Course Wrap-Up

CSE 351 Spring 2021

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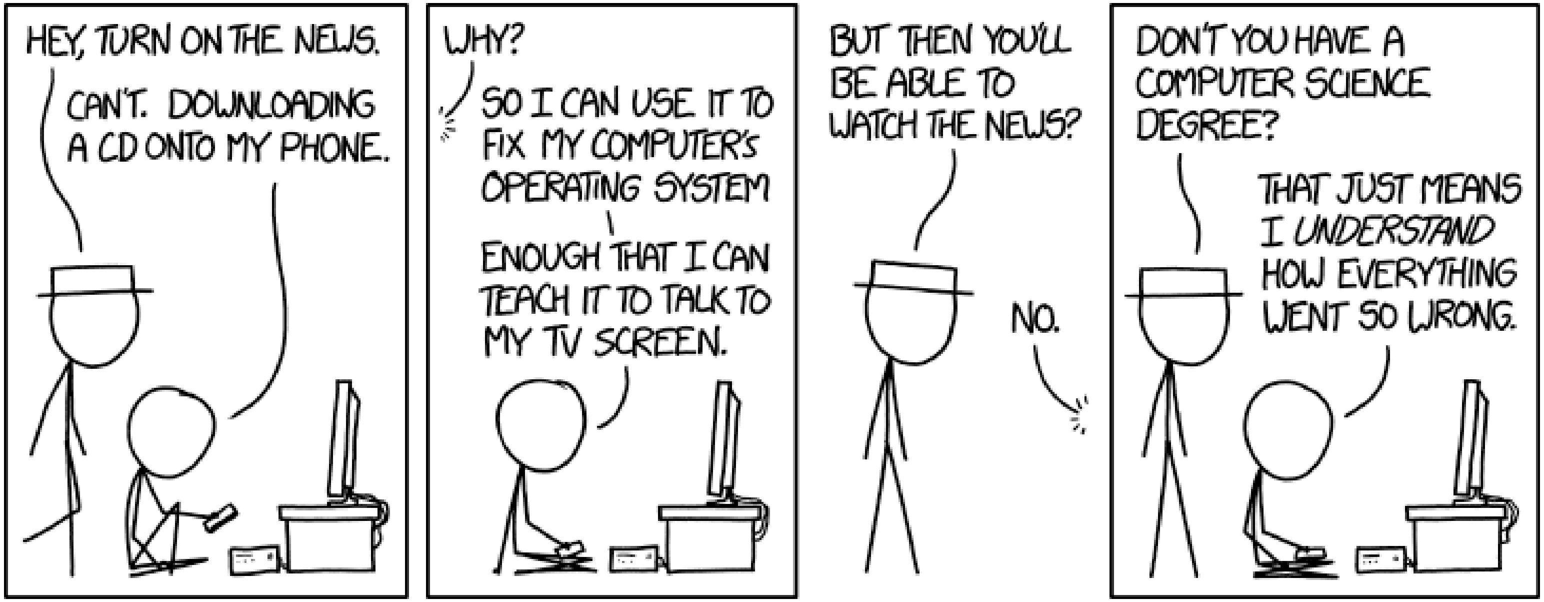

HEY, TURN ON THE NEWS.
CAN'T. DOWNLOADING A CD ONTO MY PHONE.
WHY?
SO I CAN USE IT TO FIX MY COMPUTER'S OPERATING SYSTEM ENOUGH THAT I CAN TEACH IT TO TALK TO MY TV SCREEN.
BUT THEN YOU'LL BE ABLE TO WATCH THE NEWS?
NO.
DON'T YOU HAVE A COMPUTER SCIENCE DEGREE?
THAT JUST MEANS I UNDERSTAND HOW EVERYTHING WENT SO WRONG.

https://xkcd.com/1760/

Administrivia

- Lab 5 (on Mem Alloc) due TONIGHT (6/04)
  - Can be submitted at most ONE day late. (Sun 6/06)
- hw28 on Java and C – due Wed (6/09)
- Unit Summary #4 – due Wed (6/09)
  - No task #3 for Unit Summary #4
- Course evaluations now open
  - Please fill these out! Close Monday (6/07)
  - Separate ones for Lecture and Section

- **Questions Docs**: Use @uw google account to access!!
  - https://tinyurl.com/CSE351-21sp-Questions

Today

- End-to-end Review
  - What happens after you write your source code?
    - How code becomes a program
    - How your computer executes your code
- Victory lap and high-level concepts (key points)
  - More useful for "5 years from now"

C: The Low-Level High-Level Language

- C is a “hands-off” language that “exposes” more of hardware (especially memory)
  - Weakly-typed language that stresses data as bits
    - Anything can be represented with a number!
  - Unconstrained pointers can hold address of *anything*
    - And no bounds checking – buffer overflow possible!
  - Efficient by leaving everything up to the programmer

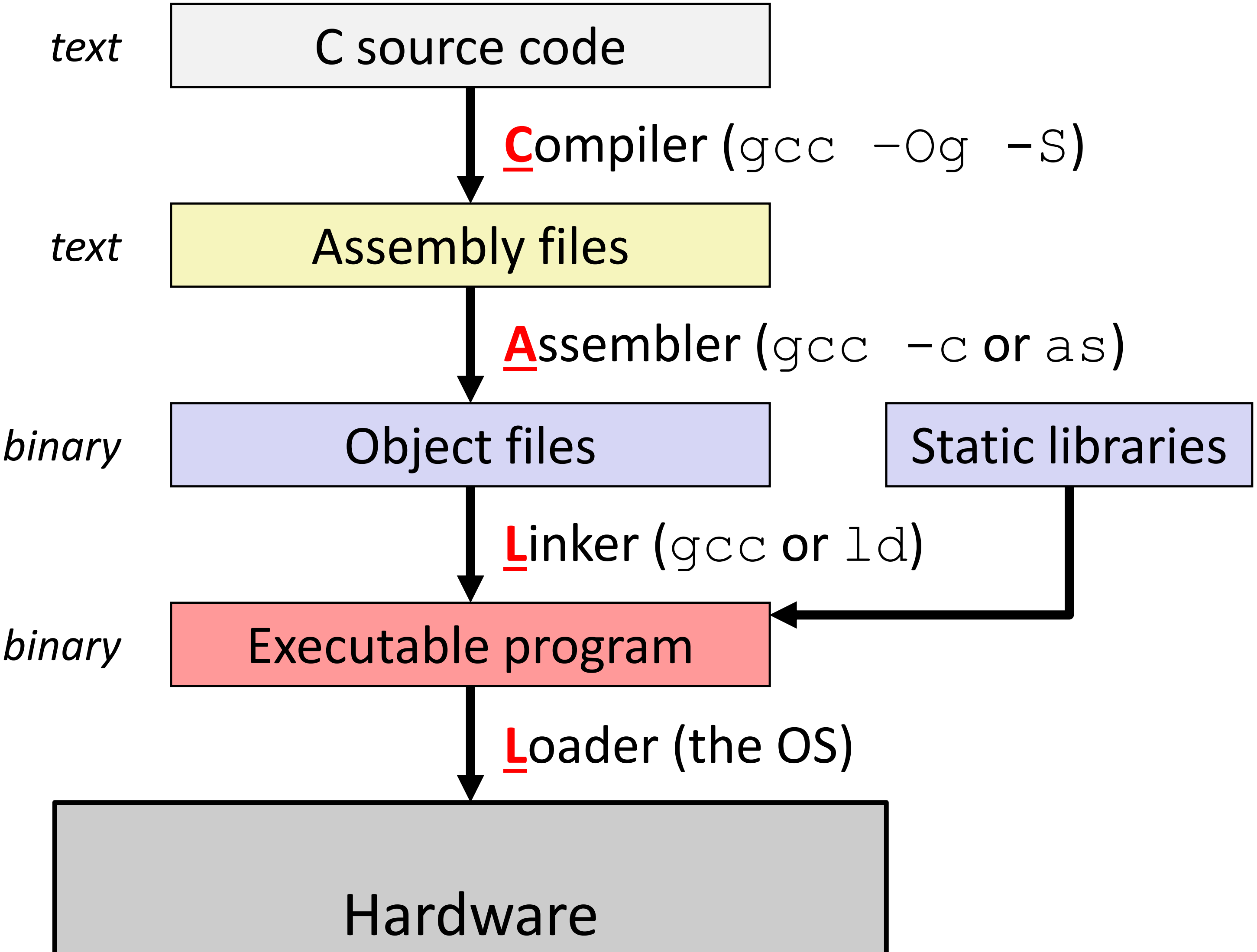
C Data Types

- C Primitive types
  - Fixed sizes and alignments
  - Characters (`char`), Integers (`short`, `int`, `long`), Floating Point (`float`, `double`)
- C Data Structures
  - Arrays – contiguous chunks of memory
    - Multidimensional arrays = still one continuous chunk, but row-major
    - Multi-level arrays = array of pointers to other arrays
  - Structs – structured group of variables
    - Struct fields are ordered according to declaration order
    - ***Internal* fragmentation:** space between members to satisfy member alignment requirements (aligned for each primitive element)
    - ***External* fragmentation:** space after last member to satisfy overall struct alignment requirement (largest primitive member)

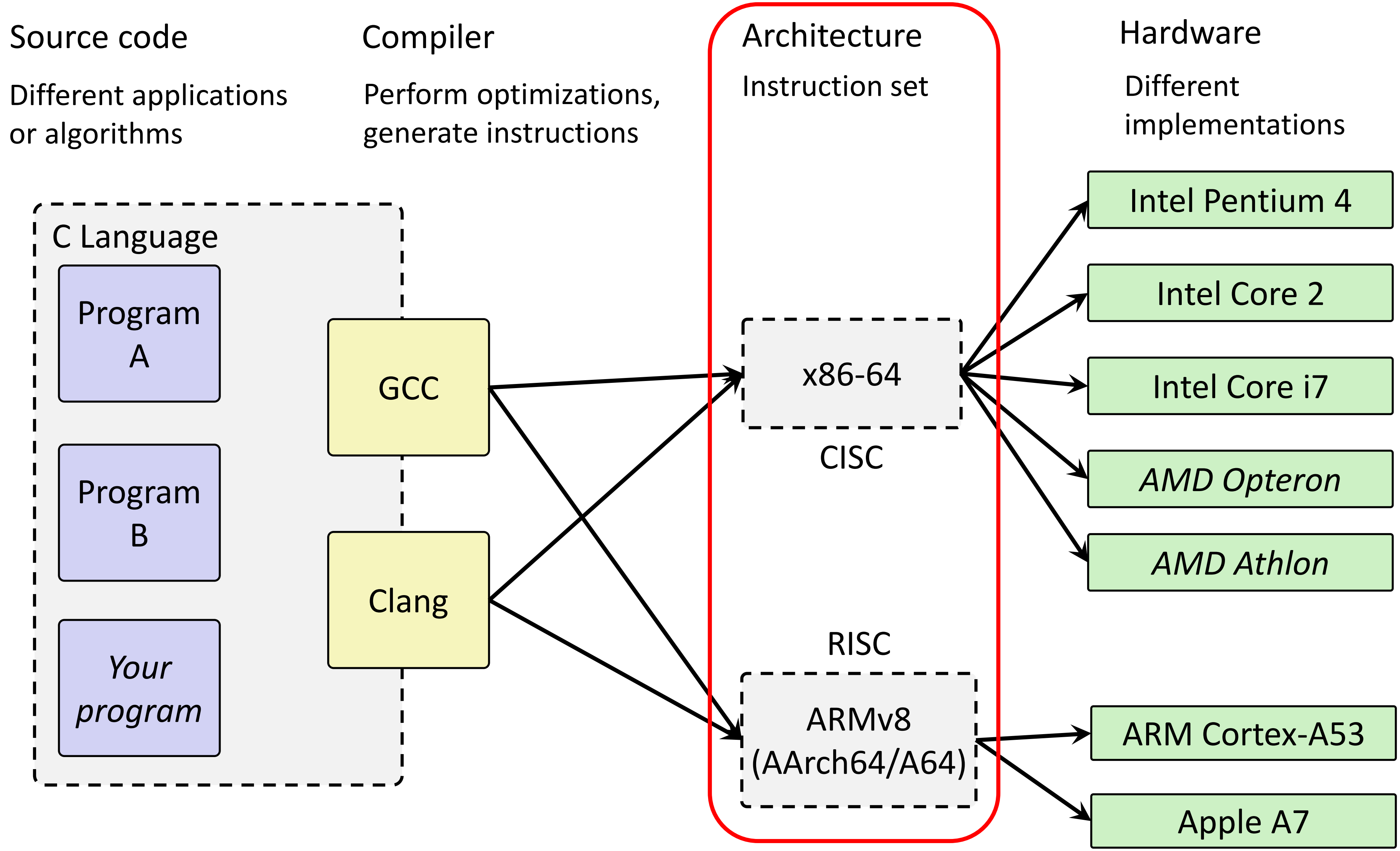
C and Memory

- Using C allowed us to examine how we store and access data in memory
  - Endianness (**only applies to memory**)
    - Is the first byte (lowest address) the least significant (little endian) or most significant (big endian) of your data?
  - Array indices and struct fields result in calculating proper addresses to access
- Consequences of accessing memory in your code:
  - Affects performance (locality)
  - Affects security
- But to understand these effects better, we had to dive deeper…

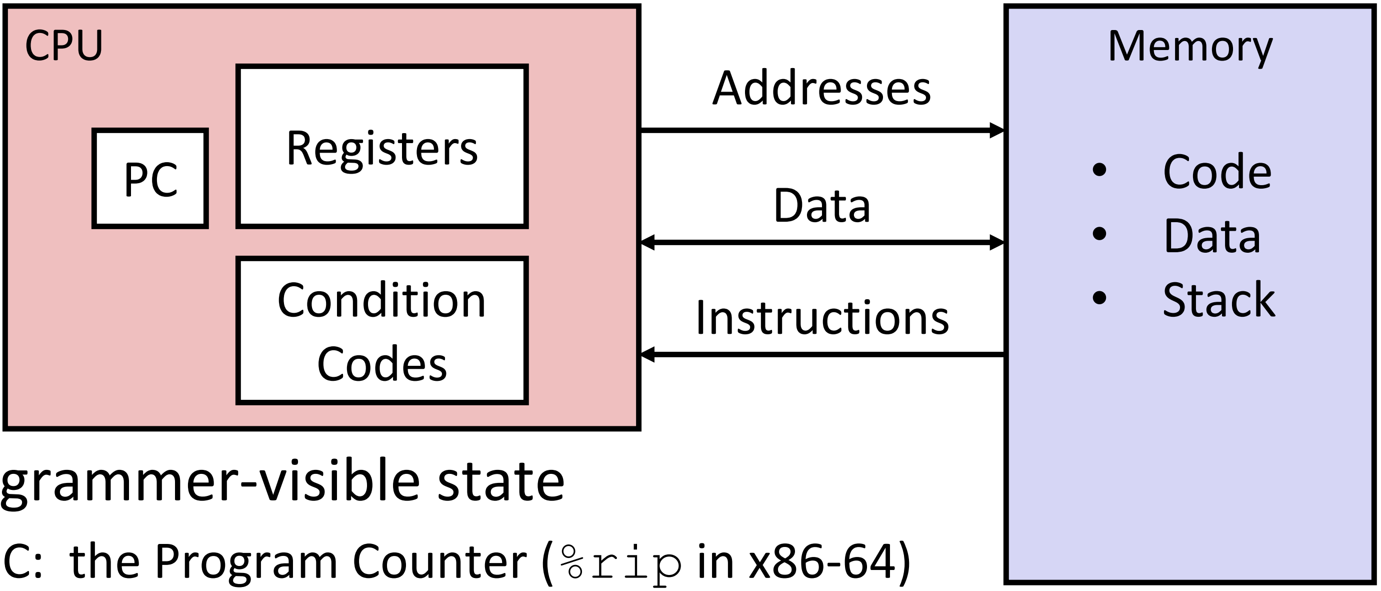
How Code Becomes a Program



Instruction Set Architecture



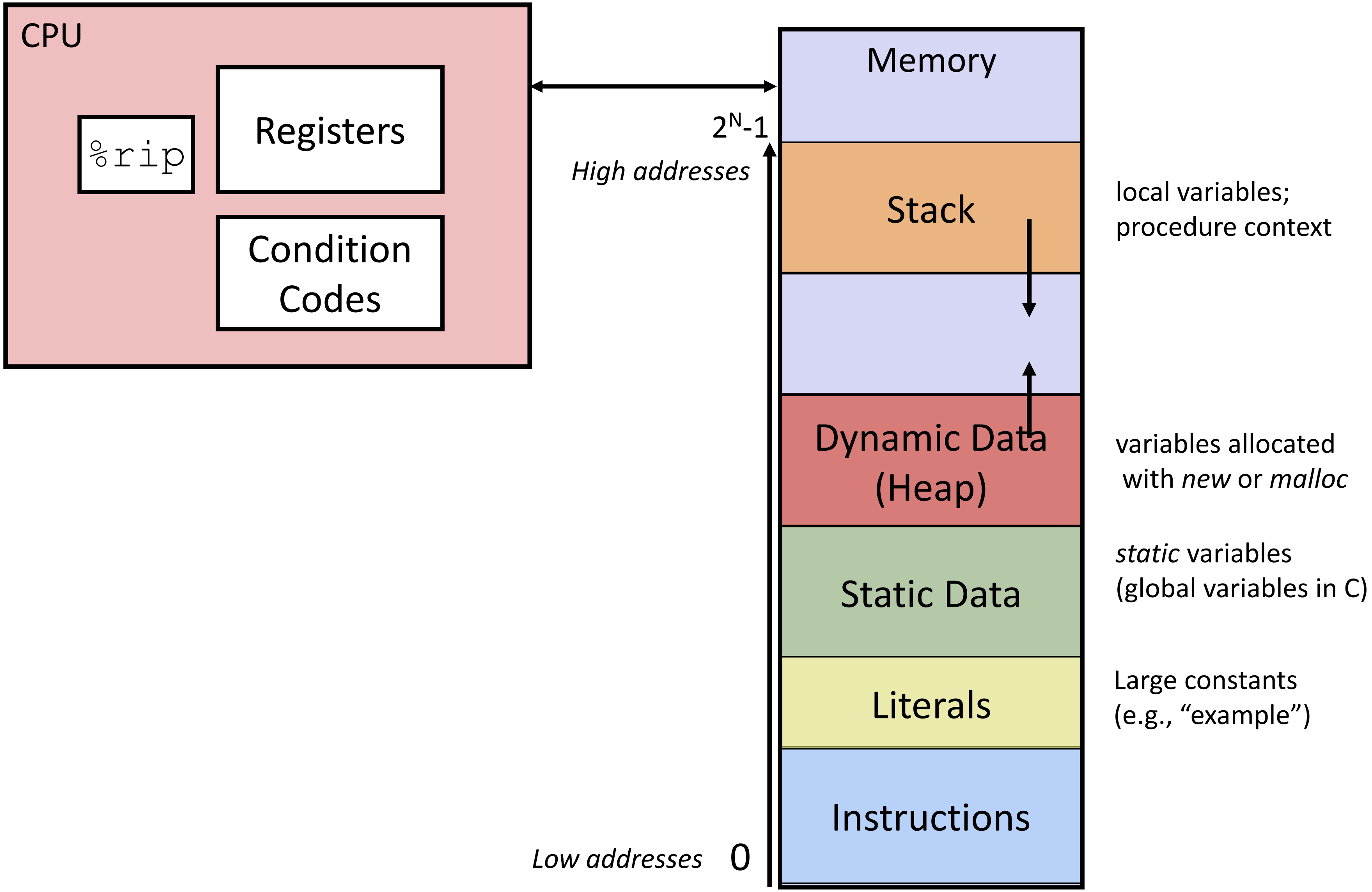
Assembly Programmer's View



- Programmer-visible state
  - PC: the Program Counter (`%rip` in x86-64)
    - Address of next instruction
  - Named registers
    - Together in "register file"
    - Heavily used program data
  - Condition codes
    - Store status information about most recent arithmetic operation
    - Used for conditional branching

- Memory
  - Byte-addressable array
  - Huge *virtual* address space
  - *Private, all to yourself…*

Program's View: Parts of Memory



local variables; procedure context

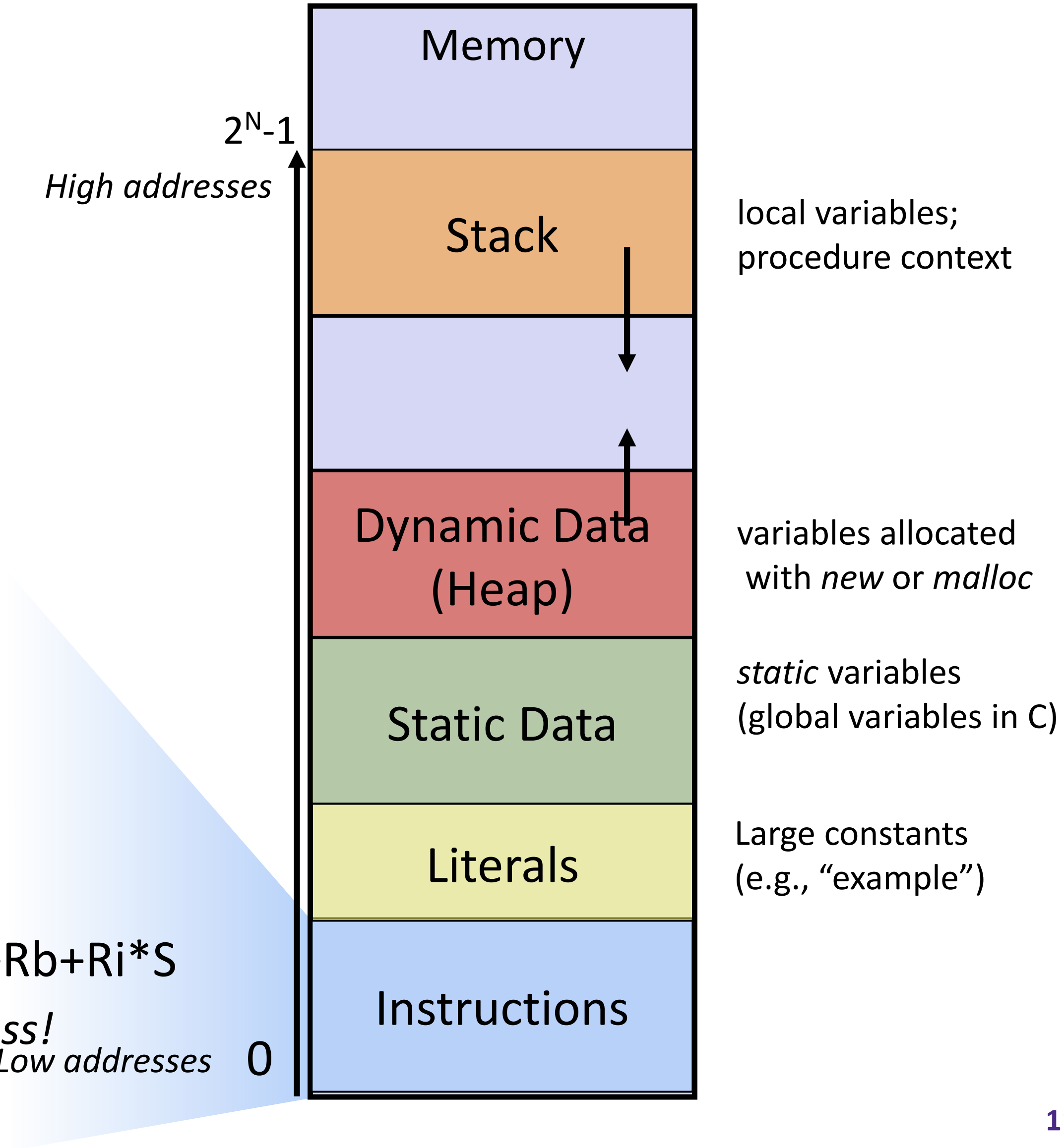
variables allocated with *new* or *malloc*

static variables (global variables in C)

Large constants (e.g., “example”)

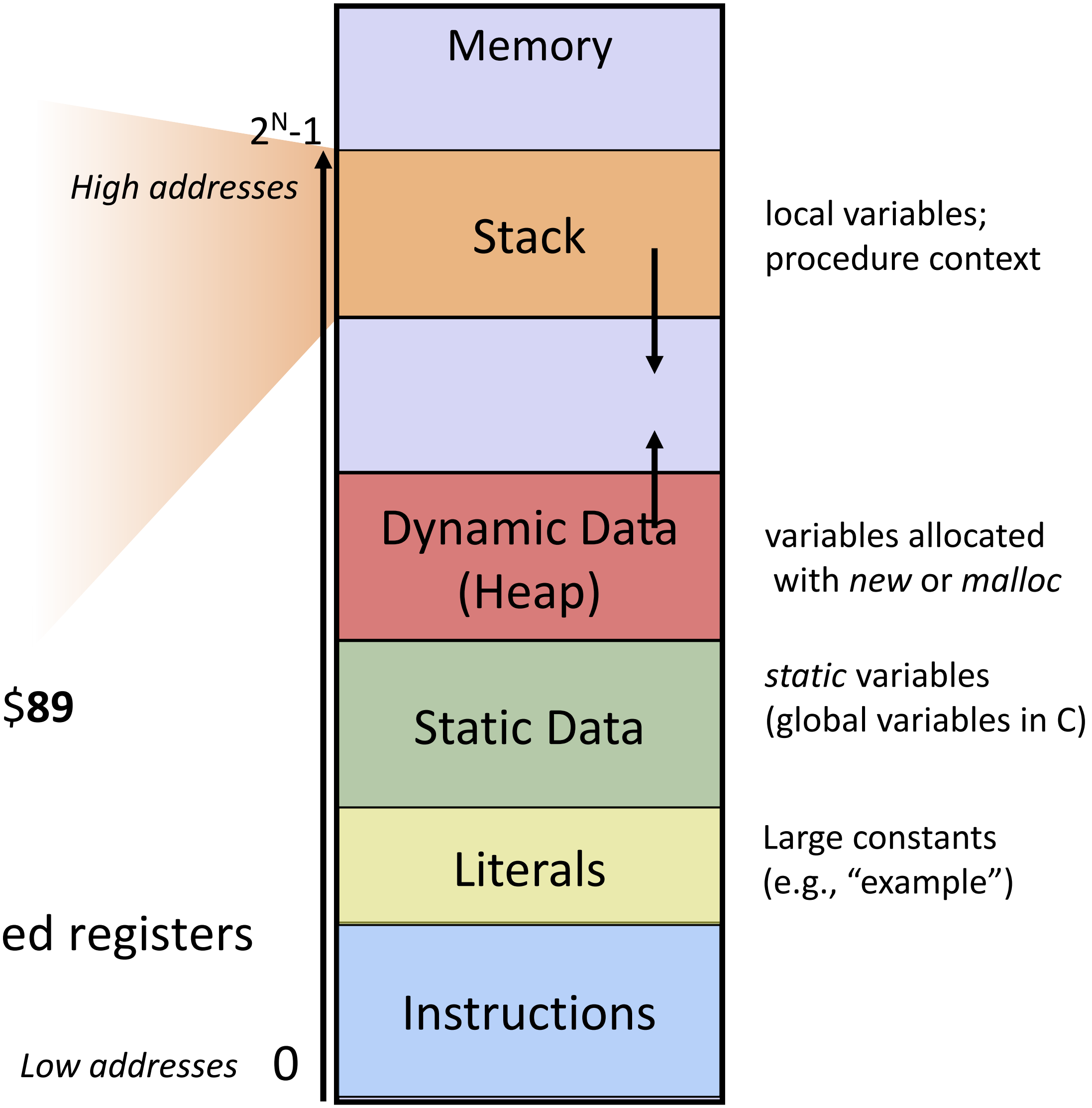
Program's View: Instructions

- Instructions
  - Data movement
    - `mov, movz, movz`
    - `push, pop`
  - Arithmetic
    - `add, sub, imul`
  - Control flow
    - `cmp, test`
    - `jmp, je, jgt, ...`
    - `call, ret`
- Operand types
  - Literal: `$8`
  - Register: `%rdi, %al`
  - Memory: D(Rb,Ri,S) = D+Rb+Ri*S
    - `lea`: *not a memory access!*



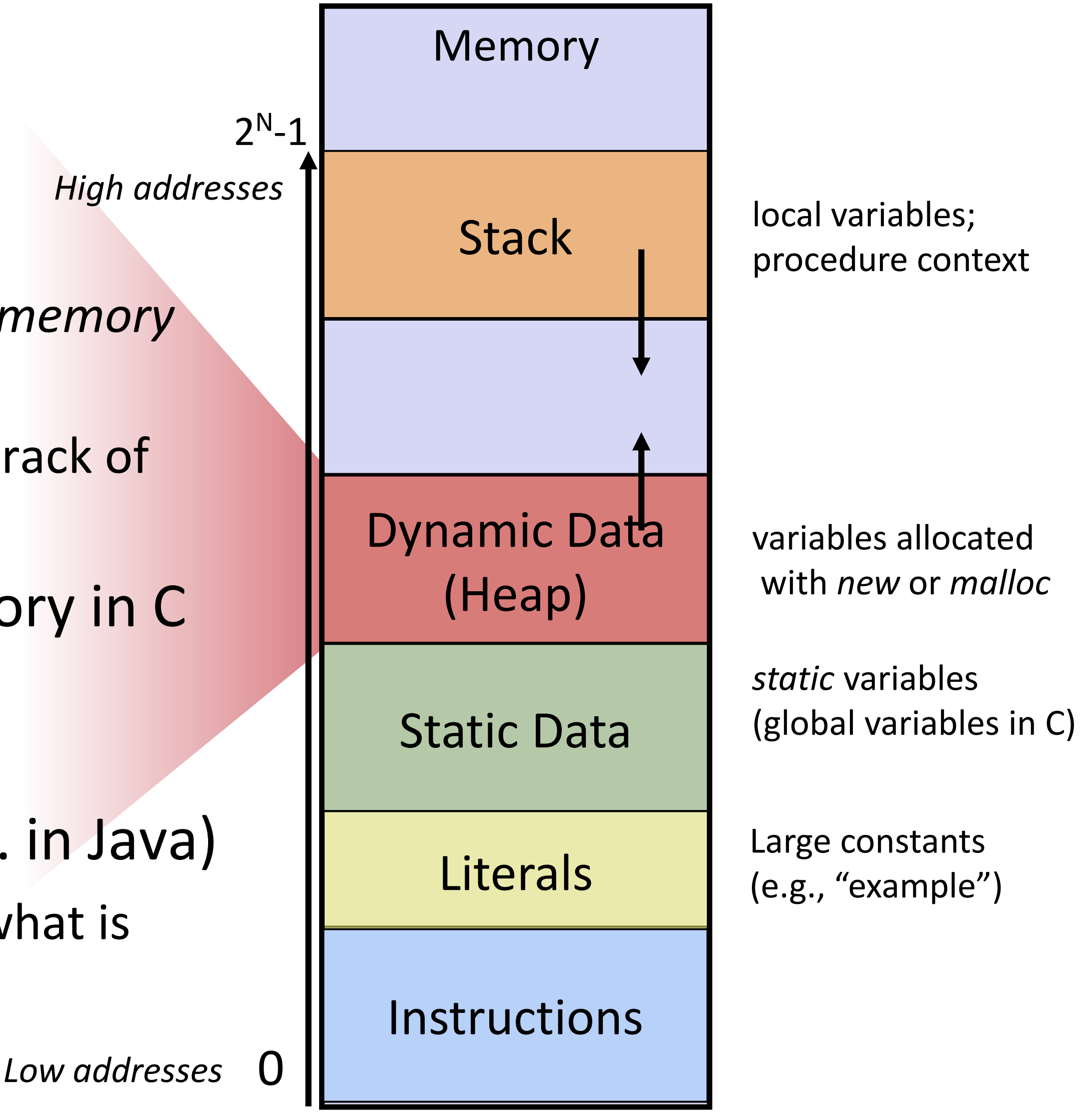
Program's View: Procedures & the Stack

- Procedures
  - Essential abstraction
  - Recursion…
- Stack discipline
  - Stack frame per call
  - Local variables
- Calling convention
  - How to pass arguments
    - **Di**ane's **Si**lk **D**ress **C**osts $**8**9
  - How to return data
  - Return address
  - Caller-saved / callee-saved registers

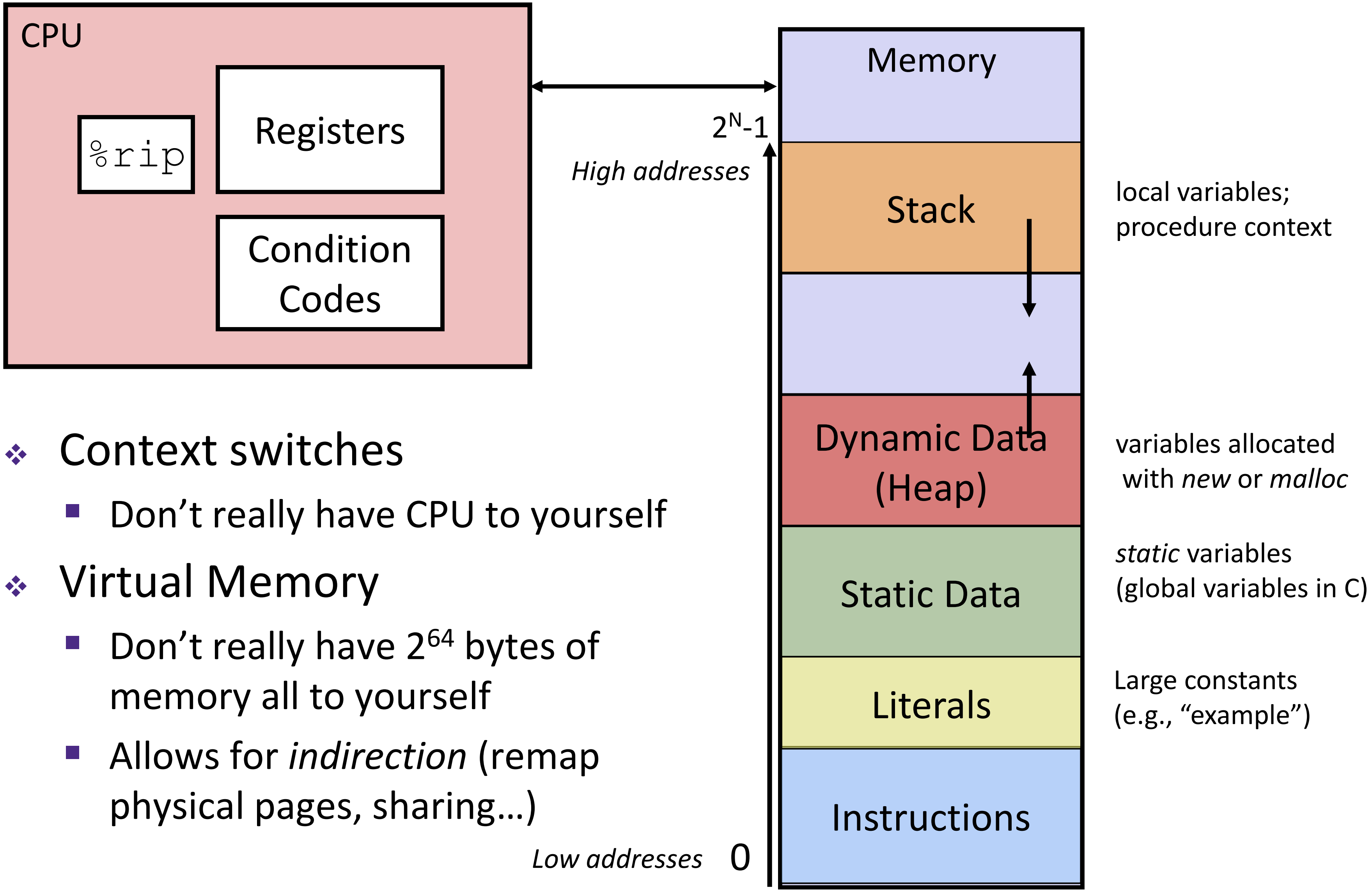


Program's View: The Heap

- Heap data
  - Flexible size & lifetime
- Allocator
  - Balance *throughput* and *memory utilization*
  - Data structures to keep track of free blocks
- Must always free memory in C
  - Failing to free results in *memory leaks*
- Garbage collection (e.g. in Java)
  - Garbage collectors find what is *reachable* from program

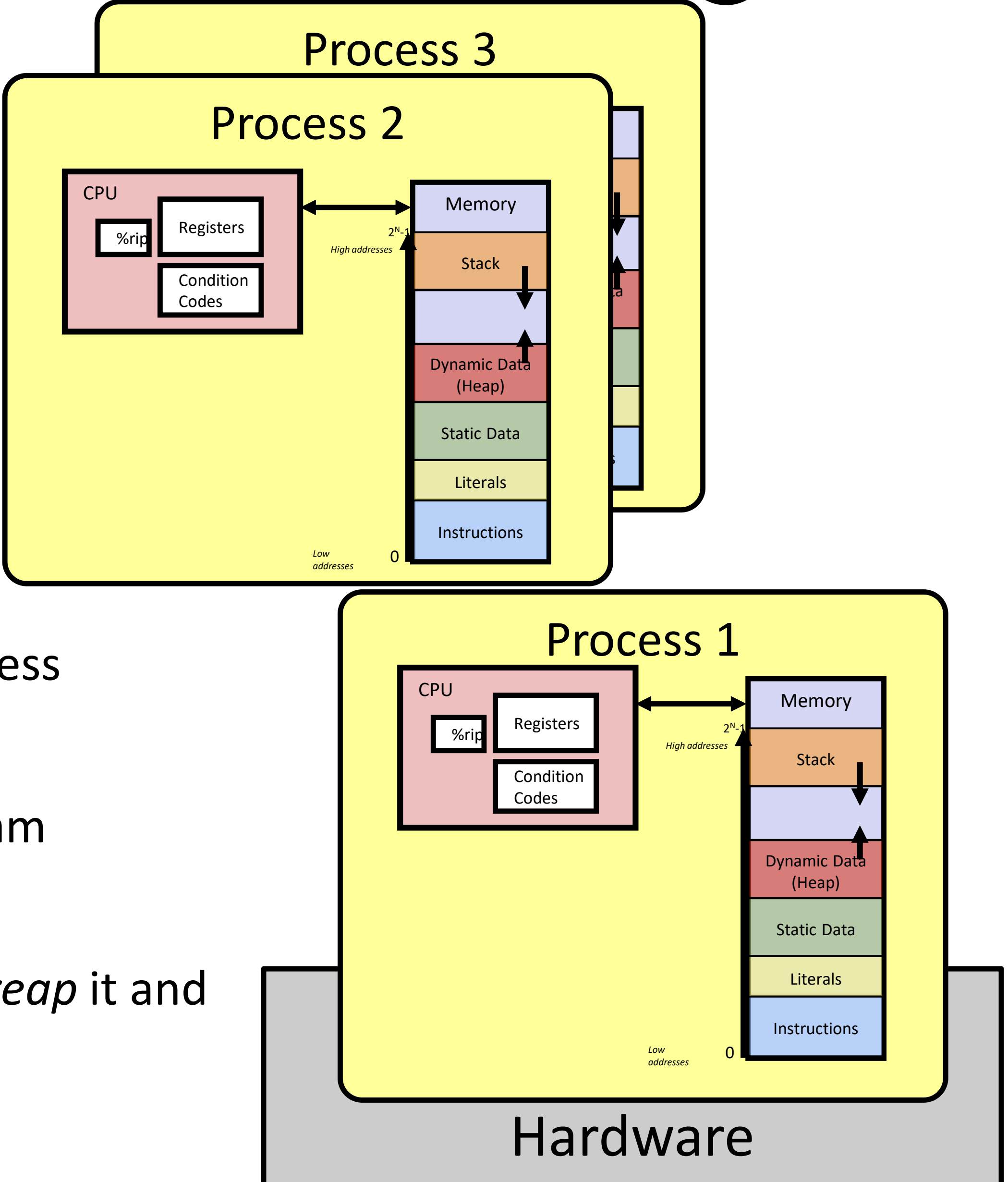


But remember… it's all an *illusion*! 😮


CPU
%rip
Registers
Condition Codes
Memory
2^N-1
High addresses
Stack
local variables; procedure context
Dynamic Data (Heap)
variables allocated with *new* or *malloc*
Static Data
static variables (global variables in C)
Literals
Large constants (e.g., "example")
Instructions
Low addresses
0

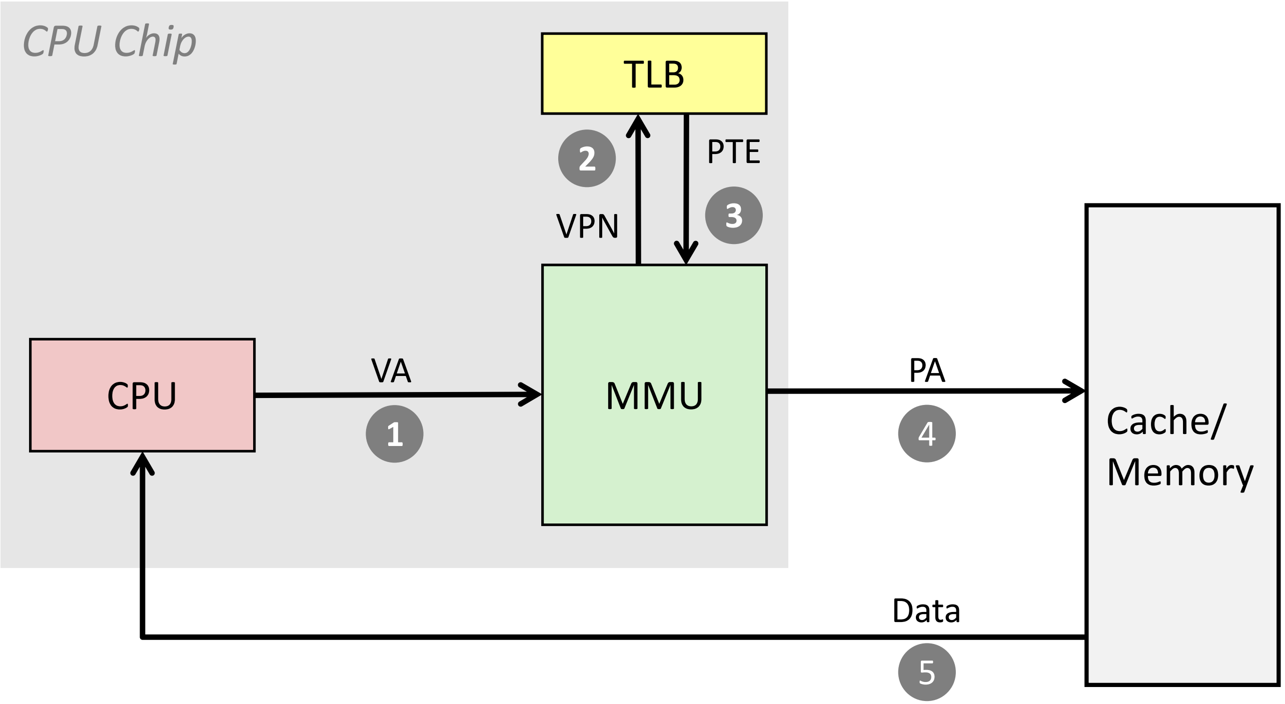
- Context switches
  - Don't really have CPU to yourself
- Virtual Memory
  - Don't really have 2^{64} bytes of memory all to yourself
  - Allows for *indirection* (remap physical pages, sharing…)

But remember… it's all an *illusion*! 😮



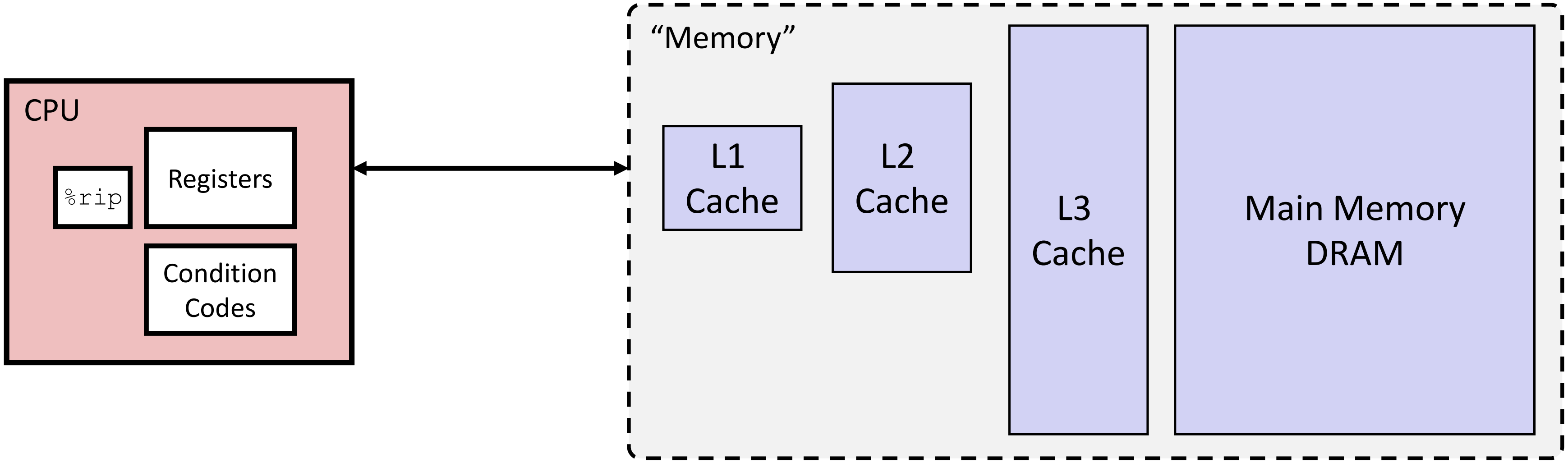
- `fork`
  - Creates copy of the process
- `execv`
  - Replace with new program
- `wait`
  - Wait for child to die (to *reap* it and prevent *zombies*)

Virtual Memory



- Address Translation
  - Every memory access must first be converted from virtual to physical
  - *Indirection:* just change the address mapping when switching processes
  - Luckily, TLB (and page size) makes it pretty fast

But Memory is Also a Lie! 😮

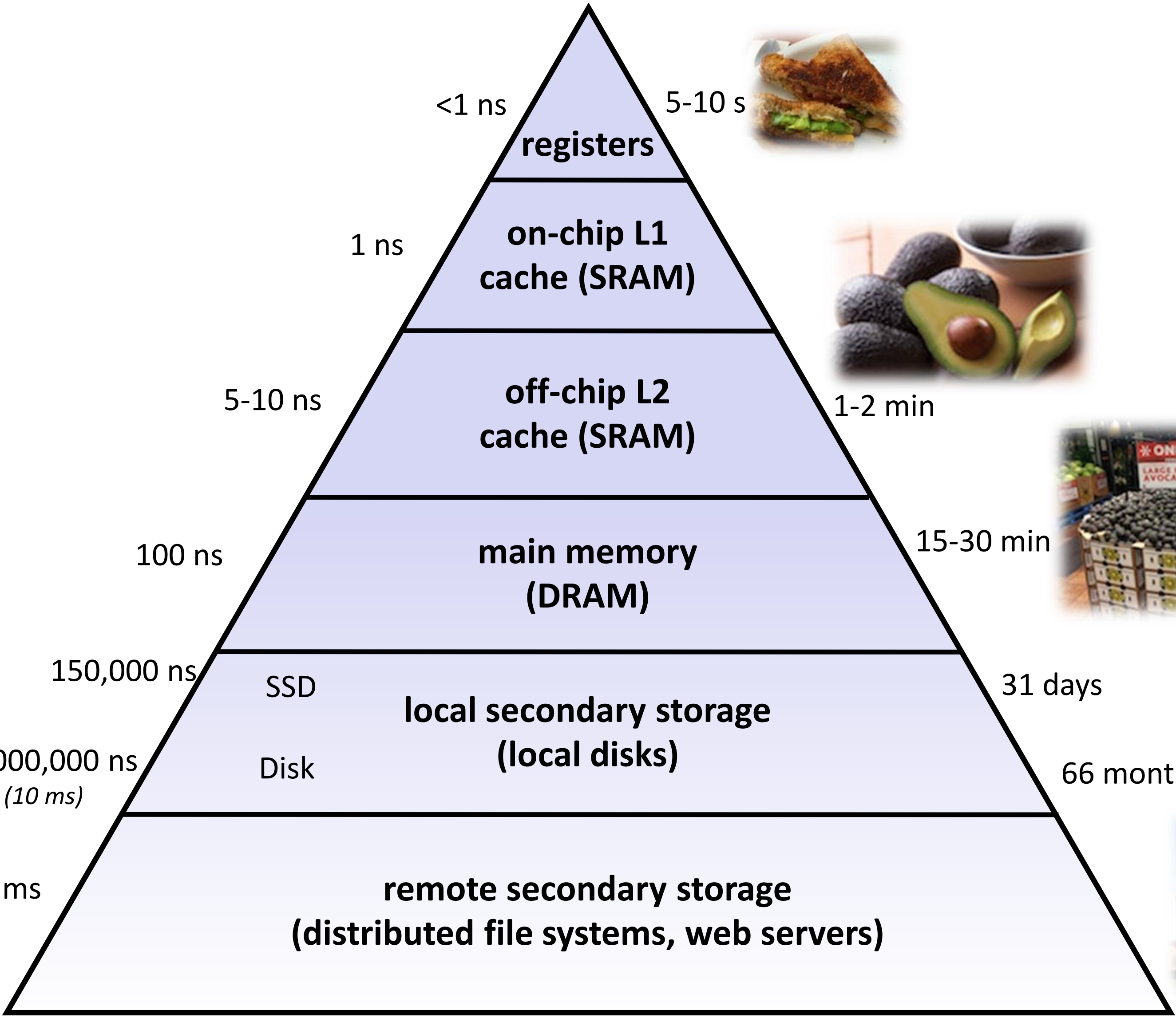


- *Illusion* of one flat array of bytes
  - But *caches* invisibly make accesses to physical addresses faster!
- Caches
  - **Associativity** tradeoff with miss rate and access time
  - **Block size** tradeoff with spatial and temporal locality
  - **Cache size** tradeoff with miss rate and cost

Memory Hierarchy

Smaller, faster, costlier per byte

Larger, slower, cheaper per byte



<1 ns **registers** 5-10 s

1 ns **on-chip L1 cache (SRAM)**

5-10 ns **off-chip L2 cache (SRAM)** 1-2 min

100 ns **main memory (DRAM)** 15-30 min

150,000 ns SSD 31 days

local secondary storage (local disks)

10,000,000 ns *(10 ms)* Disk 66 months = 5.5 years

1-150 ms **remote secondary storage (distributed file systems, web servers)**

1 - 15 years

Review of Course Themes

- Review course goals
  - They should make much more sense now!

Big Theme: Abstractions and Interfaces

- Computing is about abstractions
  - (but we can’t forget reality)
- What are the abstractions that we use?
- What do you need to know about them?
  - When do they break down and you have to peek under the hood?
  - What bugs can they cause and how do you find them?
- How does the hardware relate to the software?
  - Become a better programmer and begin to understand the important concepts that have evolved in building ever more complex computer systems

Little Theme 1: Representation

- All digital systems represent everything as 0s and 1s
  - The 0 and 1 are really two different voltage ranges in the wires
  - Or magnetic positions on a disc, or hole depths on a DVD, or even *DNA*…
- "Everything" includes:
  - Numbers – integers and floating point
  - Characters – the building blocks of strings
  - Instructions – the directives to the CPU that make up a program
  - Pointers – addresses of data objects stored away in memory
- Encodings are stored throughout a computer system
  - In registers, caches, memories, disks, etc.
- They all need addresses (a way to locate)
  - Find a new place to put a new item
  - Reclaim the place in memory when data no longer needed

Little Theme 2: Translation

- There is a big gap between how we think about programs and data and the 0s and 1s of computers
  - Need languages to describe what we mean
  - These languages need to be translated one level at a time

- We know Java as a programming language
  - Have to work our way down to the 0s and 1s of computers
  - Try not to lose anything in translation!
  - We encountered C language, assembly language, and machine code (for the x86 family of CPU architectures)

Little Theme 3: Control Flow

- How do computers orchestrate everything they are doing?
- Within one program:
  - How do we implement if/else, loops, switches?
  - What do we have to keep track of when we call a procedure, and then another, and then another, and so on?
  - How do we know what to do upon “return”?
- Across programs and operating systems:
  - Multiple user programs
  - Operating system has to orchestrate them all
    - Each gets a share of computing cycles
    - They may need to share system resources (memory, I/O, disks)
  - Yielding and taking control of the processor
    - Voluntary or “by force”?

Course Perspective

- CSE351 will make you a better programmer
  - Purpose is to show how software really works
    - Understanding of some of the abstractions that exist between programs and the hardware they run on, why they exist, and how they build upon each other
  - Understanding the underlying system makes you more effective
    - Better debugging
    - Better basis for evaluating performance
    - How multiple activities work in concert (e.g. OS and user programs)
  - "Stuff everybody learns and uses and forgets not knowing"

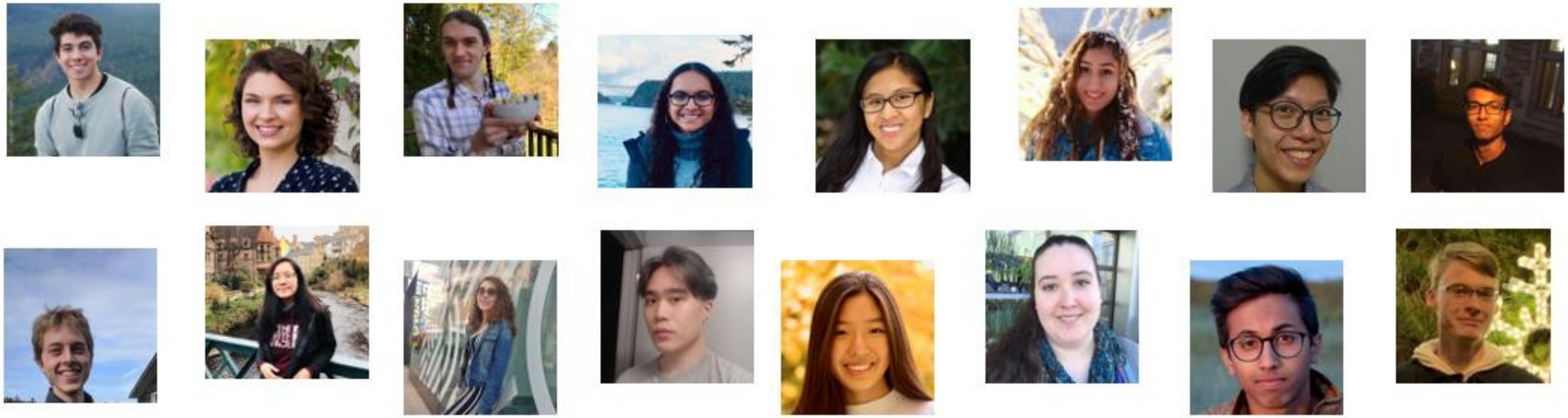
- CSE351 presents a world-view that will empower you
  - The intellectual and software tools to understand the trillions+ of 1s and 0s that are "flying around" when your program runs

Courses: What's Next?

- Staying near the hardware/software interface:
  - **CSE369/EE271:** Digital Design – basic hardware design using FPGAs
  - **CSE474/EE474:** Embedded Systems – software design for microcontrollers
- Systems software (CSE major/any-major courses)
  - **CSE341/CSE413:** Programming Languages
  - **CSE332/CSE373:** Data Structures and Parallelism
  - **CSE333/CSE374:** Systems Programming – building well-structured systems in C/C++
- Looking ahead
  - **CSE401/CSE413:** Compilers (pre-reqs: 332/373)
  - **CSE451:** Operating Systems (pre-reqs: 332, 333)
  - **CSE461:** Networks (pre-reqs: 332, 333)

Thanks for a great quarter!

- Huge thanks to your awesome TAs!



- Don’t be a stranger!
  - Stop by to say “hi” in the fall (Ruth’s Office: CSE 558)!
  - I hope to see you in a course sometime in the future!