

Course Wrap-Up

CSE 351 Autumn 2019

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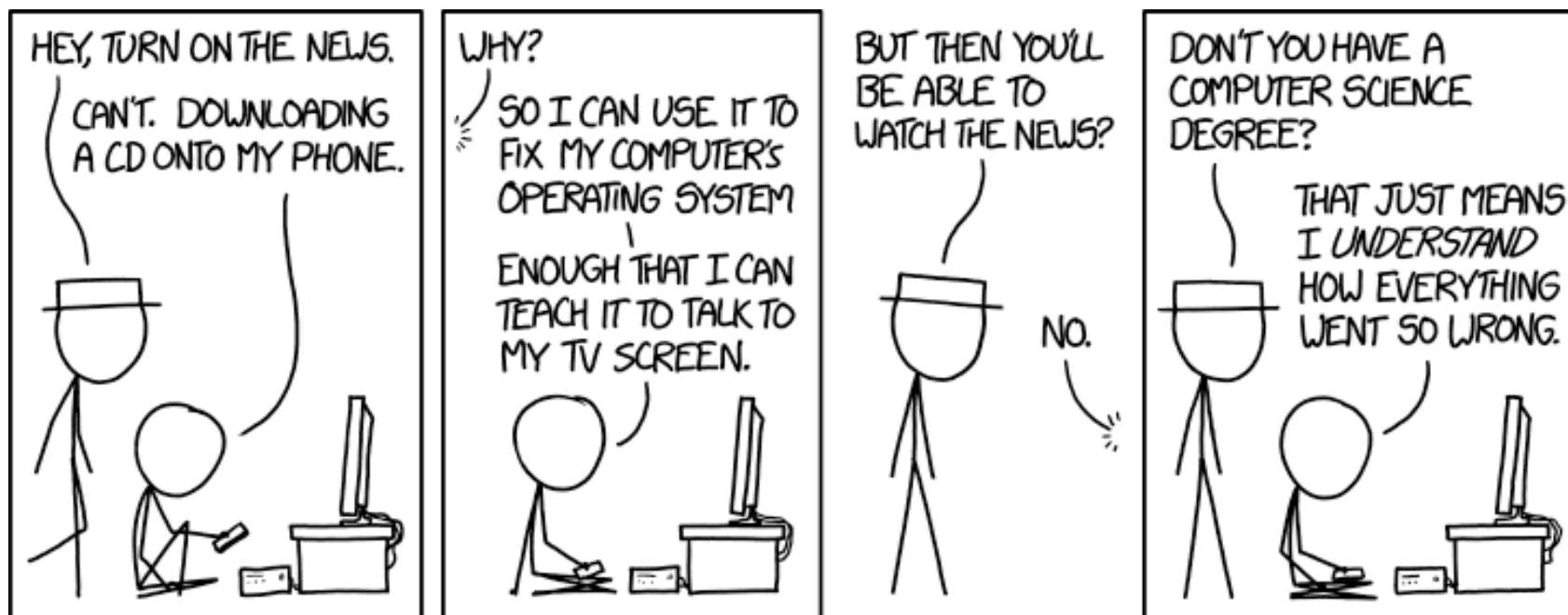
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<https://xkcd.com/1760/>

Administrivia

- ❖ Please fill out the **course evaluation!**
 - Evaluations close this Sunday, December 8th at 11:59 pm
 - Not viewable until after grades are submitted
 - We take these seriously and use them to improve our teaching and this class!

- ❖ **Final Exam:** Tue 12/10, 12:30-2:20 pm in KNE 120
 - Review Session: Sun 12/8, 3:30-6 pm in SAV 260
 - Cumulative (midterm clobber policy applies)
 - TWO double-sided handwritten 8.5×11" cheat sheets
 - Recommended that you reuse or remake your midterm cheat sheet

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 “next week’s 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`)

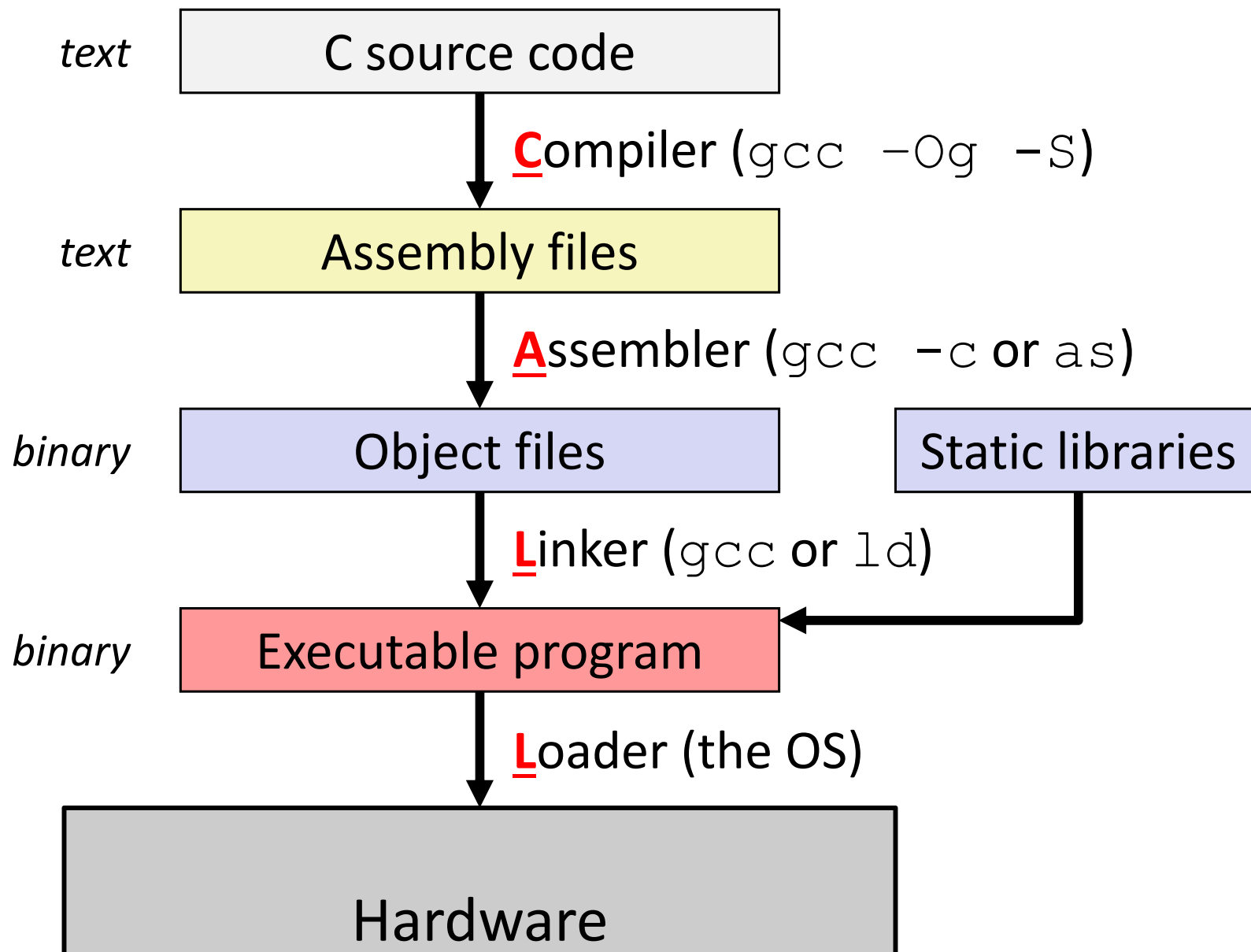
❖ C Data Structures

- 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

Source code

Different applications or algorithms

Compiler

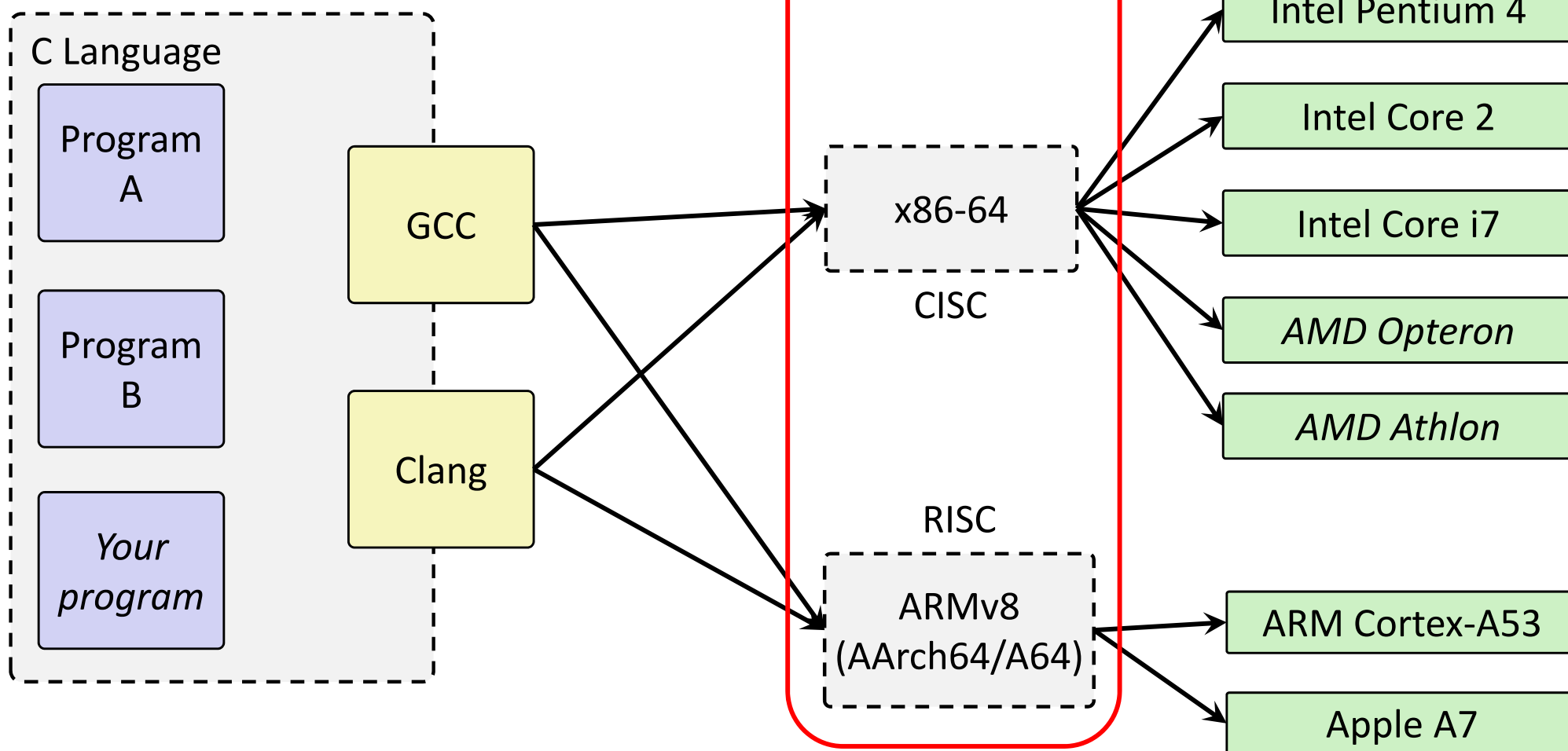
Perform optimizations, generate instructions

Architecture

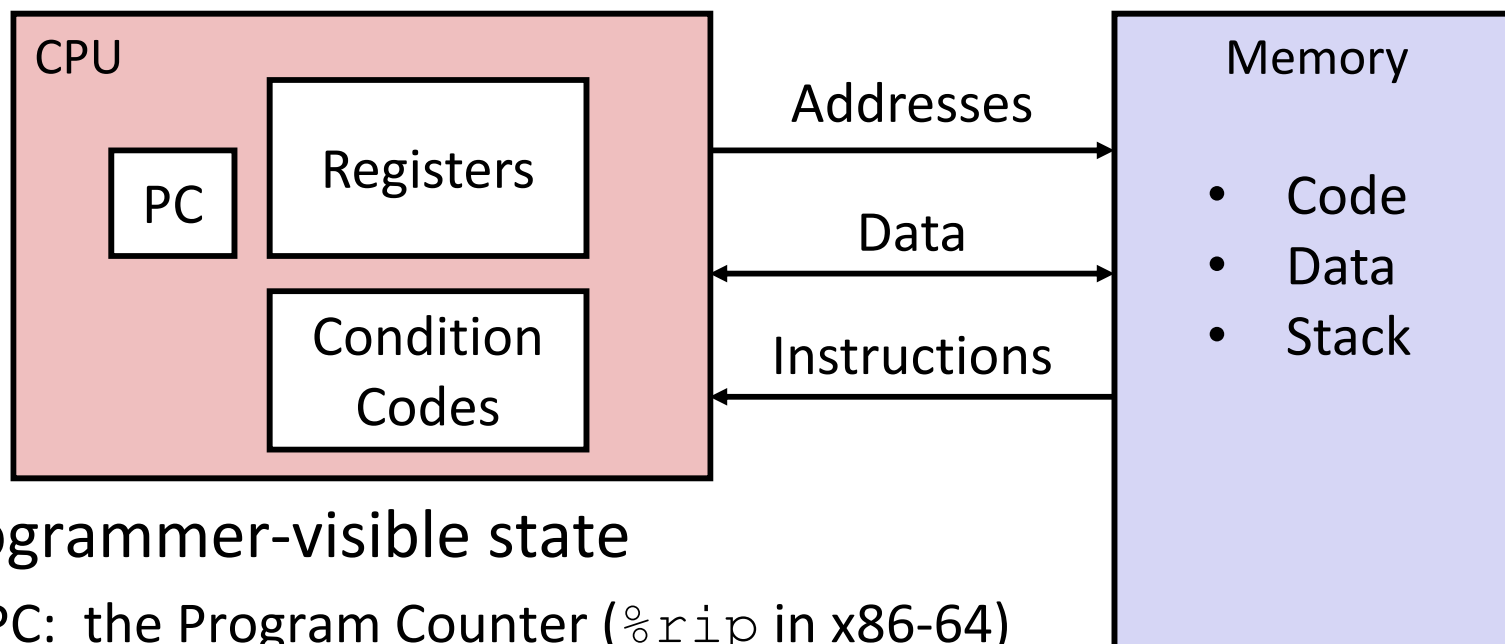
Instruction set

Hardware

Different implementations



Assembly Programmer's View



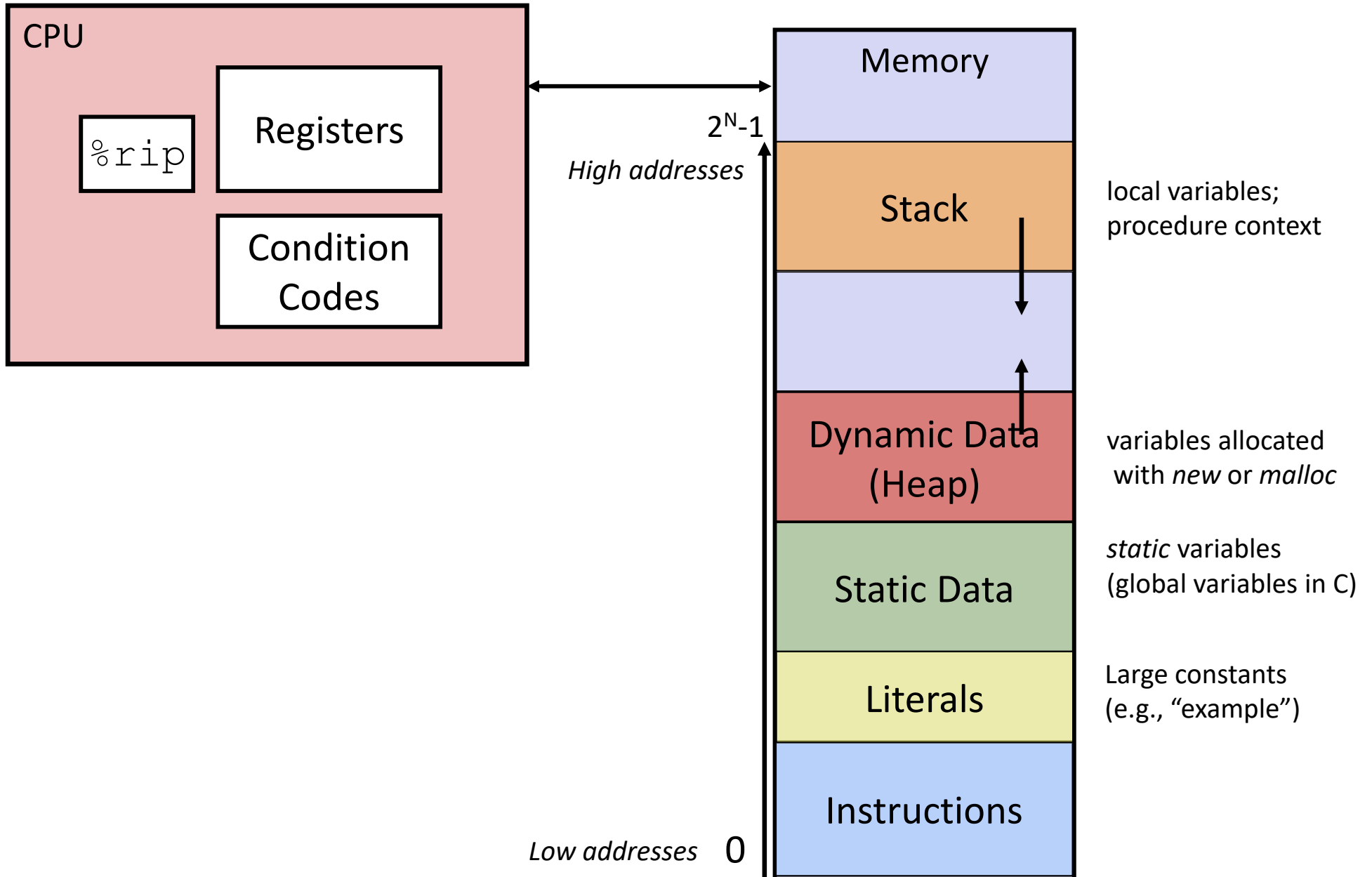
❖ Programmer-visible state

- 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`

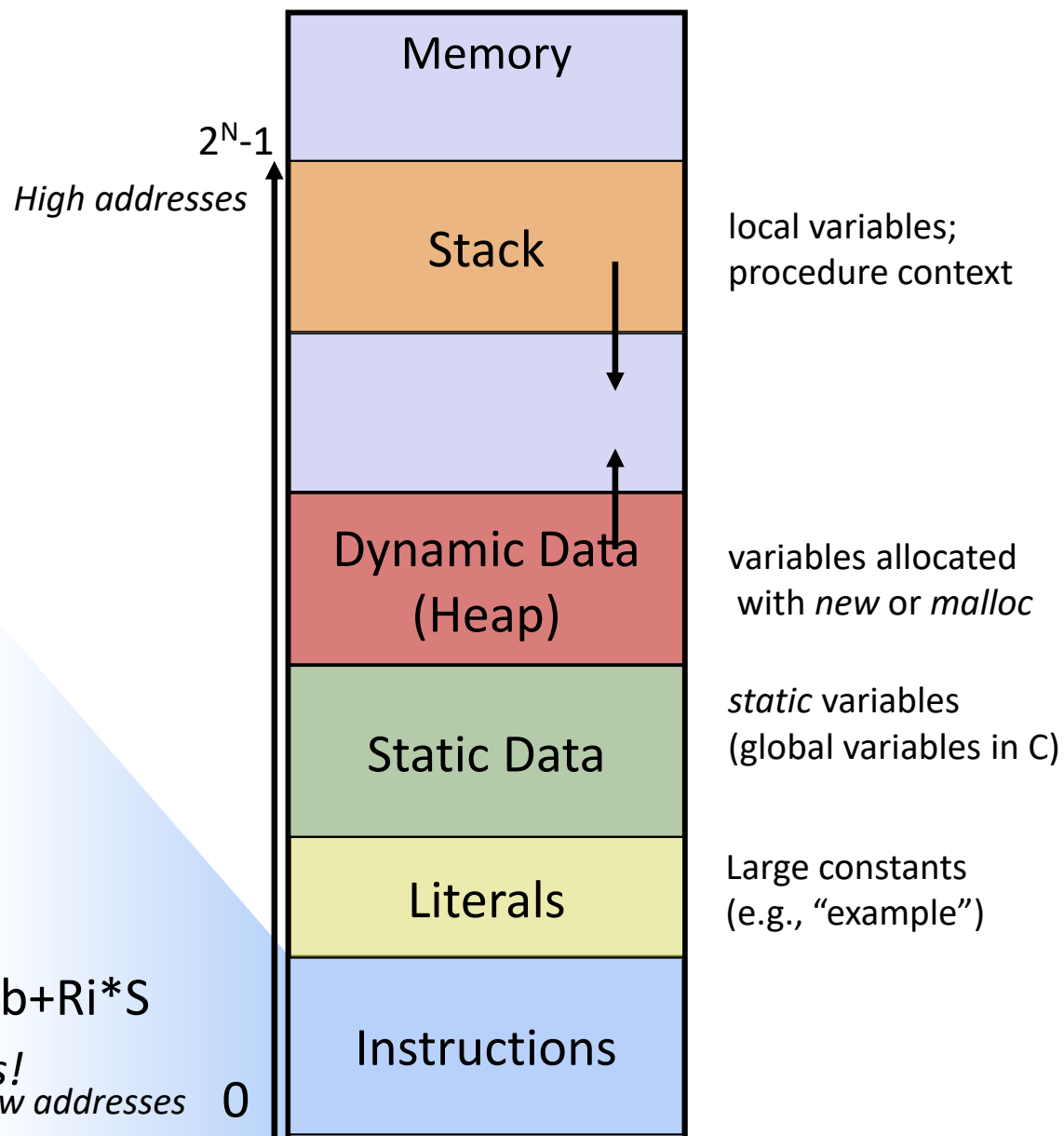
❖ Operand types

■ Literal: `$8`

■ Register: `%rdi, %al`

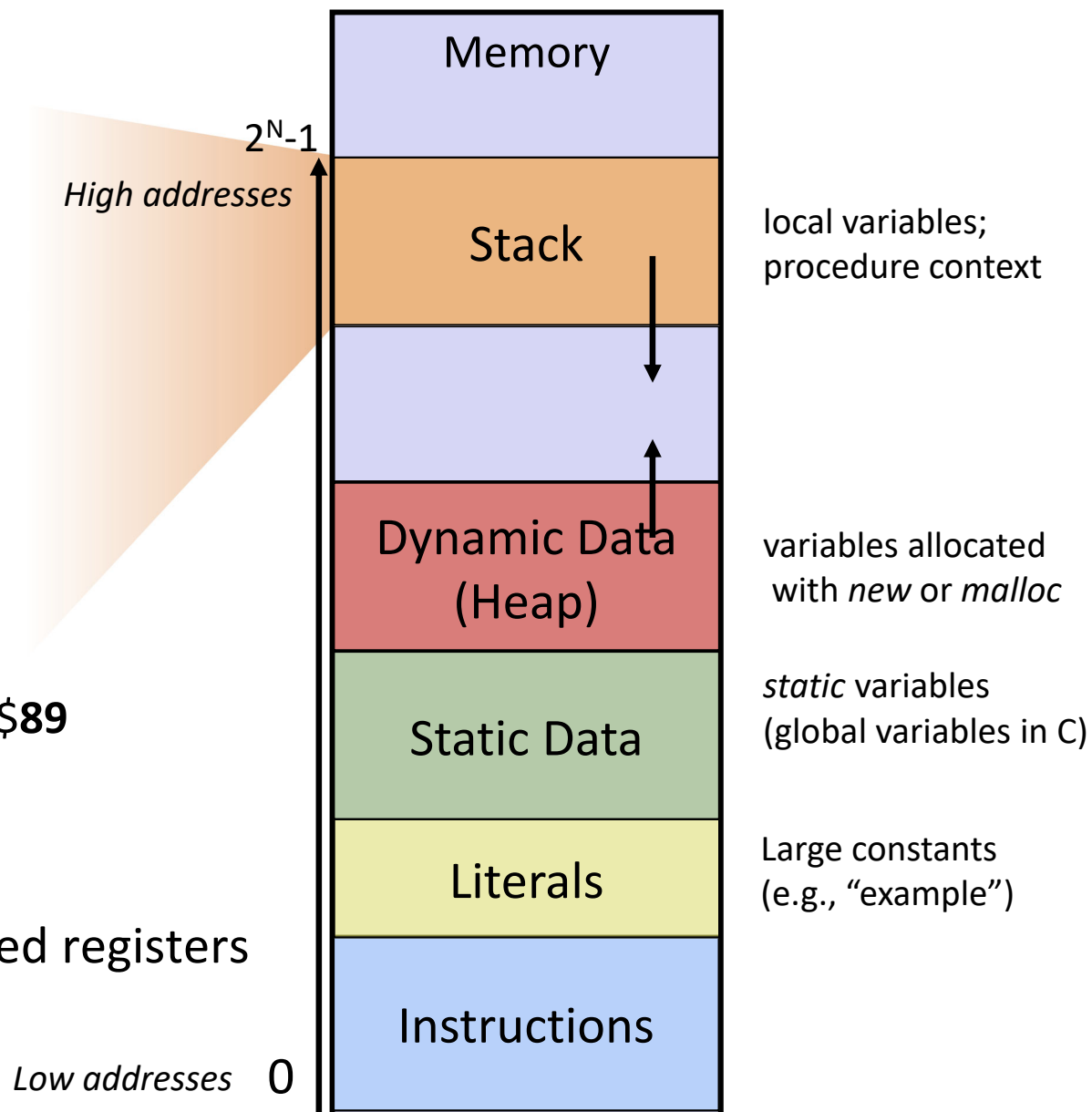
■ Memory: $D(Rb, Ri, S) = D + Rb + Ri * S$

- `lea`: *not a memory access!*



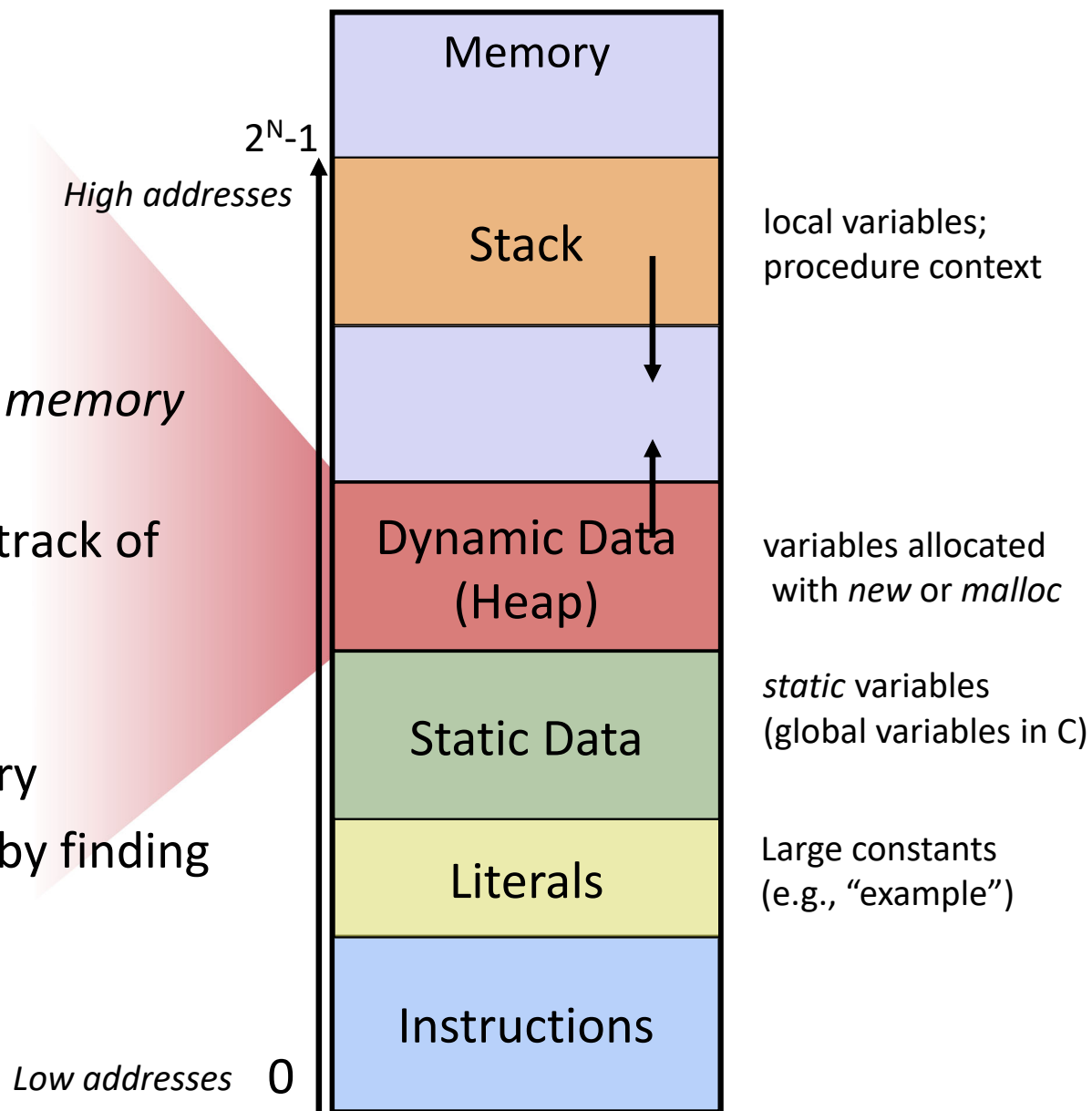
Program's View

- ❖ Procedures
 - Essential abstraction
 - Recursion...
- ❖ Stack discipline
 - Stack frame per call
 - Local variables
- ❖ Calling convention
 - How to pass arguments
 - Diane's Silk Dress Costs \$89
 - How to return data
 - Return address
 - Caller-saved / callee-saved registers

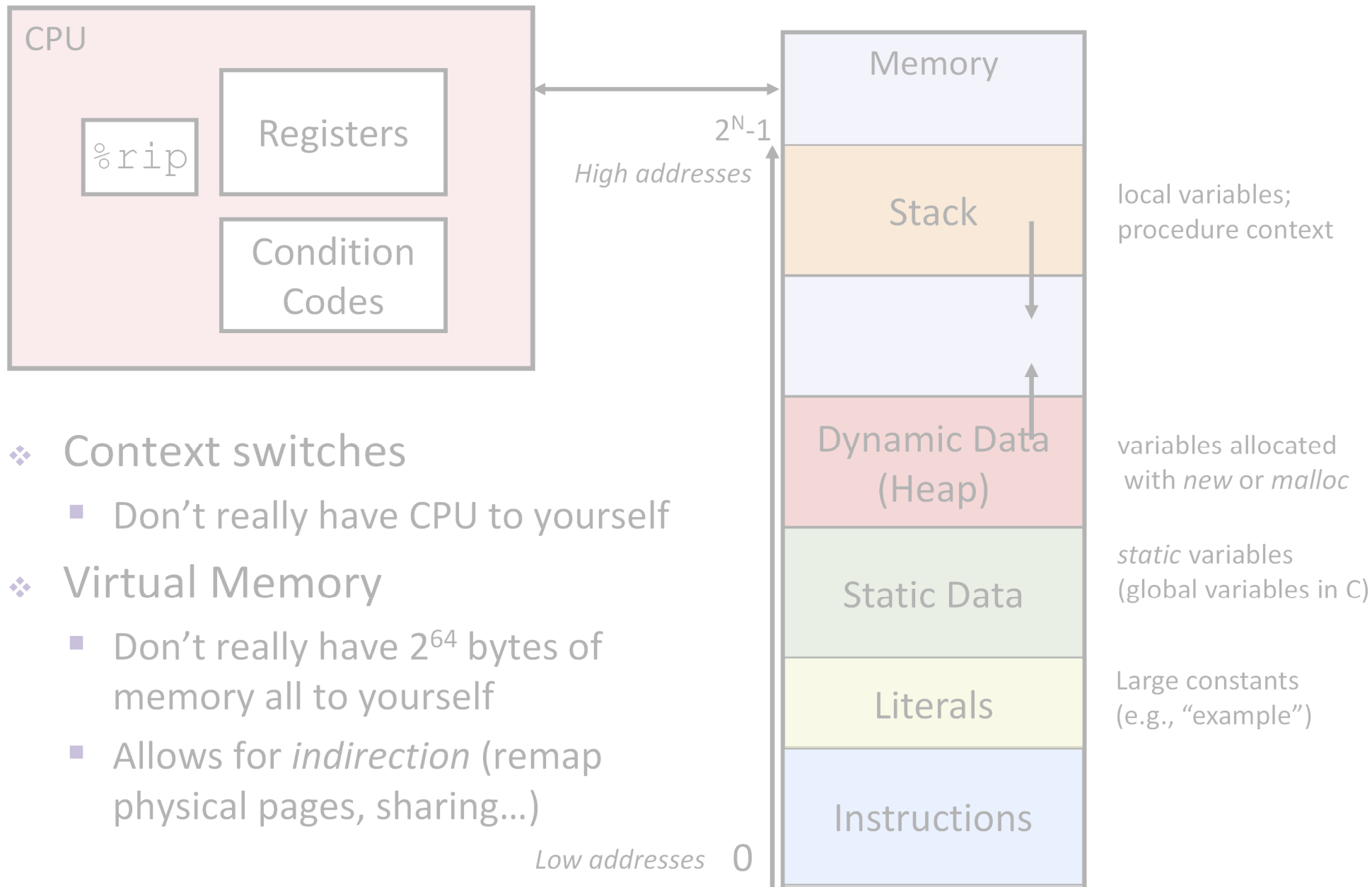


Program's View

- ❖ 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*

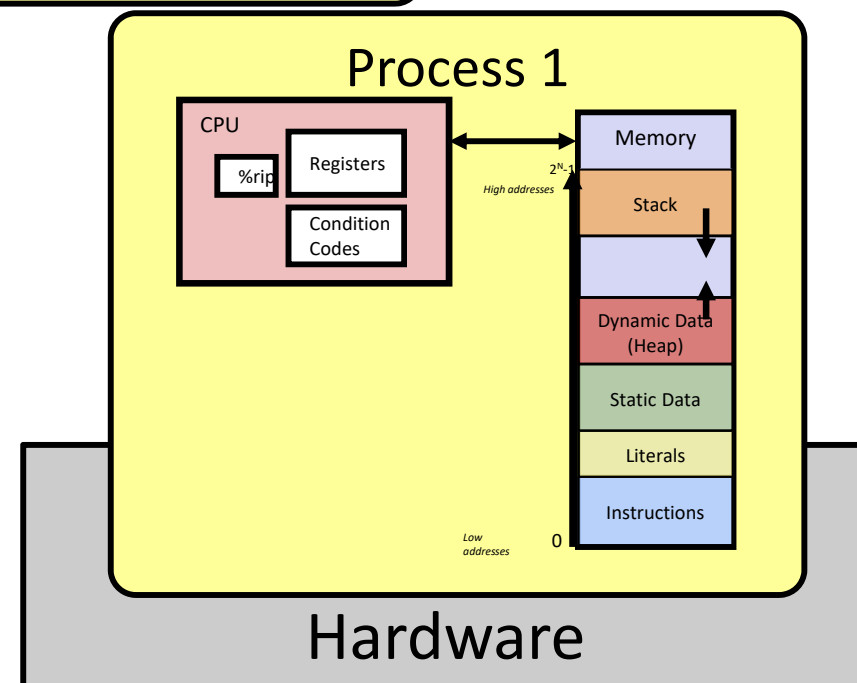
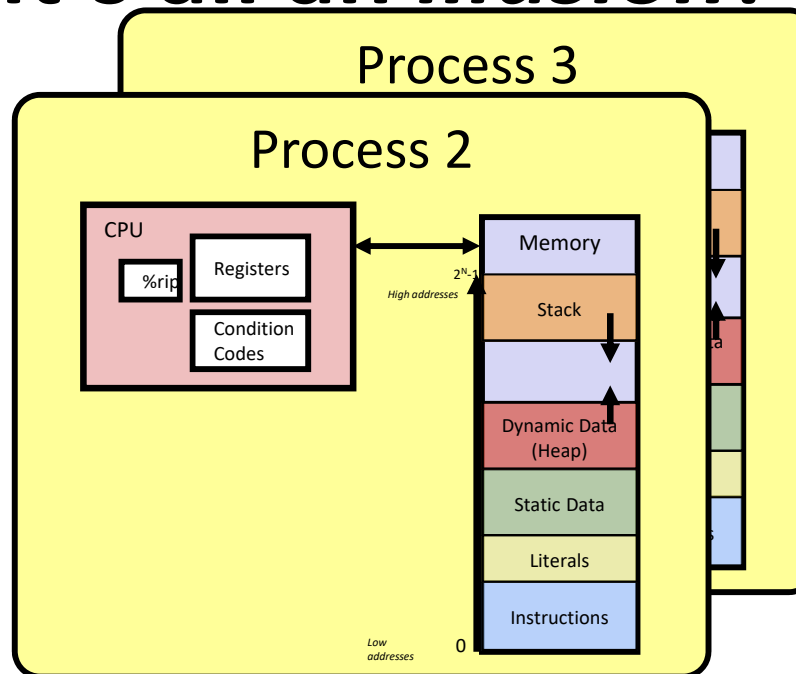


But remember... it's all an *illusion!* 😲



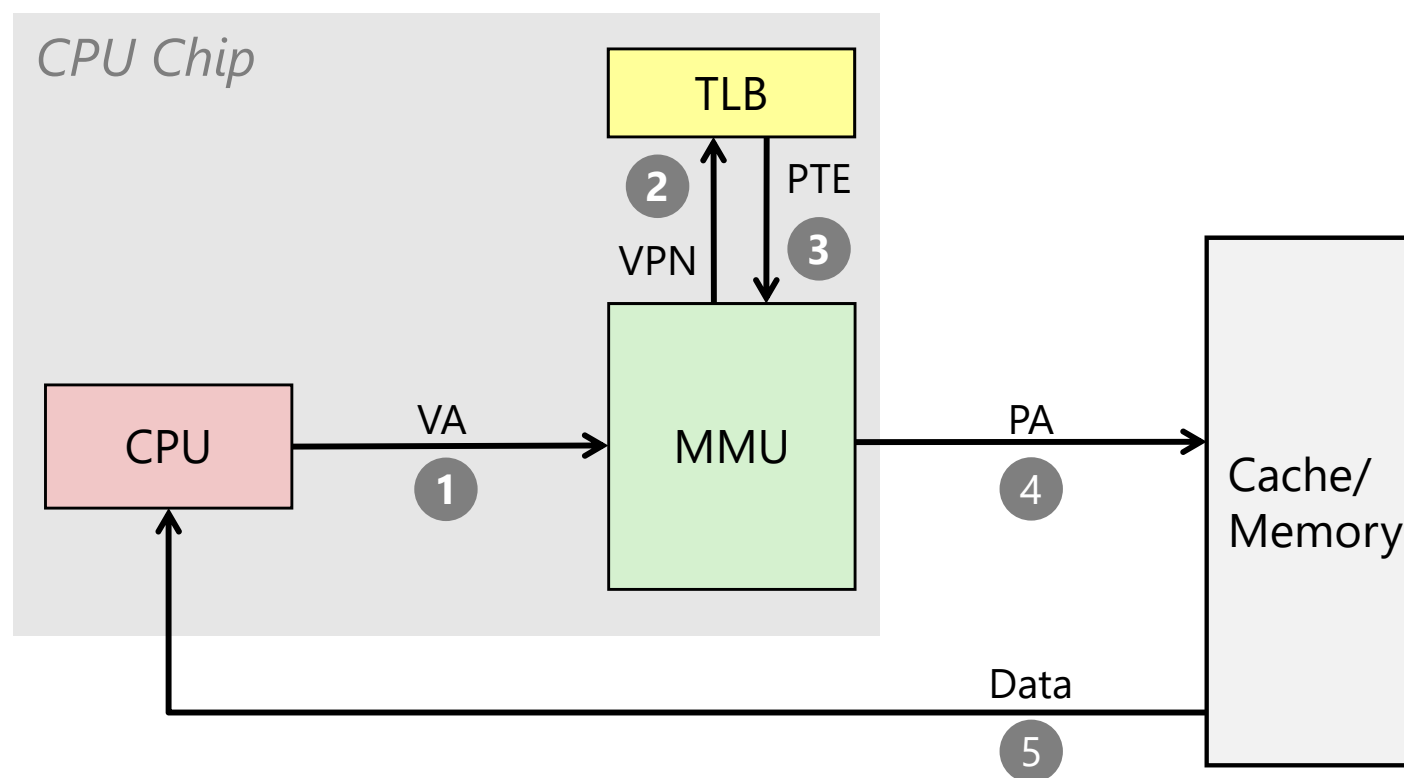
- ❖ Context switches
 - Don't really have CPU to yourself
- ❖ Virtual Memory
 - Don't really have 2^{64} bytes of memory all to yourself
 - Allows for *indirection* (remap physical pages, sharing...)

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*)

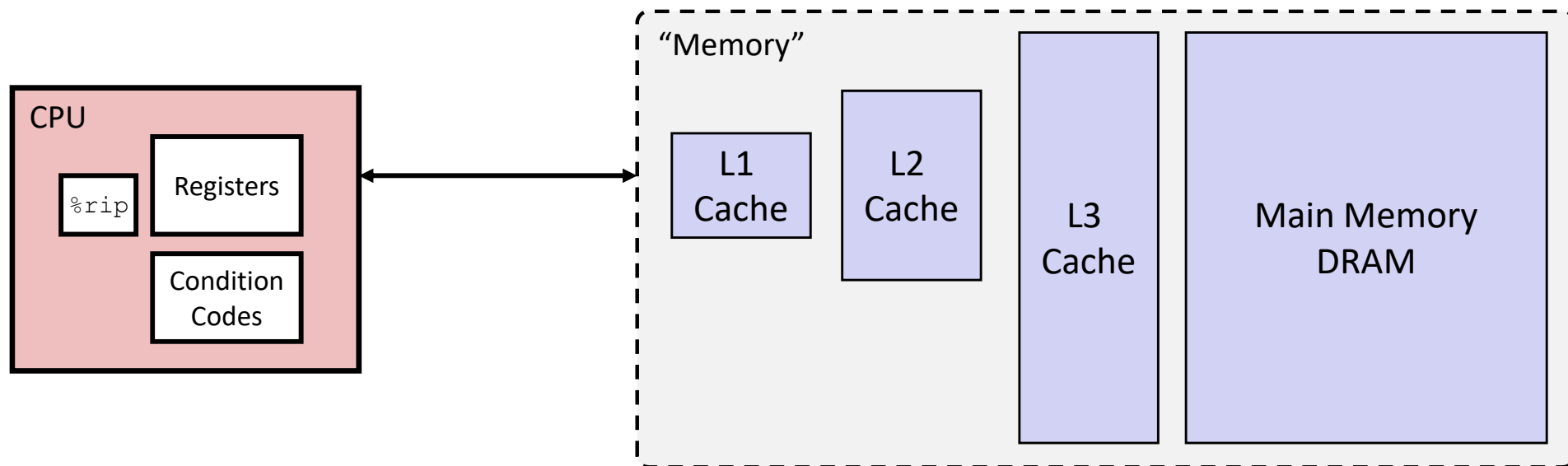
Virtual Memory



❖ Address Translation

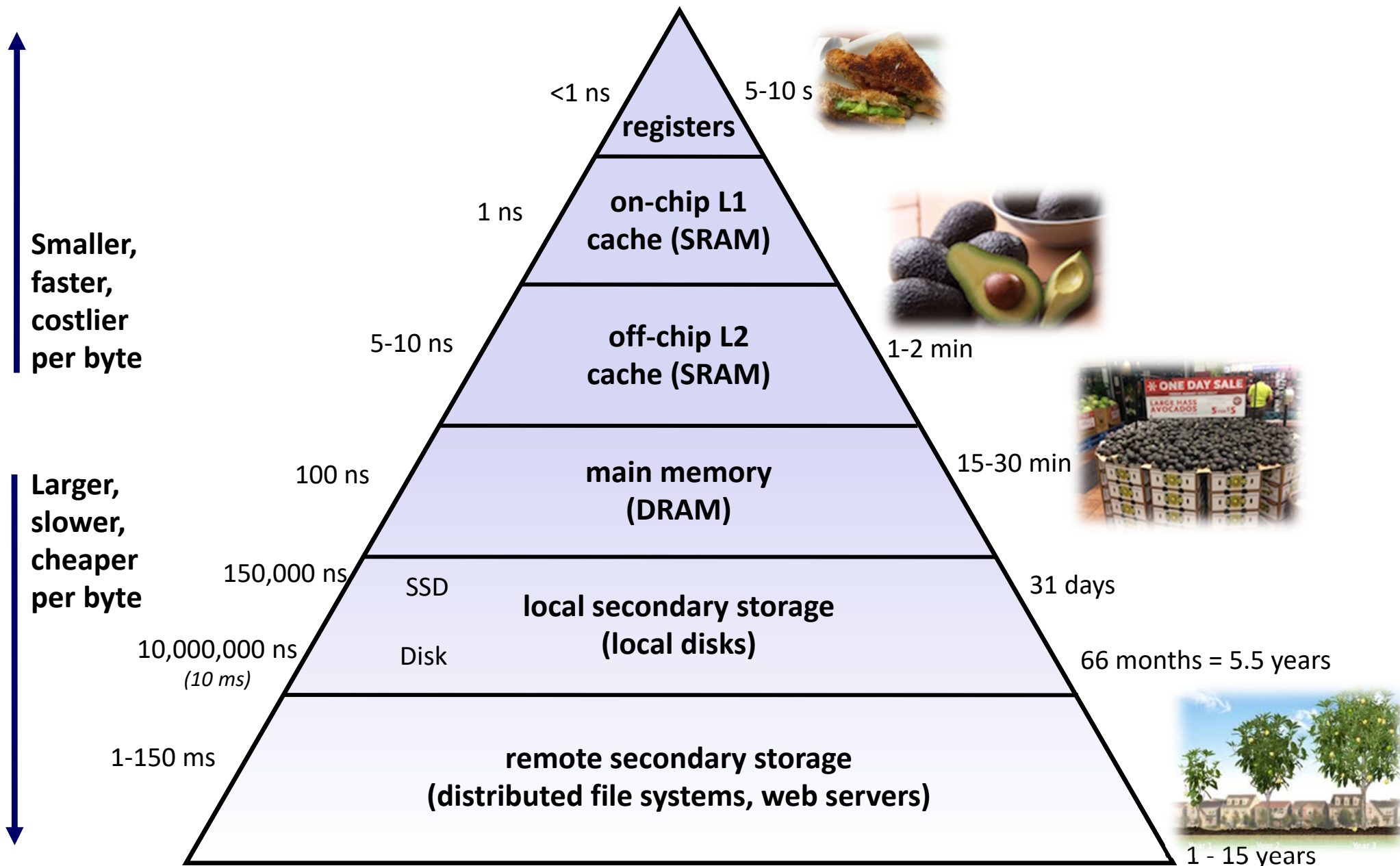
- Every memory access must first be converted from virtual to physical
- *Indirection*: just change the address mapping when switching processes
- Luckily, TLB (and page size) makes it pretty fast

But Memory is Also a Lie! 😬



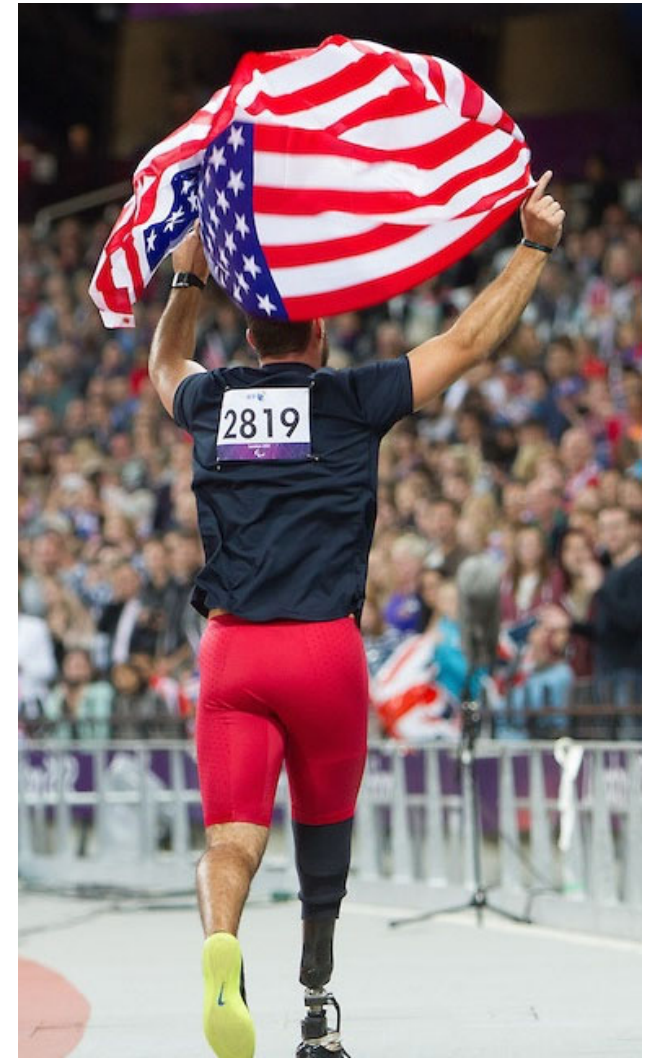
- ❖ *Illusion* of one flat array of bytes
 - But *caches* invisibly make accesses to physical addresses faster!
- ❖ Caches
 - **Associativity** tradeoff with miss rate and access time
 - **Block size** tradeoff with spatial and temporal locality
 - **Cache size** tradeoff with miss rate and cost

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: 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 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? (<http://PollEv.com/justinh>)
 - 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



Courses: What's Next?

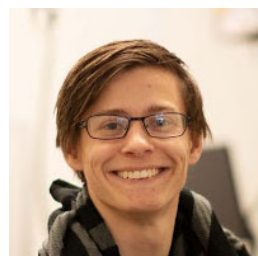
- ❖ Staying near the hardware/software interface:
 - **CSE369/EE271**: Digital Design – basic hardware design using FPGAs
 - **CSE474/EE474**: Embedded Systems – software design for microcontrollers
- ❖ Systems software
 - **CSE341/CSE413**: Programming Languages
 - **CSE332/CSE373**: Data Structures 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!

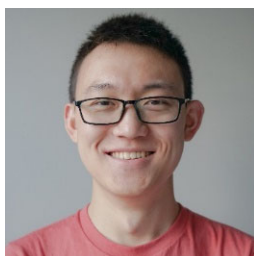
❖ Huge thanks to your awesome TAs!



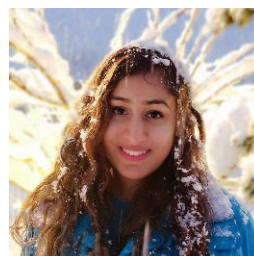
Andrew



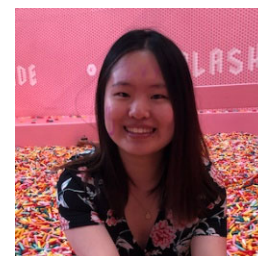
Antonio



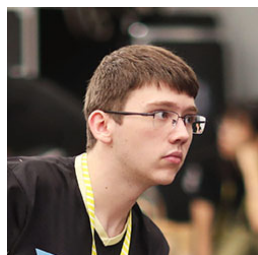
Cosmo



Diya



Ivy



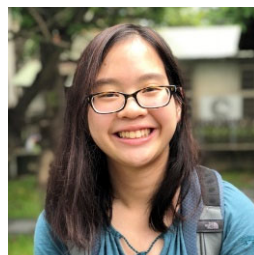
Kaelin



Maurice



Melissa



Millicent



Suraj

❖ Don't be a stranger!

- If interested, I'm teaching CSE333 (Wi20), CSE369 (Wi20), and CSE371 (Sp20)

Ask Me Anything





That's all Folks!