Course Wrap-Up

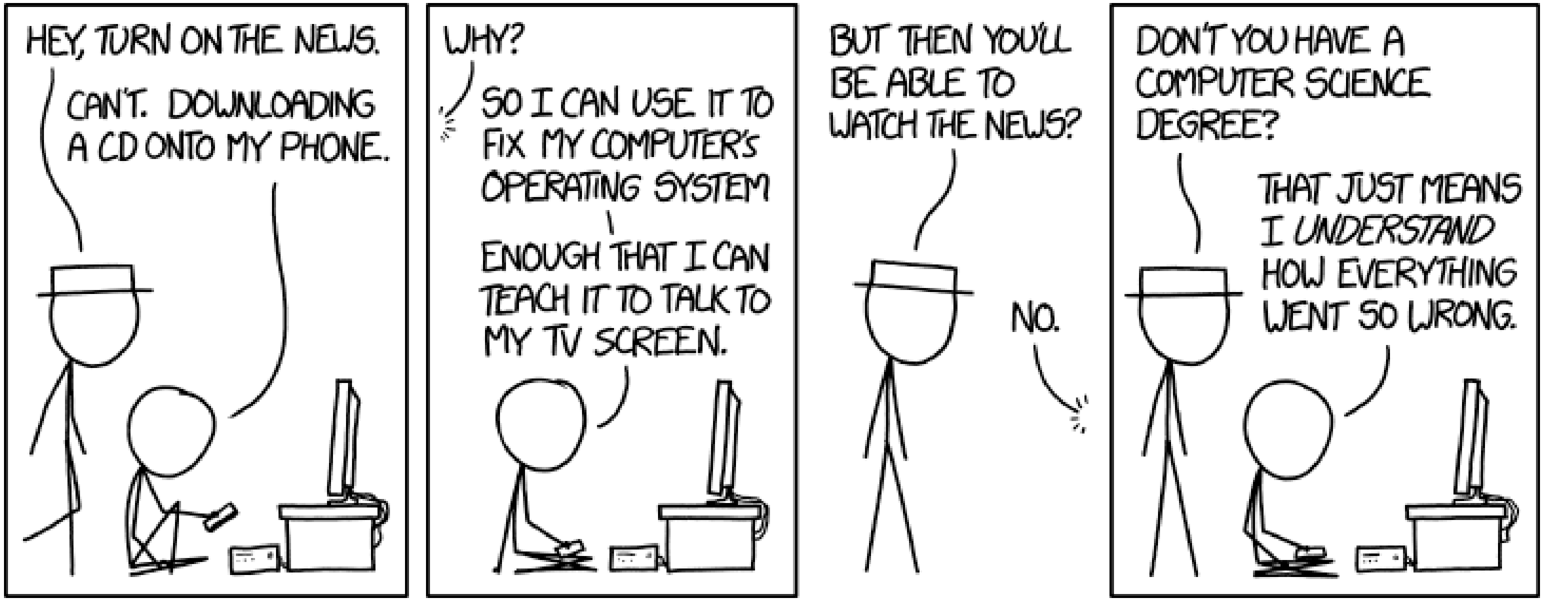
CSE 351 Autumn 2021

Instructor:

Justin Hsia

Teaching Assistants:

Allie Pfleger	Anirudh Kumar	Assaf Vayner
Atharva Deodhar	Celeste Zeng	Dominick Ta
Francesca Wang	Hamsa Shankar	Isabella Nguyen
Joy Dang	Julia Wang	Maggie Jiang
Monty Nitschke	Morel Fotsing	Sanjana Chintalapati



https://xkcd.com/1760/

Relevant Course Information

- Please fill out the **course evaluation**!
  - Evaluations close Sunday, December 12th at 11:59 pm
    - Not viewable until after grades are submitted
  - See Ed post #985 for links (separate for Lecture and Section)
  - We take these seriously and use them to improve our teaching and this class!

- **Final Exam:** take-home Dec. 13-15
  - Review Session: tonight, 4:30-6:30 pm on Zoom
  - Similar structure to Midterm, including Gilligan's Island Rule
  - Final review packet and reference sheet on website

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 (points)
  - More useful for “5 years from now” than “the final”
- Question time

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 is good for two things: being beautiful and creating catastrophic 0days in memory management." (https://medium.com/message/everything-is-broken-81e5f33a24e1)

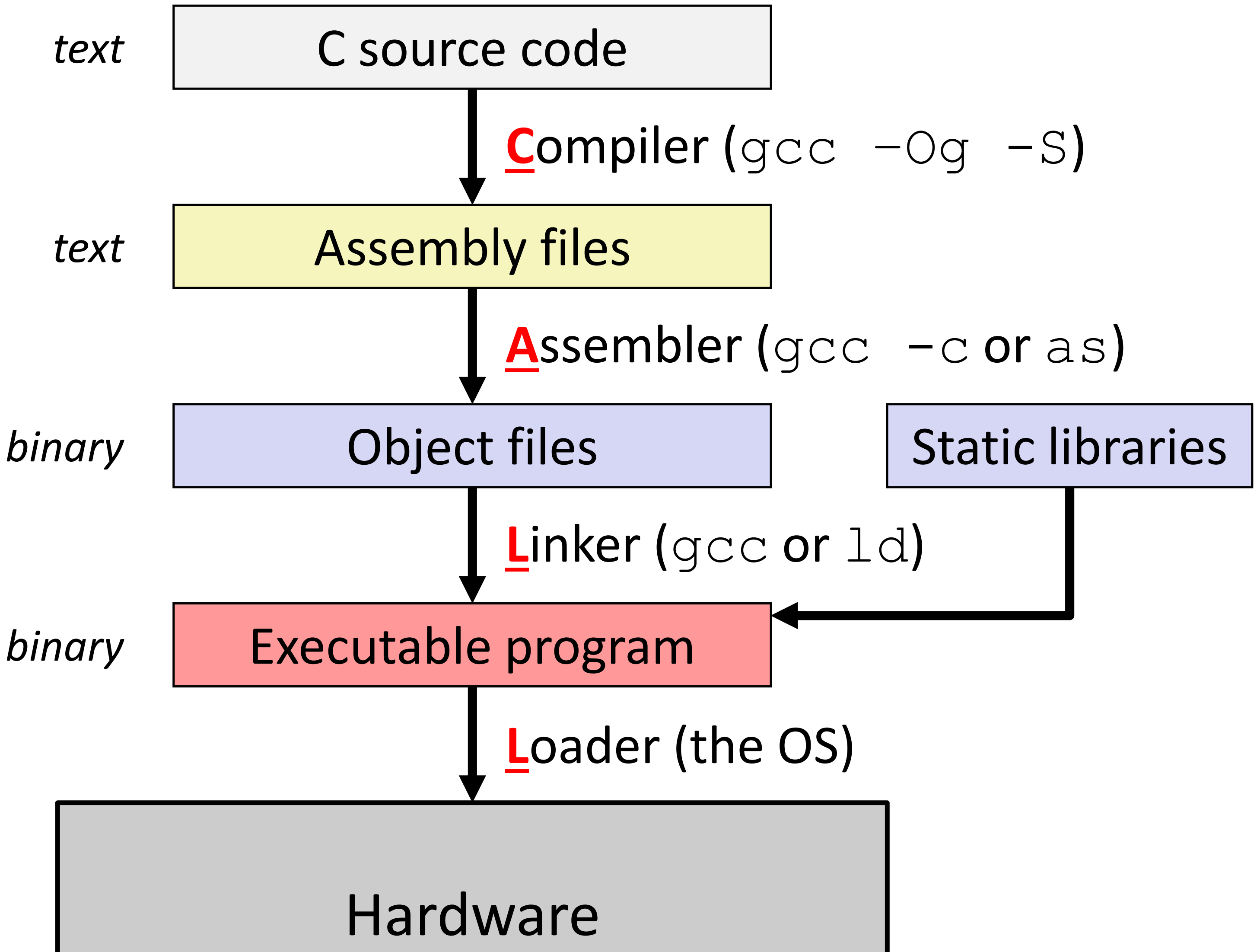
C Data Types

- 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)

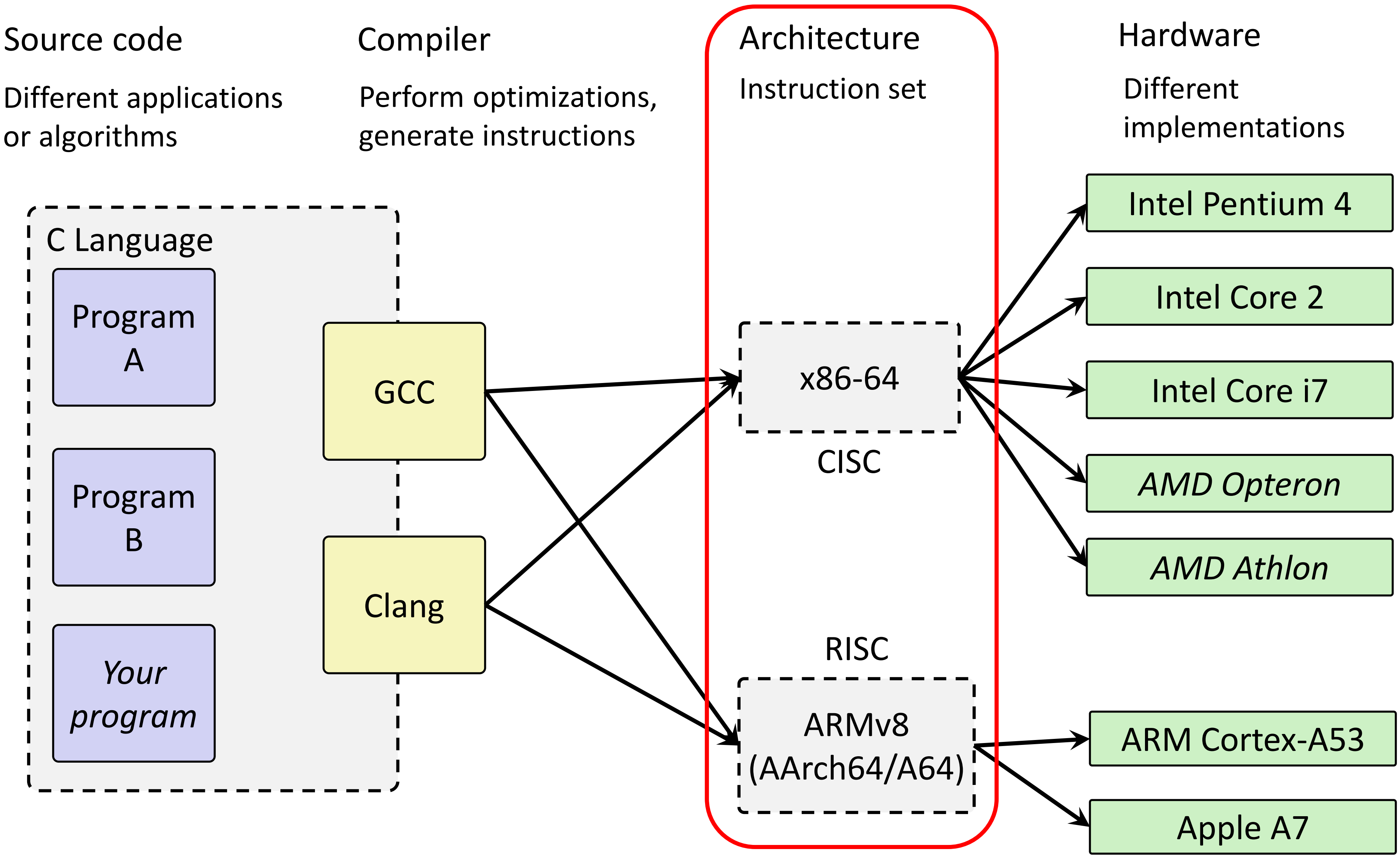
C and Memory

- 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 your code:
  - Affects performance (locality)
  - Affects security
- But to understand these effects better, we had to dive deeper…

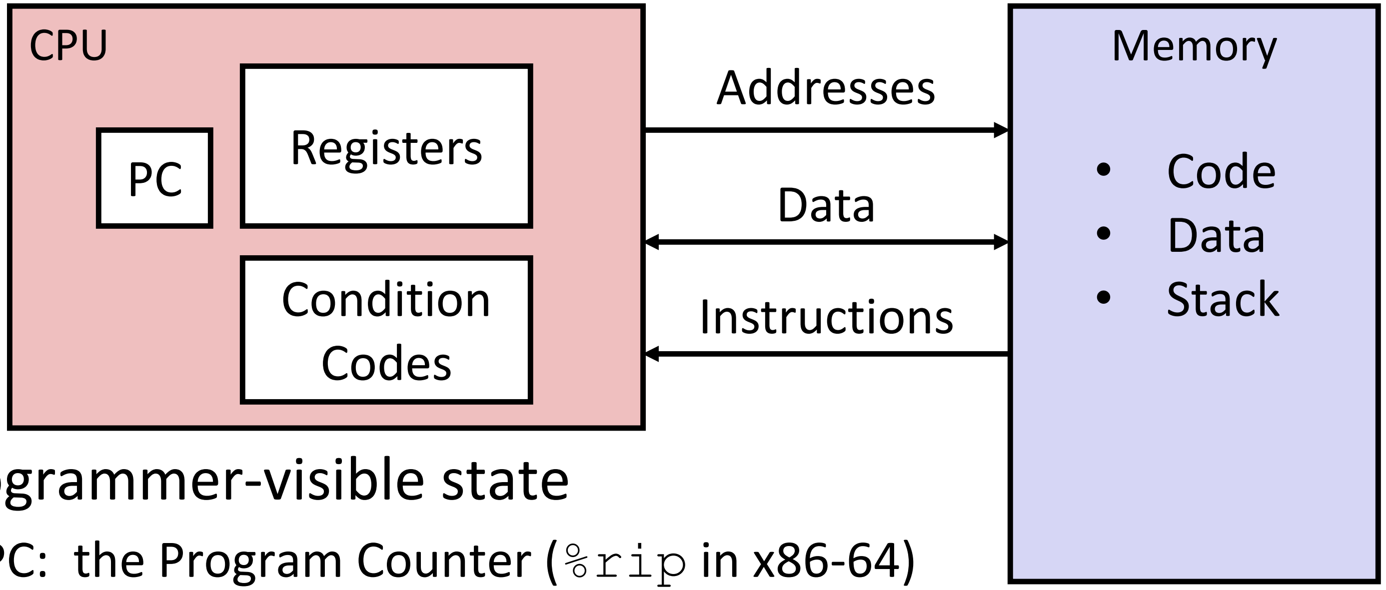
How Code Becomes a Program



Instruction Set Architecture



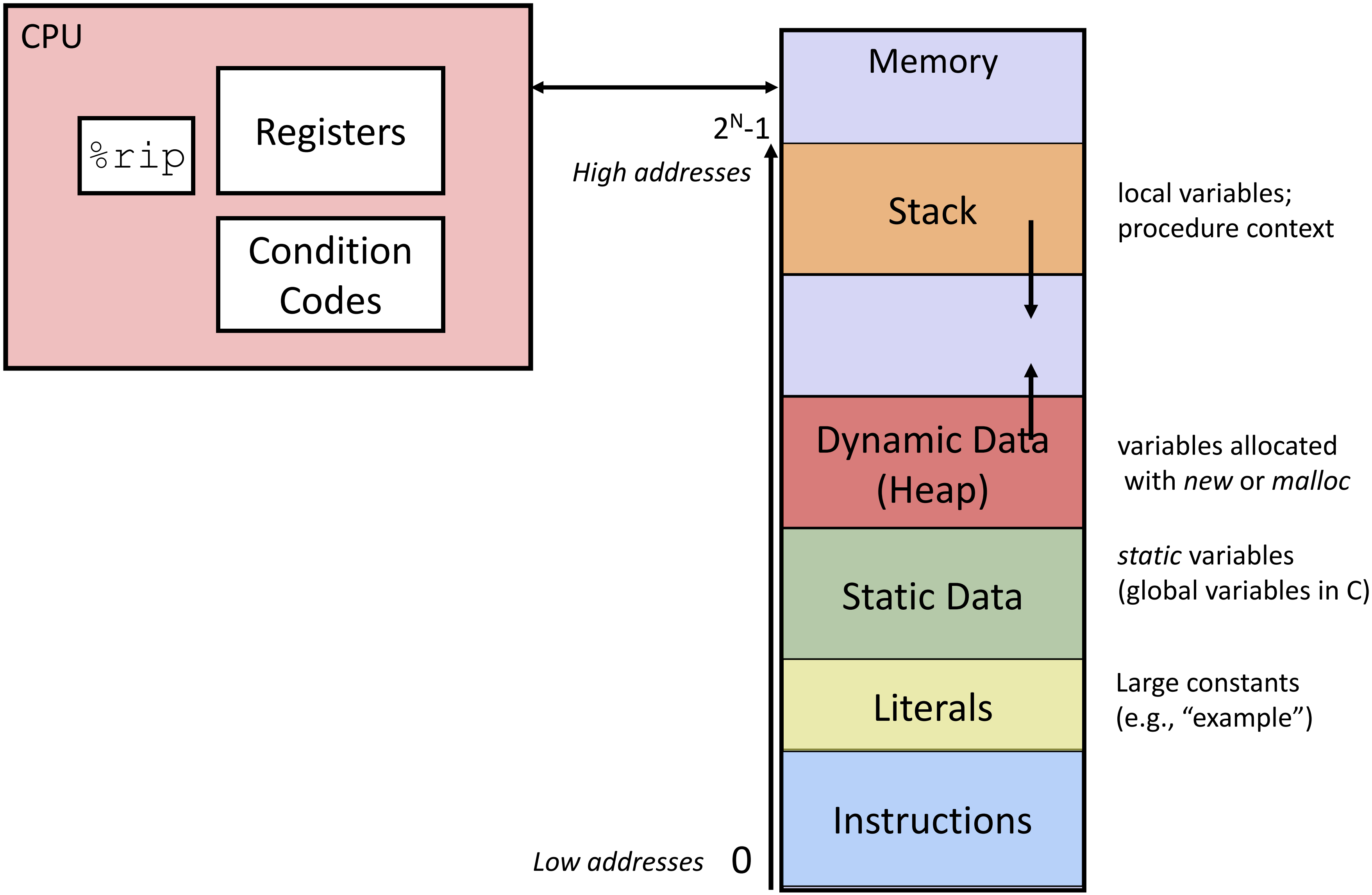
Assembly Programmer's View



- 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

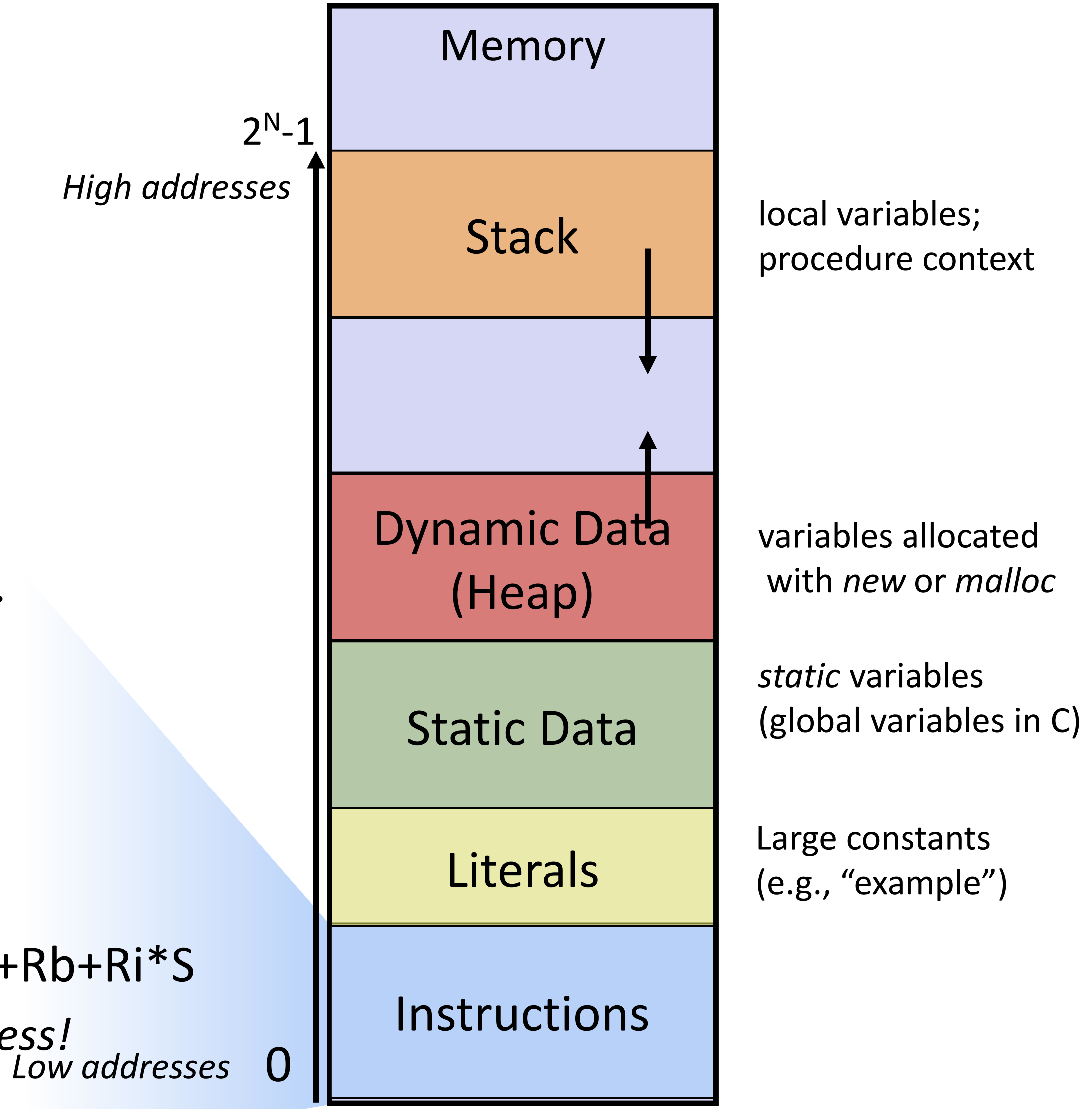
- Memory
  - Byte-addressable array
  - Huge *virtual* address space
  - *Private, all to yourself…*

Program’s View



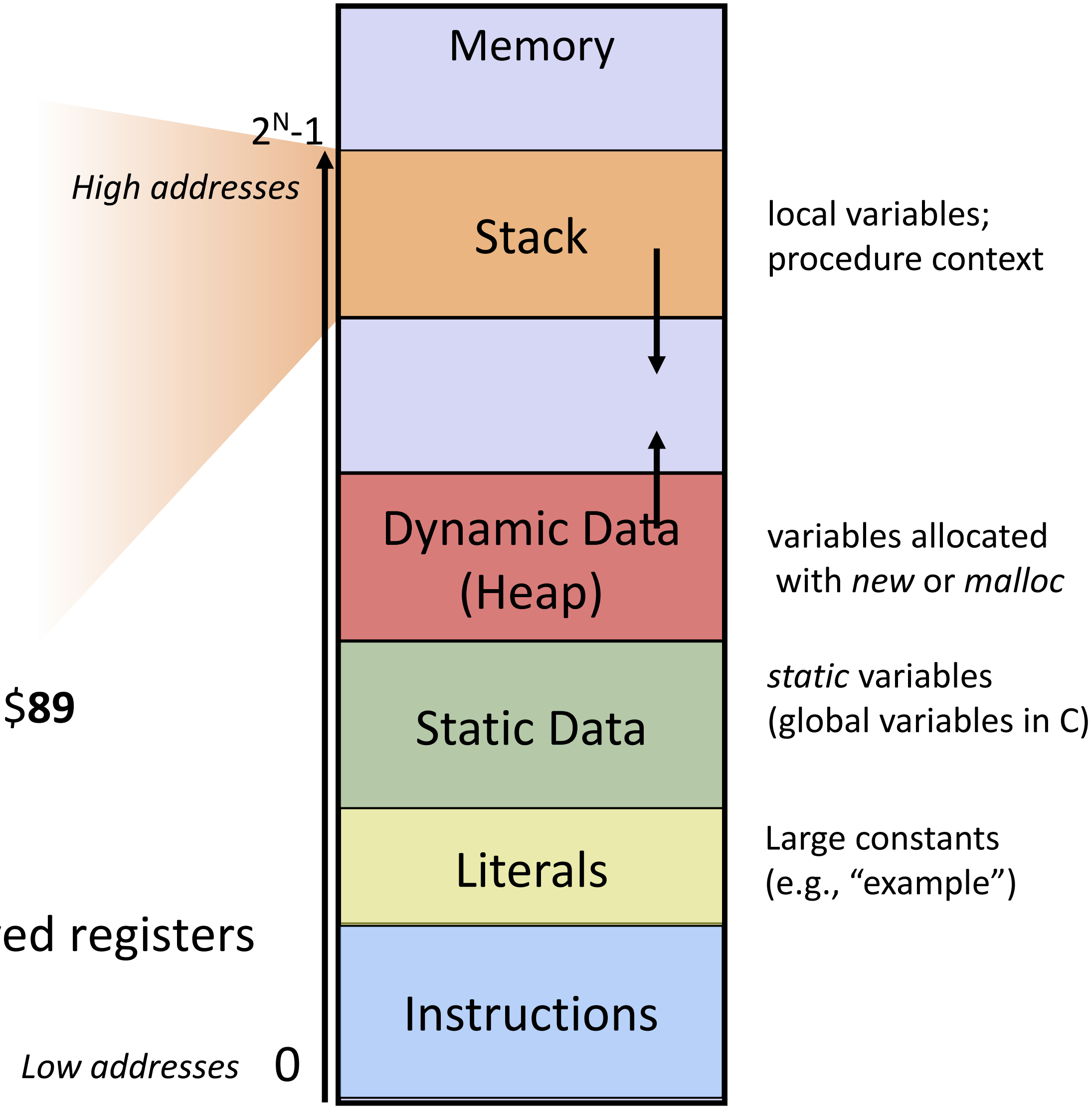
Program's View

- 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!*



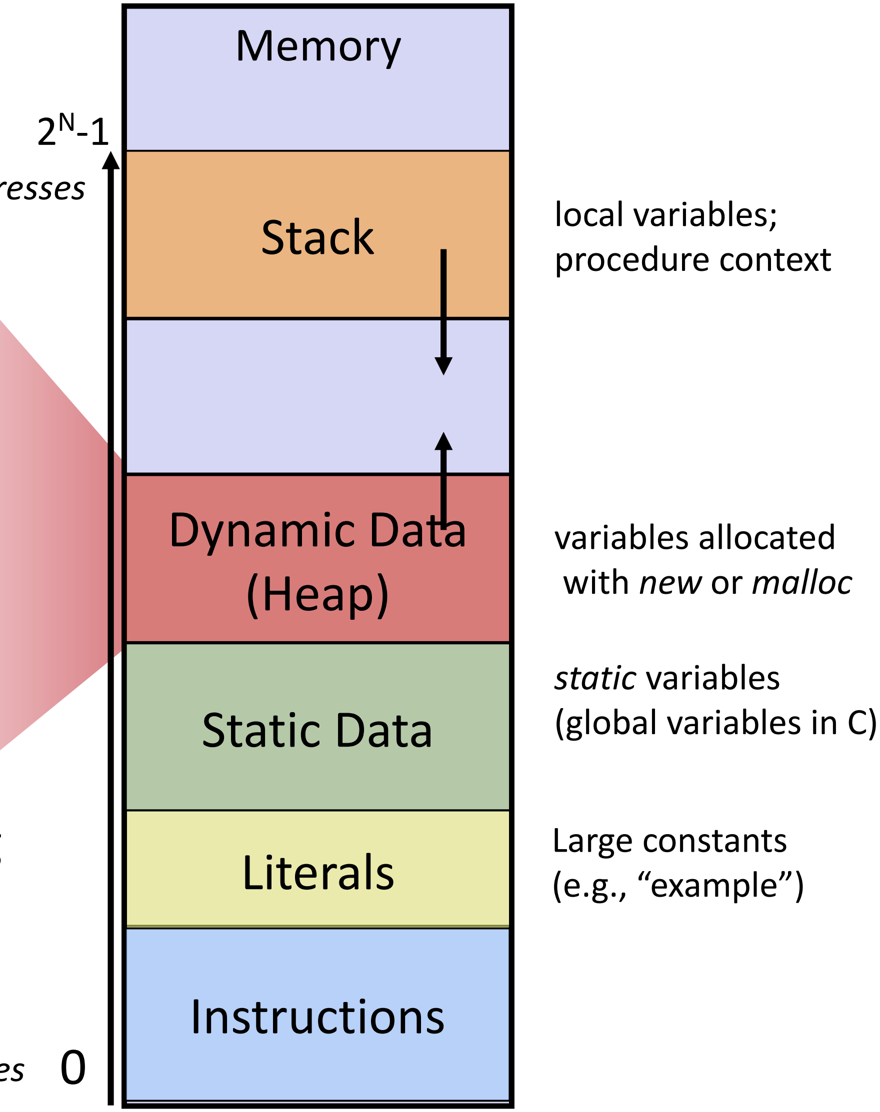
Program's View

- Procedures
  - Essential abstraction
  - Recursion…
- Stack discipline
  - Stack frame per call
  - Local variables
- Calling convention
  - How to pass arguments
    - **D**iane's **Si**lk **D**ress **C**osts $**89**
  - How to return data
  - Return address
  - Caller-saved / callee-saved registers

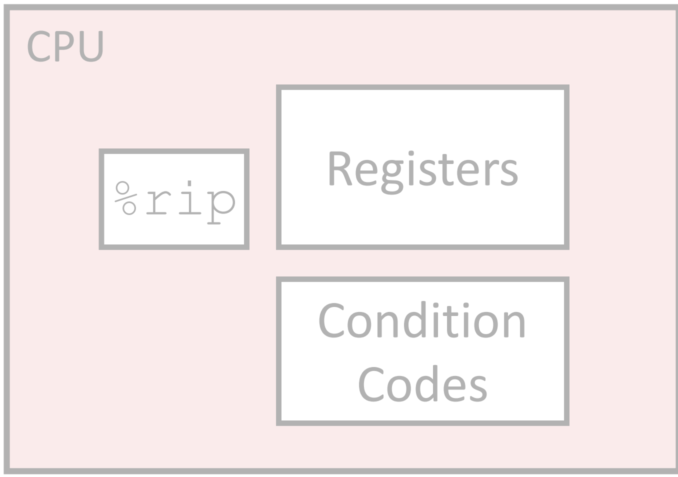


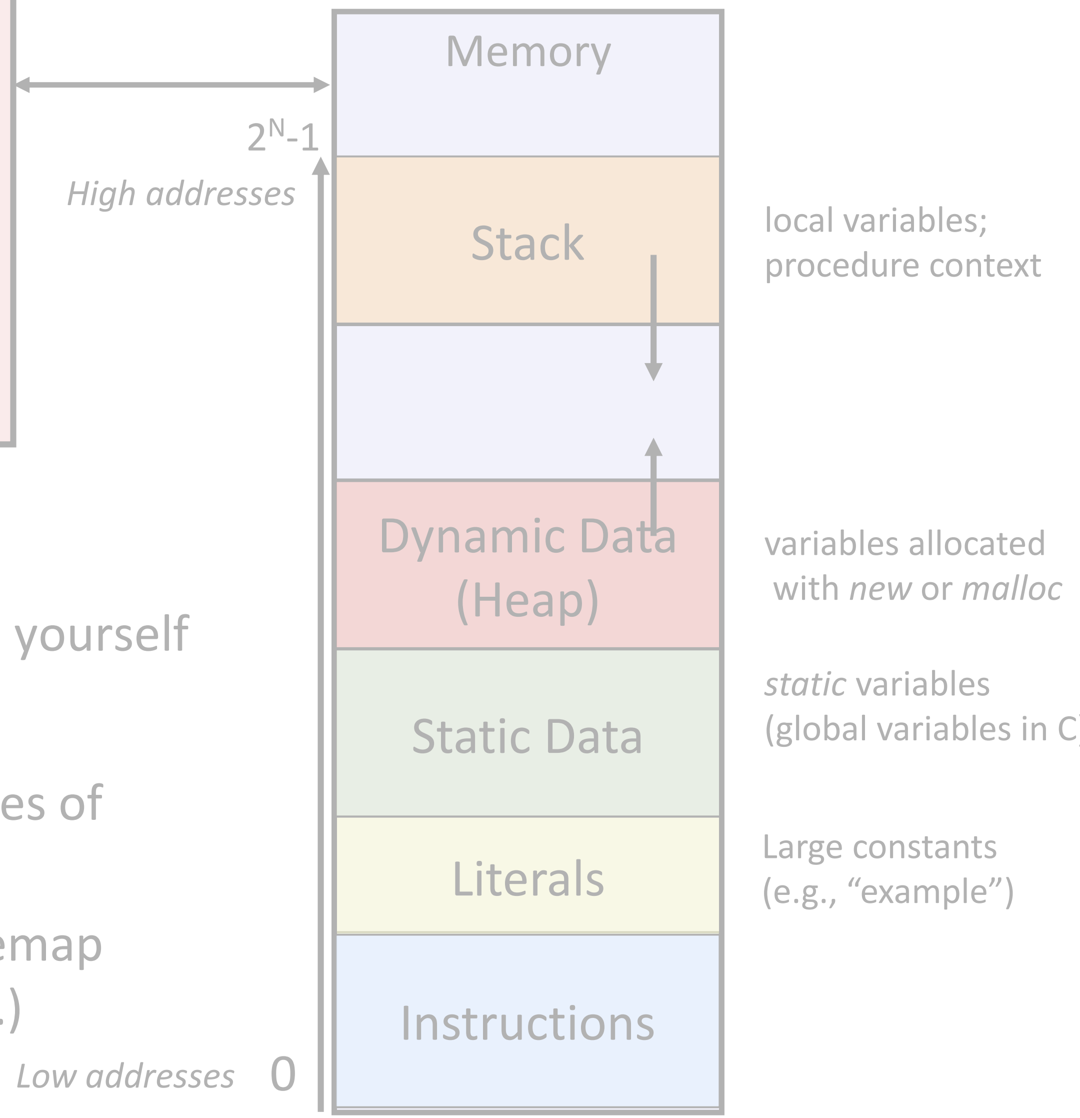
Program's View

- Heap data
  - Variable size
  - Variable lifetime
- Allocator
  - Balance *throughput* and *memory utilization*
  - Data structures to keep track of free blocks
- Garbage collection
  - Must always free memory
  - Garbage collectors help by finding anything *reachable*
  - Failing to free results in *memory leaks*



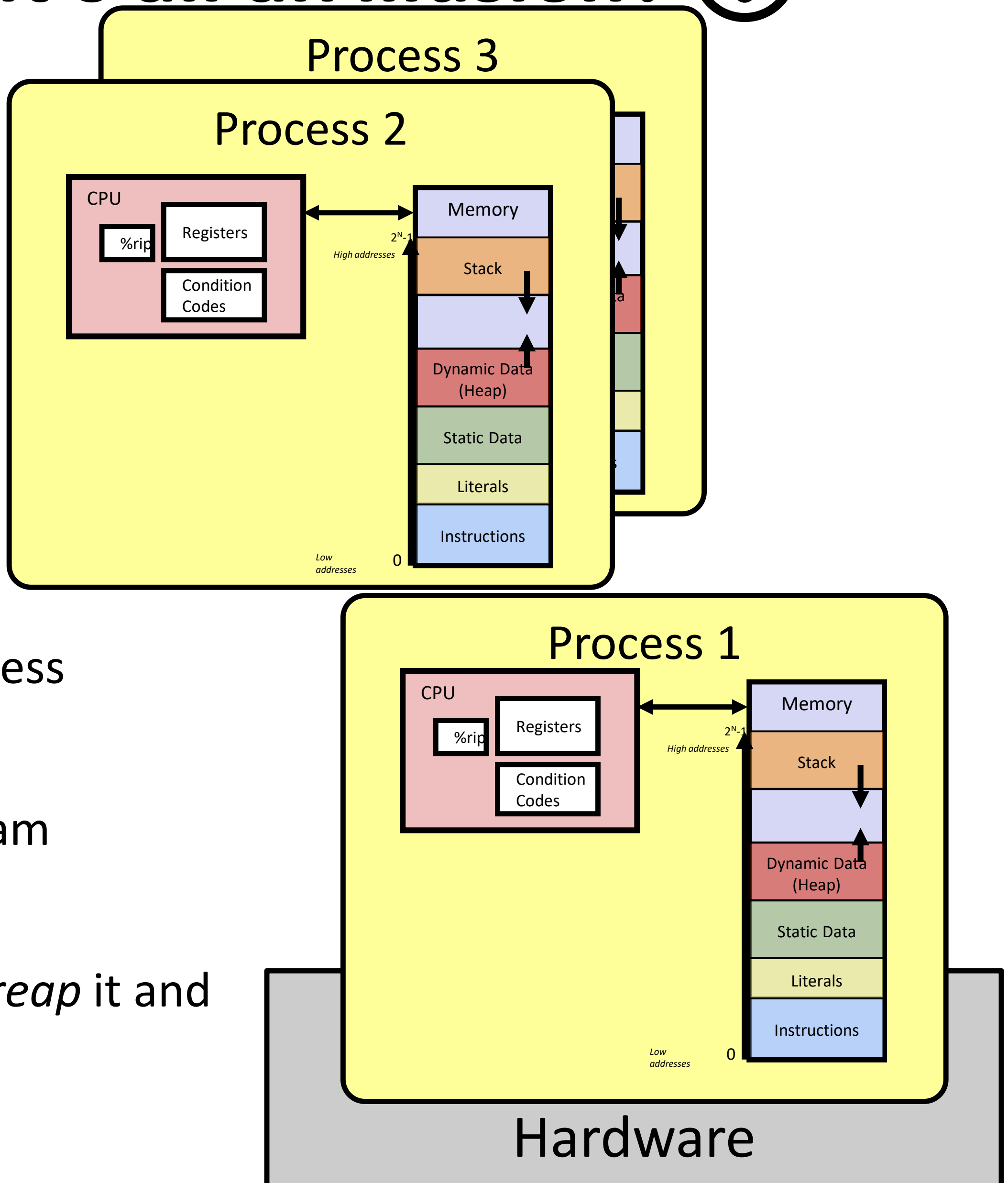
But remember… it's all an *illusion*! 😮





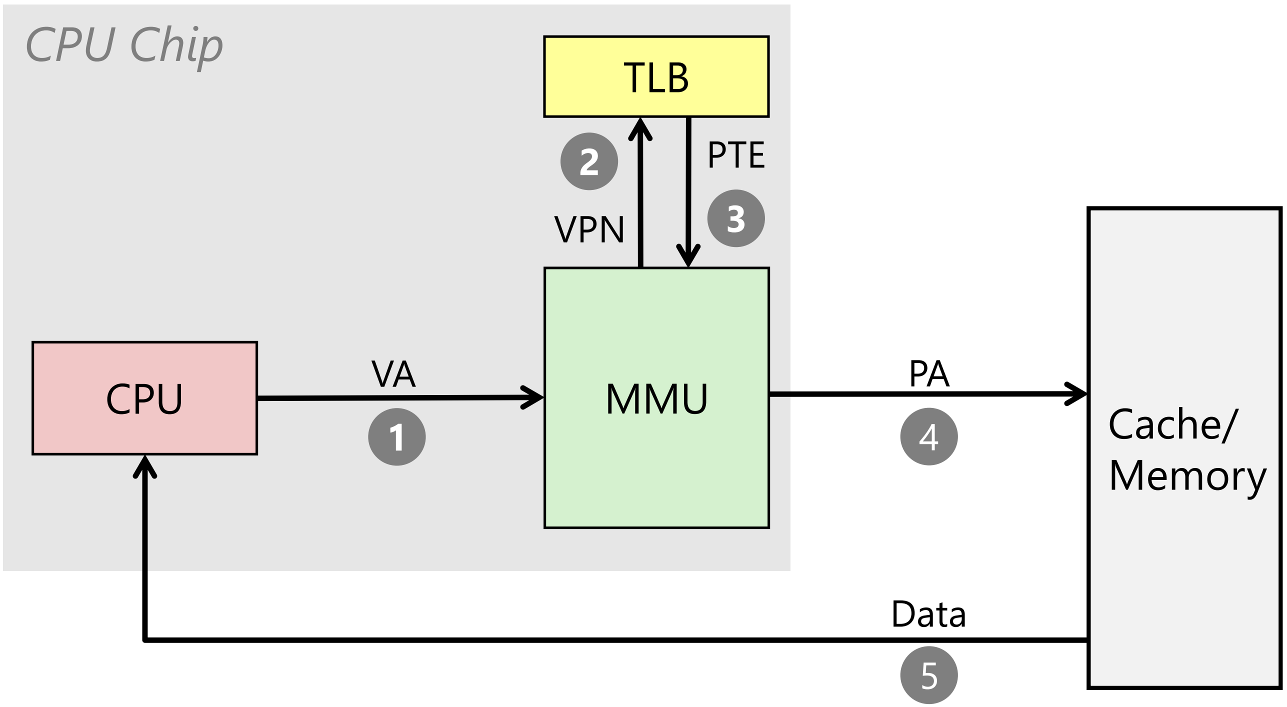
- Context switches
  - Don't really have CPU to yourself
- Virtual Memory
  - Don't really have 2^{64} bytes of memory all to yourself
  - Allows for *indirection* (remap physical pages, sharing…)

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



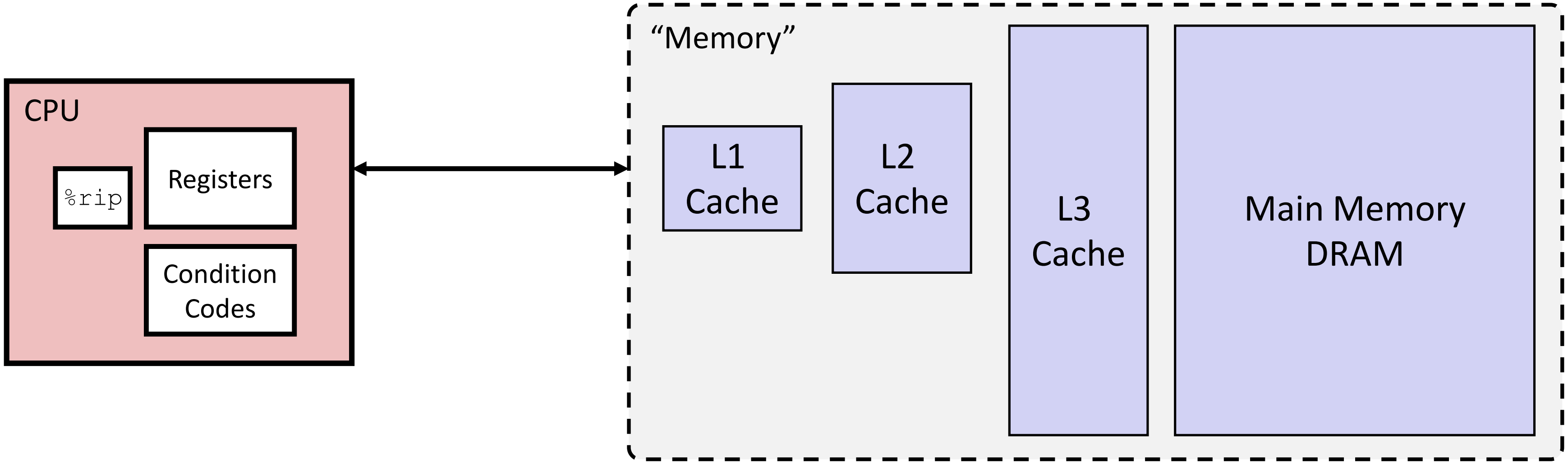
- `fork`
  - Creates copy of the process
- `execv`
  - Replace with new program
- `wait`
  - Wait for child to die (to *reap* it and prevent *zombies*)

Virtual Memory



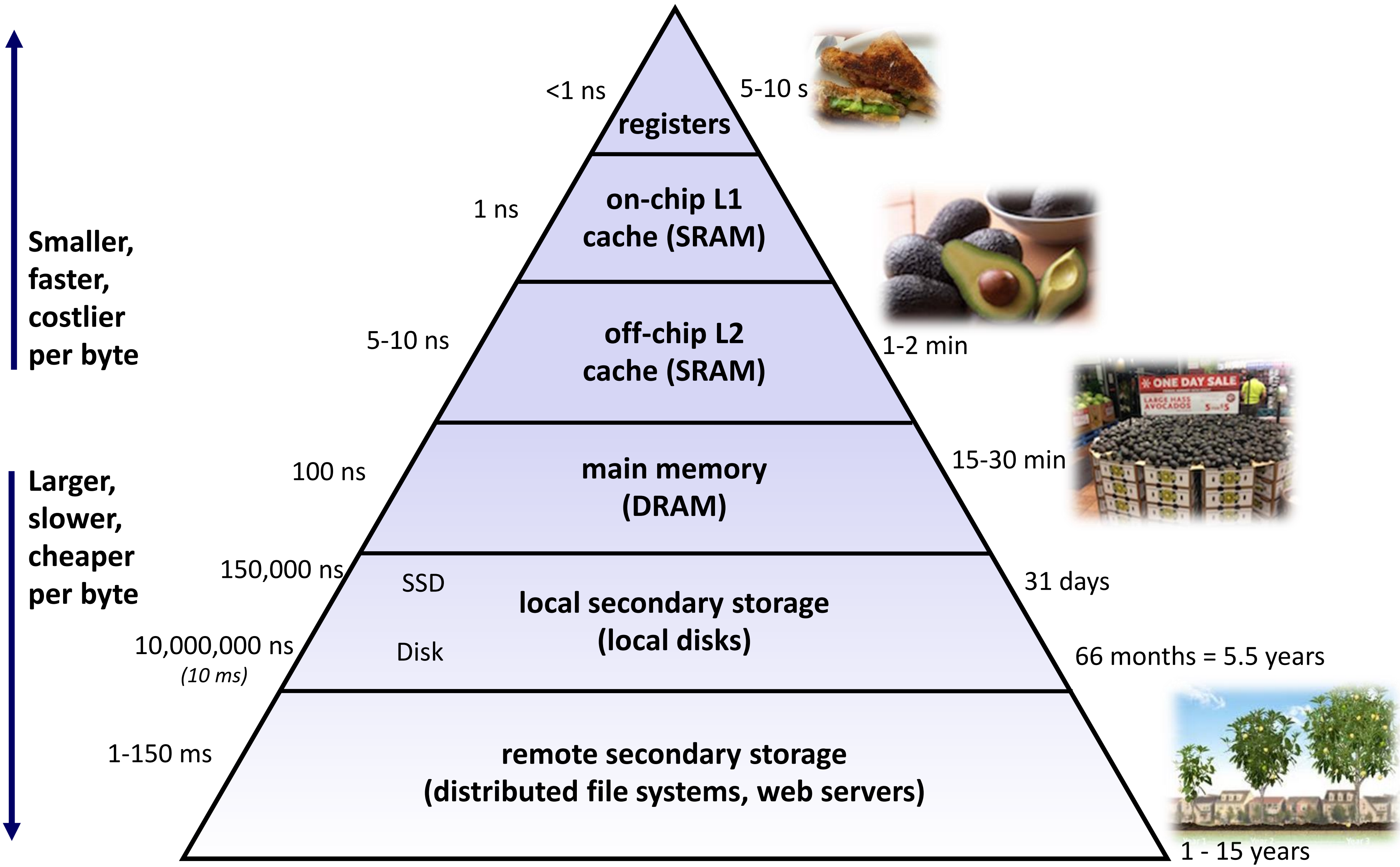
- Address Translation
  - Every memory access must first be converted from virtual to physical
  - *Indirection:* just change the address mapping when switching processes
  - Luckily, TLB (and page size) makes it pretty fast

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



Victory Lap

- A victory lap is an extra trip around the track
  - By the exhausted victors (that's us) ☺
- Review course goals
  - Put everything in perspective

Big Theme 1: Abstractions and Interfaces

- Computing is about abstractions
  - (but we can't forget reality)
- What are the abstractions that we use?
- What do <u>you</u> 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/Encoding

- 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

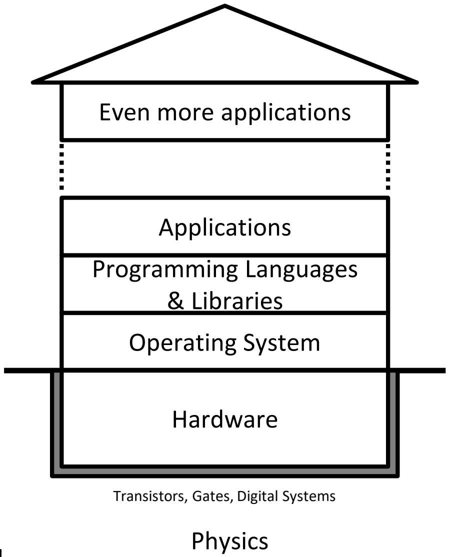
- We know Java as a programming language
  - Have to work our way down to the 0s and 1s of computers
  - Try not to lose anything in translation!
  - We encountered C language, assembly language, and machine code (for the x86 family of CPU architectures)

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"?

Big Theme 2: Design Values

- Design choices are a combination of goals and context
  - Based on history and the society of the times
    - Usually assumptions about normativity or "common case"
  - Imbued with the values of the creators (and/or those with power)
    - Think critically about what you are told & sold!



- Nothing is future-proof
  - The House of Computing needs remodeling!
    - Built on the values of efficiency, profit, and militarism
  - Need to reexamine your heading and vision periodically
    - Check your metrics and definition of success

Course Perspective

- CSE351 will make you a more informed programmer
  - Purpose is to show how software really works
  - 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)
  - Not just a course for hardware enthusiasts!
    - What **every** CSE major needs to know (plus many more details)
    - See many **patterns** that come up over and over in computing (like caching)
  - "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

Can You Now Explain These to a Friend?

- Which of the following did you actually find the most interesting to learn about? (vote in Ed Lessons)

a) What is a GFLOP and why is it used in computer benchmarks?
b) How and why does running many programs for a long time eat into your memory (RAM)?
c) What is stack overflow and how does it happen?
d) Why does your computer slow down when you run out of *disk* space?
e) What was the flaw behind the original Internet worm and the Heartbleed bug?
f) What is the meaning behind the different CPU specifications? (*e.g.*, # of cores, # and size of cache, supported memory types)

The Very First Comic of the Quarter

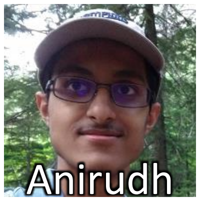
http://xkcd.com/676/

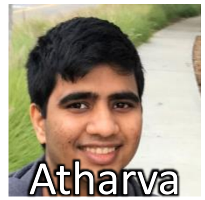
Courses: What's Next?

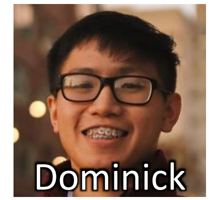
- Staying near the hardware/software interface:
  - **CSE369/EE271:** Digital Design – basic hardware design using FPGAs
  - **CSE474/EE474:** Embedded Systems – software design for microcontrollers
- Systems software
  - **CSE341/CSE413:** Programming Languages
  - **CSE332/CSE373:** Data Structures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

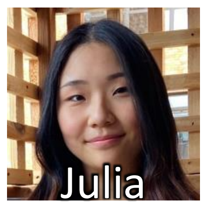
Thanks for a great quarter!

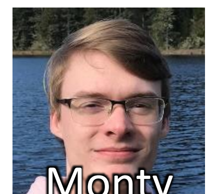
- Huge thanks to your awesome TAs!











- Don’t be a stranger!
  - If interested, I’m teaching CSE333 (Wi22), CSE369 (Wi22), and EE/CSE371 (Sp22)
  - If you TA, I co-lead CSE General TA Training
  - I attend CSE590E: CS Education research seminar