - › Memory addresses:
    - pointer types (unsigned long encoding)
  - › **Now a new one…..the code itself!**
    - **Instructions** (AMD64 encoding)

# What happens when we compile our code?

ANATOMY OF AN EXECUTABLE FILE

# What happens when we compile our code?

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

---

```
> make
> ls
Makefile  sum  sum.c
> objdump -d sum
```

```
000000000040055d <sum_array>:
  40055d:       ba 00 00 00 00          mov    $0x0,%edx
  400562:       b8 00 00 00 00          mov    $0x0,%eax
  400567:       eb 09                   jmp    400572
  400569:       48 63 ca                movslq %edx,%rcx
  40056c:       03 04 8f                add    (%rdi,%rcx,4),%eax
  40056f:       83 c2 01                add    $0x1,%edx
  400572:       39 f2                   cmp    %esi,%edx
  400574:       7c f3                   jl     400569
  400576:       f3 c3                   repz retq
```

```
000000000040055d <sum_array>:
  40055d:        ba 00 00 00 00          mov    $0x0,%edx
  400562:        b8 00 00 00 00          mov    $0x0,%eax
  400567                                        400572
  400569                                   .q   %edx,%rcx
  40056c                                        (%rdi,%rcx,4),%eax
  40056f                                        $0x1,%edx
  400572                                        %esi,%edx
  400574:        7c f3                   jl     400569
  400576:        f3 c3                   repz retq
```

Name of the function (same as in the C code) and the memory address where the code for this function starts

```
000000000040055d <sum_array>:
  40055d:    ba 00 00 00 00    mov    $0x0,%edx
  400562:    b8 00 00 00 00    mov    $0x0,%eax
  400567:    eb 09             jmp    400572
  400569:                      vslq   %edx,%rcx
  40056c:                      d      (%rdi,%rcx,4),%eax
  40056f:                      d      $0x1,%edx
  400572:                      p      %esi,%edx
  400574:                             400569
  400576:                      pz retq
```

Memory address where each of line of instruction is found—sequential instructions are found sequentially in memory

```
000000000040055d <sum_array>:
  40055d:     ba 00 00 00 00     mov    $0x0,%edx
  400562:     b8 00 00 00 00     mov    $0x0,%eax
  400567:     eb 09              jmp    400572
  400569:     48 63 ca           movslq %edx,%rcx
  40056c:     03 04 8f           add    (%rdi,%rcx,4),%eax
  40056f:                        add    $0x1,%edx
  400572:                        cmp    %esi,%edx
  400574:                        jl     400569
  400576:                        repz retq
```

Assembly code: “human-readable” version of each instruction

```
000000000040055d <sum_array>:
  40055d:       ba 00 00 00 00          mov    $0x0,%edx
  400562:       b8 00 00 00 00          mov    $0x0,%eax
  400567:       eb 09                   jmp    400572
  400569:       48 63 ca
  40056c:       03 04 8f                              4),%eax
  40056f:       83 c2 01
  400572:       39 f2
  400574:       7c f3
  400576:       f3 c3
```

Machine code: raw hexadecimal version of each instruction, representing the binary as it would be read by the computer

# Anatomy of an individual instruction

# Anatomy of an individual instruction

```
40056c:    03 04 8f    add   (%rdi,%rcx,4),%eax
40056f:    83 c2 01    add   $0x1,%edx
400572:    39 f2       cmp   %esi,%edx
400574:    7c f3       jl    400569
```

Operation name (sometimes called "opcode")

Operands (like arguments)

# Anatomy of an individual instruction

```
40056c:    03 04 8f    add    (%rdi,%rcx,4),%eax
40056f:    83 c2 01    add    $0x1,%edx
400572:    39 f2       cmp    %esi,%edx
400574:    7c f3       jl     400569
```

%[name] names a register—these are a small collection of memory slots right on the CPU that can hold variables' values

# Anatomy of an individual instruction

```
40056c:    03 04 8f    add   (%rdi,%rcx,4),%eax
40056f:    83 c2 01    add   $0x1,%edx
400572:    39 f2       cmp   %esi,%edx
400574:    7c f3       jl    400569
```

$[number] means a constant value (this is the number 1)

# `add` and `sub` instruction breakdowns

| Op | Source1 | Source2/Dest | Dest Comments |
|---|---|---|---|
| `add` | op1 | op2 | op2 += op1 |

| Op | Source1 | Source2/Dest | Dest Comments |
|---|---|---|---|
| `sub` | op1 | op2 | op2 += op1 |

- Note that you have no choice but to overwrite op2 with the sum (or difference) of op2 and op1
  - *No separate third destination operand*
- Op1 and op2 can be registers (e.g., **`%rax`**) or constants (e.g., **`$1`**)
  - *Plus some more complex options we will learn about later*

```
0000000000040055d <sum_array>:
  40055d:       ba 00 00 00 00          mov    $0x0,%edx
  400562:       b8 00 00 00 00          mov    $0x0,%eax
  400567:       eb 09                   jmp    400572
  400569:       48 63 ca                movslq %edx,%rcx
  40056c:       03 04 8f                add    (%rdi,%rcx,4),%eax
  40056f:       83 c2 01                add    $0x1,%edx
  400572:       39 f2                   cmp    %esi,%edx
  400574:       7c f3                   jl     400569
  400576:       f3 c3                   repz retq
```

**Guessing game:** which part of the `sum_array` C code do you think corresponds to the marked assembly instruction?

```
int sum_array(int arr[], int nelems) {
    int sum = 0;                              // (A)
    for (int i = 0; i < nelems; i++) {        // (B)
        sum += arr[i];                        // (C)
    }                                         // or (D) other?
    return sum;
}
```

```
<add_stuff>:
mov    $0x0,%eax
```

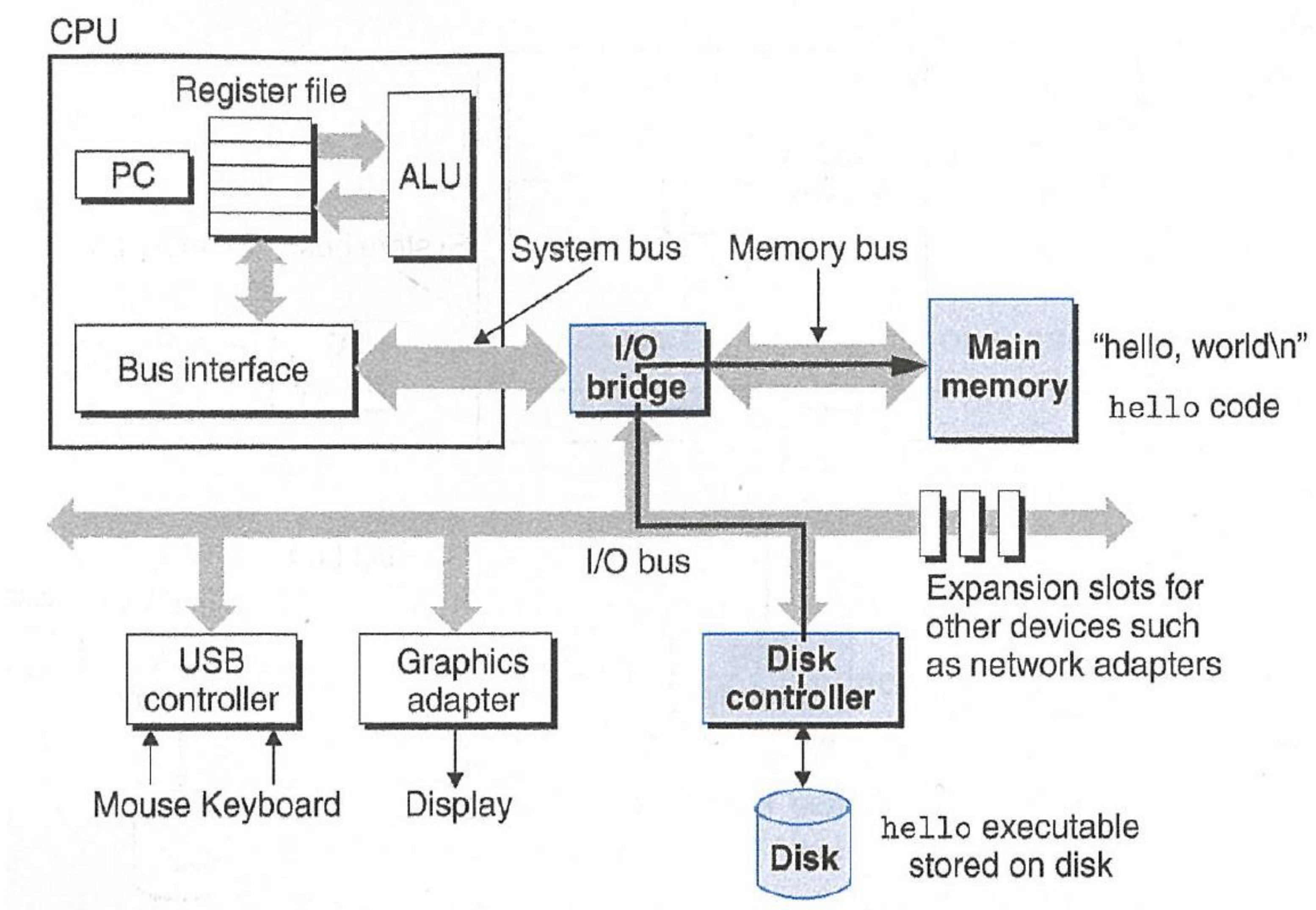
**Your turn:** can we write assembly code to match this C code?

```
int add_stuff(int edi, int esi, int edx) {
    int sum = 0;
    edi = edi + 3;
    esi = esi + edx;
    sum = edi + esi;
    return sum;
}
```

# Registers and memory

ANATOMY OF THE COMPUTER

# An architecture view of computer hardware



# The mov instruction

Our first instruction

# Dude, where's my data?

- **A main job of assembly language is to manage data:**
  - Data can be on the CPU (in registers) or in memory (at an address)
    - Turns out this distinction REALLY MATTERS for performance
    - https://people.eecs.berkeley.edu/~rcs/research/interactive_latency.html
  - Instructions often want to move data:
    - Move from one place in memory to another
    - Move from one register to another
    - Move from memory to register
    - Move from register to memory
  - Instructions often want to operate on data:
    - Add contents of register X to contents of register Y

- **Hence "mov" (move) instruction is paramount!**

# mov

- **`mov src,dst`**
  - Optional suffix (b,w,l,q): `movb, movw, movl, movq`
  - One confusing thing about “move” it makes it sound like it leaves the src “empty”—no!
    - Does a **copy**, like the assignment operator you are familiar with
  - `src,dst` options:
    - Immediate (AKA constant value)
    - Register
    - Memory

# Basic addressing modes (Think: assembly version of VARIABLES)

- Notice that one major difference between high-level code and assembly instructions is the absence of programmer-chosen, descriptive variable names:

```
int total_goodness = nReeses + nButterfinger;

addl 8(%rbp),%eax
```

- We don't get to choose variable names, we have to talk directly about places in hardware
- **"Addressing modes" are allowable ways of naming these places**

# Basic addressing modes

(Think: assembly version of VARIABLES)

| Op | Source | Dest | Dest Comments |
|---|---|---|---|
| `movl` | `$0,` | `%eax` | Name of a register |
| `movl` | `$0,` | `0x8f2713e0` | Actual address literal (note address literals are different from other literals—don't need $ in front) |
| `movl` | `$0,` | `(%rax)` | Look in the register named, find an address there, and use it |

Reminder: need to put $ in front of immediate values (constant literals)

# Basic addressing modes

(Think: assembly version of VARIABLES)

| Op | Source | Dest | Dest Comments |
|---|---|---|---|
| `movl` | `$0,` | `%eax` | Name of a register |
| `movl` | `$0,` | `0x8f2713e0` | Actual address literal (note address literals are different from other literals—don't need $ in front) |
| `movl` | `$0,` | `(%rax)` | Look in the register named, find an address there, and use it |
| `movl` | `$0,` | `-24(%rbp)` | Add -24 to an address in the named register, and use that address |

Displacement must be a constant; to have a variable base and variable displacement , use two steps: add then mov

Displacement can be positive or negative

# Basic addressing modes (Think: assembly version of VARIABLES)

| Op | Source | Dest | Dest Comments |
|---|---|---|---|
| `movl` | `$0,` | `%eax` | Name of a register |
| `movl` | `$0,` | `0x8f2713e0` | Actual address literal (note address literals are different from other literals—don't need $ in front) |
| `movl` | `$0,` | `(%rax)` | Look in the register named, find an address there, and use it |
| `movl` | `$0,` | `-24(%rbp)` | Add -24 to an address in the named register, and use that address |
| `movl` | `$0` | `8(%rbp, %eax, 2)` | Address to use = (8 + address in rbp) + (2 * index in eax) |

Any constant allowed

Only 1, 2, 4, 8 allowed

# Matching exercise: Addressing modes use cases

- Match up which use cases make the most sense for which addressing modes (some guesswork expected)

| Op | Src | Dest | Use case? |
|---|---|---|---|
| movl | $0 | 8(%rbp, %eax, 2) | |
| movl | $0, | %eax | |
| movl | $0, | 0x8f2713e0 | |
| movl | $0, | 4(%rax) | |

| Use cases | |
|---|---|
| (a) | Prepare to use 0 in a calculation |
| (b) | Zero out a field of a struct |
| (c) | Zero out a given array bucket |
| (d) | Zero out a global variable |

# Instruction Set Architectures

Some context and terminology

# Instruction Set Architecture

- **The ISA defines:**
  - Operations that the processor can execute
  - Data transfer operations + how to access data
  - Control mechanisms like branch, jump (think loops and if-else)
  - Contract between programmer/compiler and hardware
- **Layer of abstraction:**
  - Above:
    - Programmer/compiler can write code for the ISA
    - New programming languages can be built on top of the ISA as long as the compiler will do the translation
  - Below:
    - New hardware can implement the ISA
    - Can have even potentially radical changes in hardware implementation
    - Have to “do” the same thing from programmer point of view
- **ISAs have incredible inertia!**
  - Legacy support is a huge issue for x86-64

# Two major categories of Instruction Set Architectures

- **CISC:**
  - **Complex** instruction set computers
    - e.g., x86 **(CS107 studies this)**
  - Have special instructions for each thing you might want to do
  - Can write code with fewer instructions, because each instruction is very expressive
- **RISC:**
  - **Reduced** instruction set computers
    - e.g., MIPS
  - Have only a very tiny number of instructions, optimize the heck out of them in the hardware
  - Code may need to be longer because you have to go roundabout ways of achieving what you wanted