Course Wrap-Up

CSE 351 Spring 2024

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Playlist: CSE 351 24Sp Lecture Tunes!

Announcements, Reminders

- Lab 5 due Friday at 11:59 PM!
- **Final Exam: June 3rd through June 5th** (released June 3rd at 00:01)
  - Same rules as midterm; details on Exams page
  - Stand-alone Final Exam review session next class
- End-of-Year Announcements:
  - Bob Bandes TA Award!
  - Please fill out course evaluations!
  - Great follow-up textbooks and reads!
  - Come meet Gigi on Monday!

Supporting Yourself While Debugging

- CS cultural norms **actively encourage** prolonged periods of mental concentration
  - Easy to tune everything else out when you remain immobile just a few feet from your (increasingly large) screen
  - Programmers describe sometimes being "in the zone"
  - Long coding sessions and late nights are socially and culturally encouraged
  - Hackathons are designed this way: ignore your bodily needs for 24 hours?!
  - Tech companies entice you to stay at work with free food and amenities. It's not because they're just being nice!

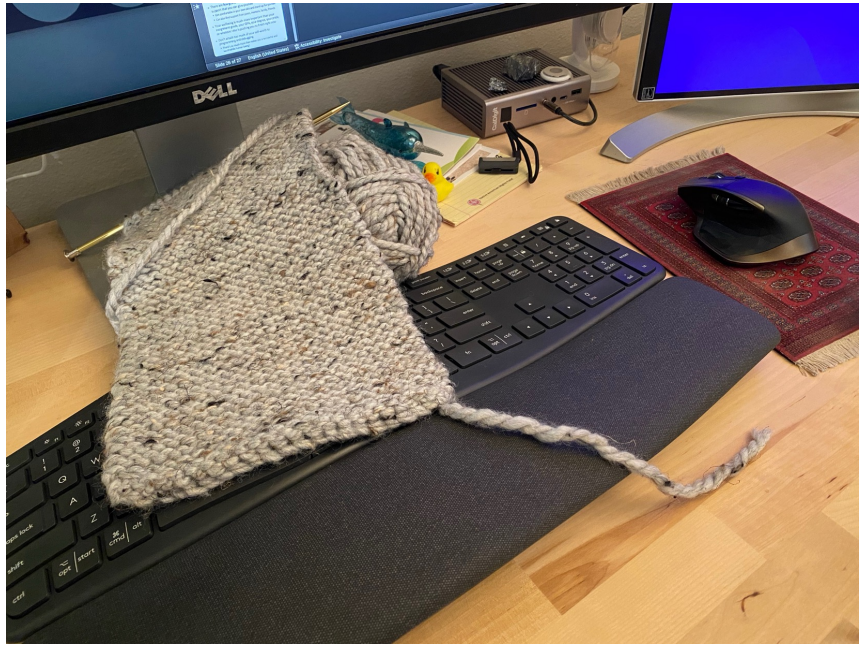
Mindfulness and Debugging

- Mindfulness: "The practice of bringing one's attention in the present moment"
  - Lots of different definitions and nuance, but we'll stick with this broad definition

- While debugging, try to be mindful of your emotional and physical state as well as your current approach
  - Am I focused on the task at hand or distracted?
  - Am I calm and/or rested enough to be thinking "clearly?"
  - How is my posture, breathing, and tenseness?
  - Do I have any physical needs that I should address?
  - What approach am I trying and **why**? Are there alternatives?

Supporting Yourself While Debugging

- Try: set a timer for some interval (e.g., 15 minutes) to evaluate your state and approach
  - Like the system timer your OS uses for context switching!
- If you're distracted, feeling negative emotions, tense, or need to address something, **take a break!**
  - You might even think of a new approach!
  - Take a shower, go for a walk, take a nap, have a snack, cook dinner, bake cookies, learn to sew…



Supporting Yourself

- There are few guarantees for support, besides the support that you can give yourself
  - Get comfortable in your own skin and stand up for yourself
  - Look to your peers, mentors, family, friends! Make use of the support systems that you do have!
- Your well-being is much more important than your assignment grade, your GPA, your degree, your pride, or whatever else is pushing you to finish right now.

Computer Science and You

- Being mindful of how you work best is important!
- CS culture tends to perpetuate certain images of what being a programmer "should" look like
- But it might not, which is also completely valid
  - **Regardless, you still belong in computer science**
  - Some personal examples: I don't do side projects, my GitHub is dead, my website is (currently) dead, I prefer to unwind away from a computer.

- The best approaches are the ones that work for you. And they don't change your value as a computer scientist or as a person.

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 for the final exam
- 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)

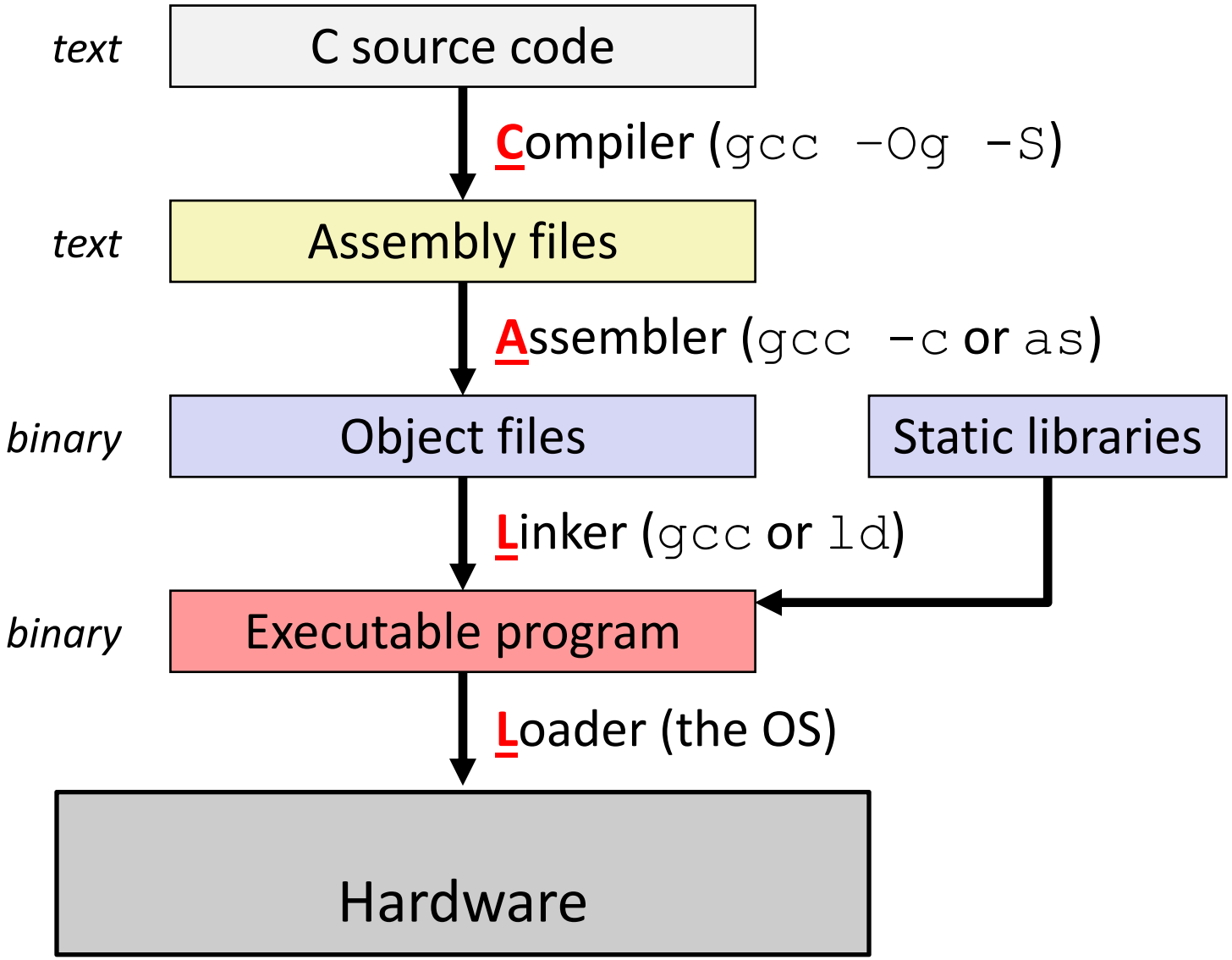
C Data Types

- 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)

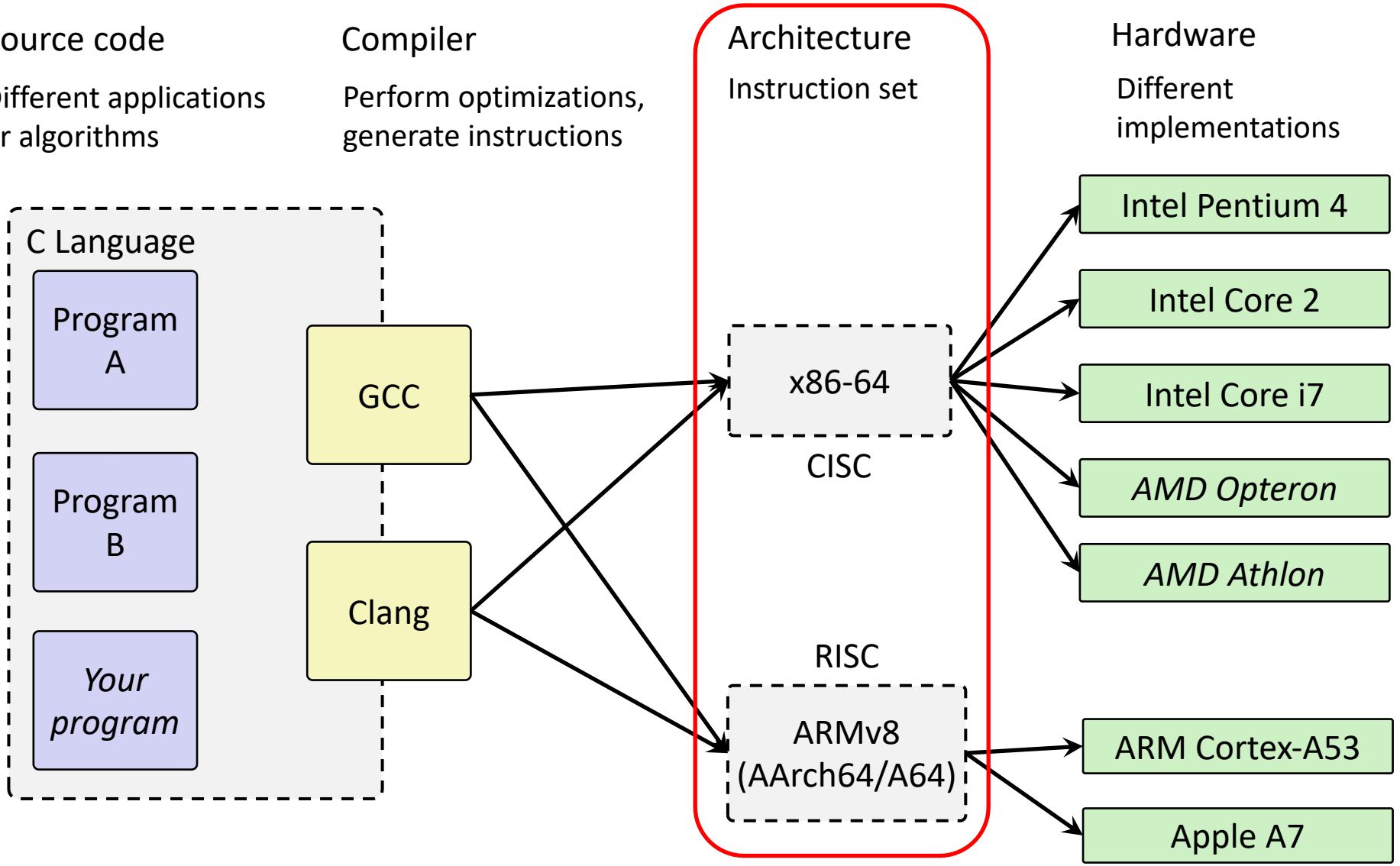
C and Memory

- 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…

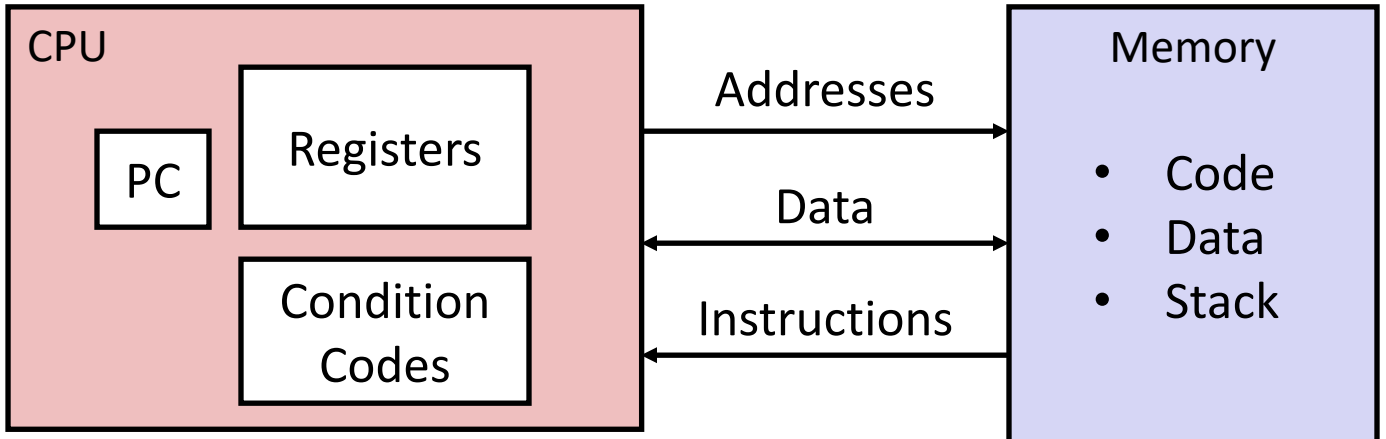
How Code Becomes a Program



Instruction Set Architecture



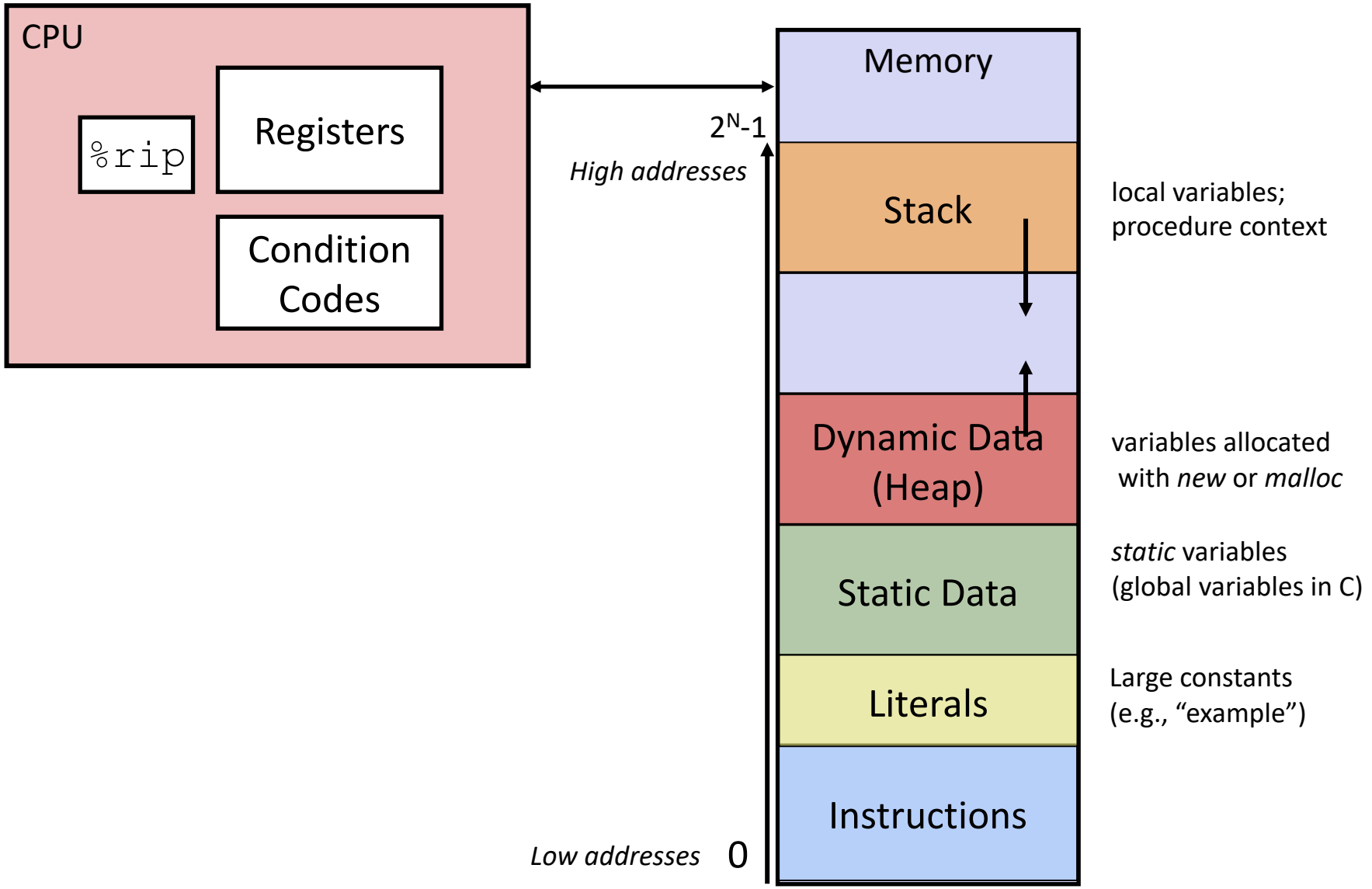
Assembly Programmer's View



- 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

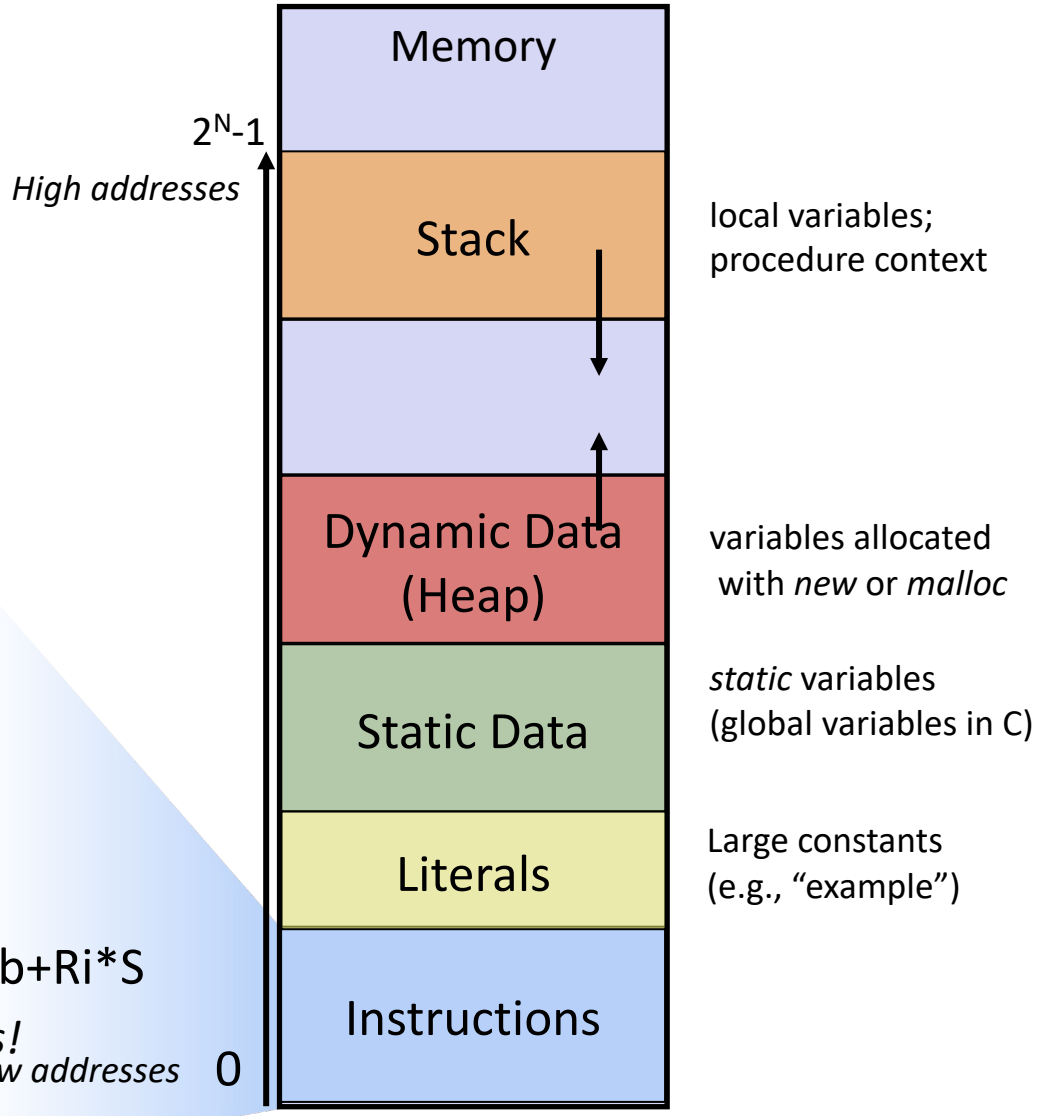
- Memory
  - Byte-addressable array
  - Huge *virtual* address space
  - *Private, all to yourself…*

Program's View: Memory Space



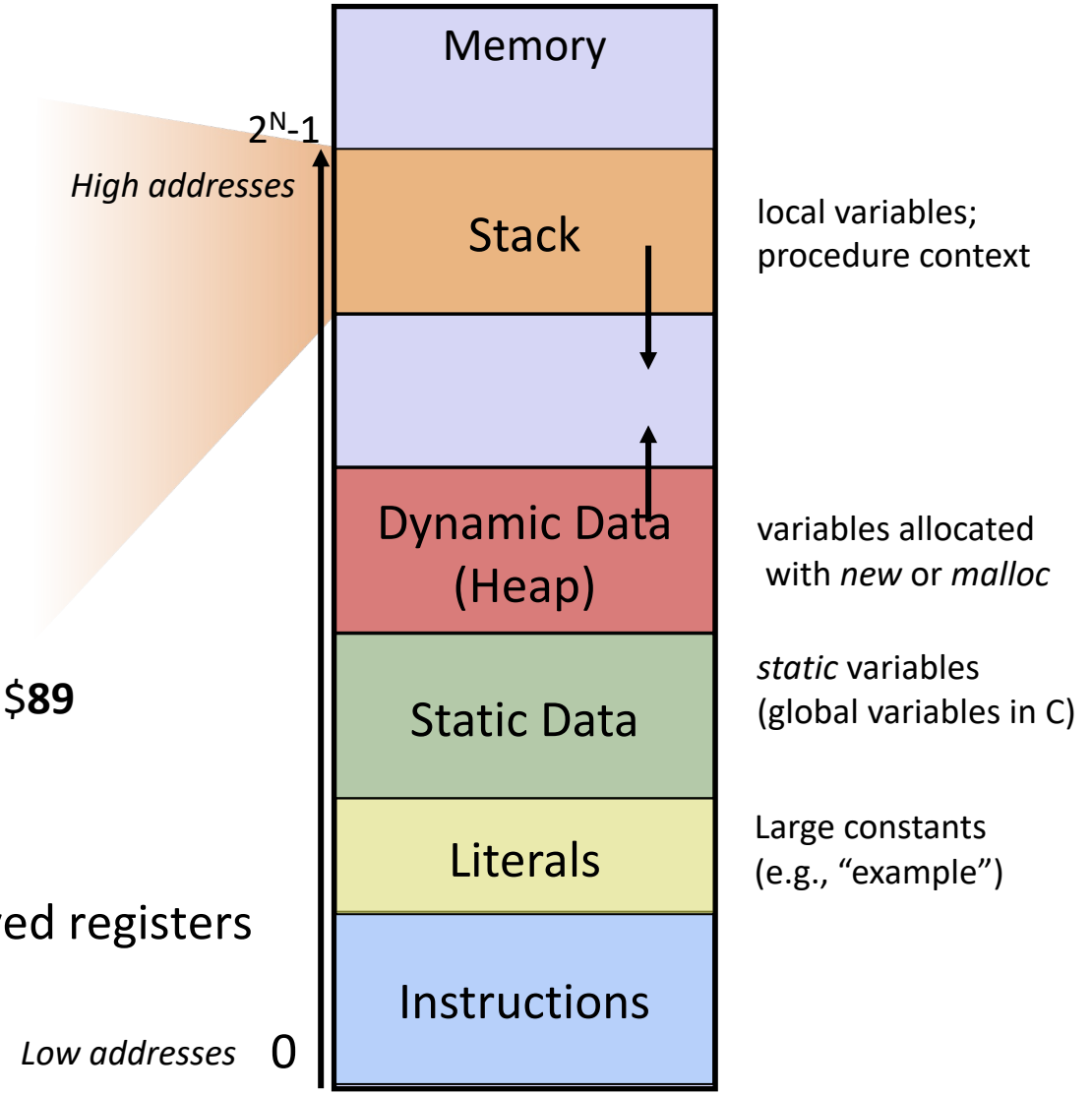
Program's View

- 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!*



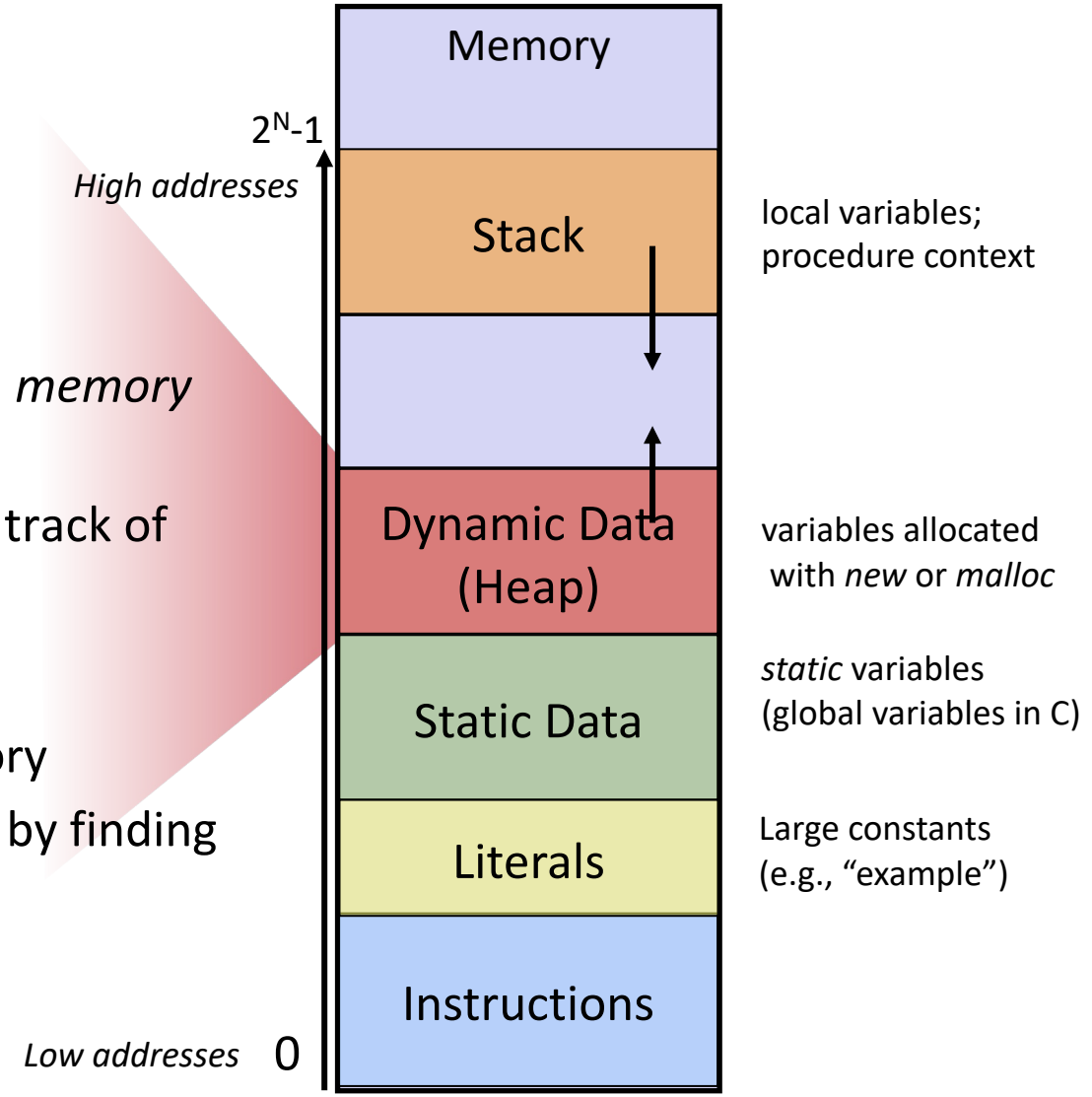
Program's View

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

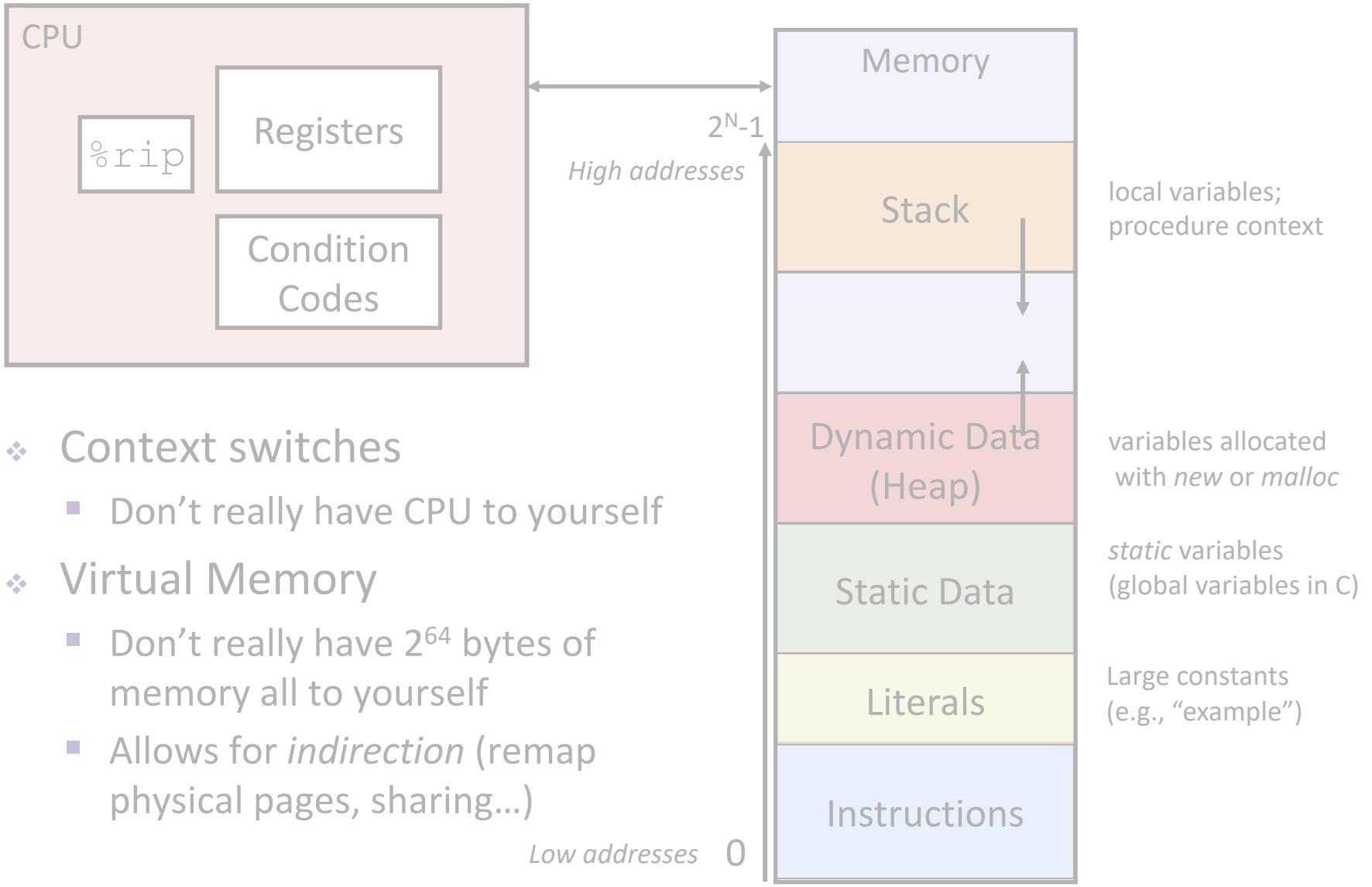


Program's View

- 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*

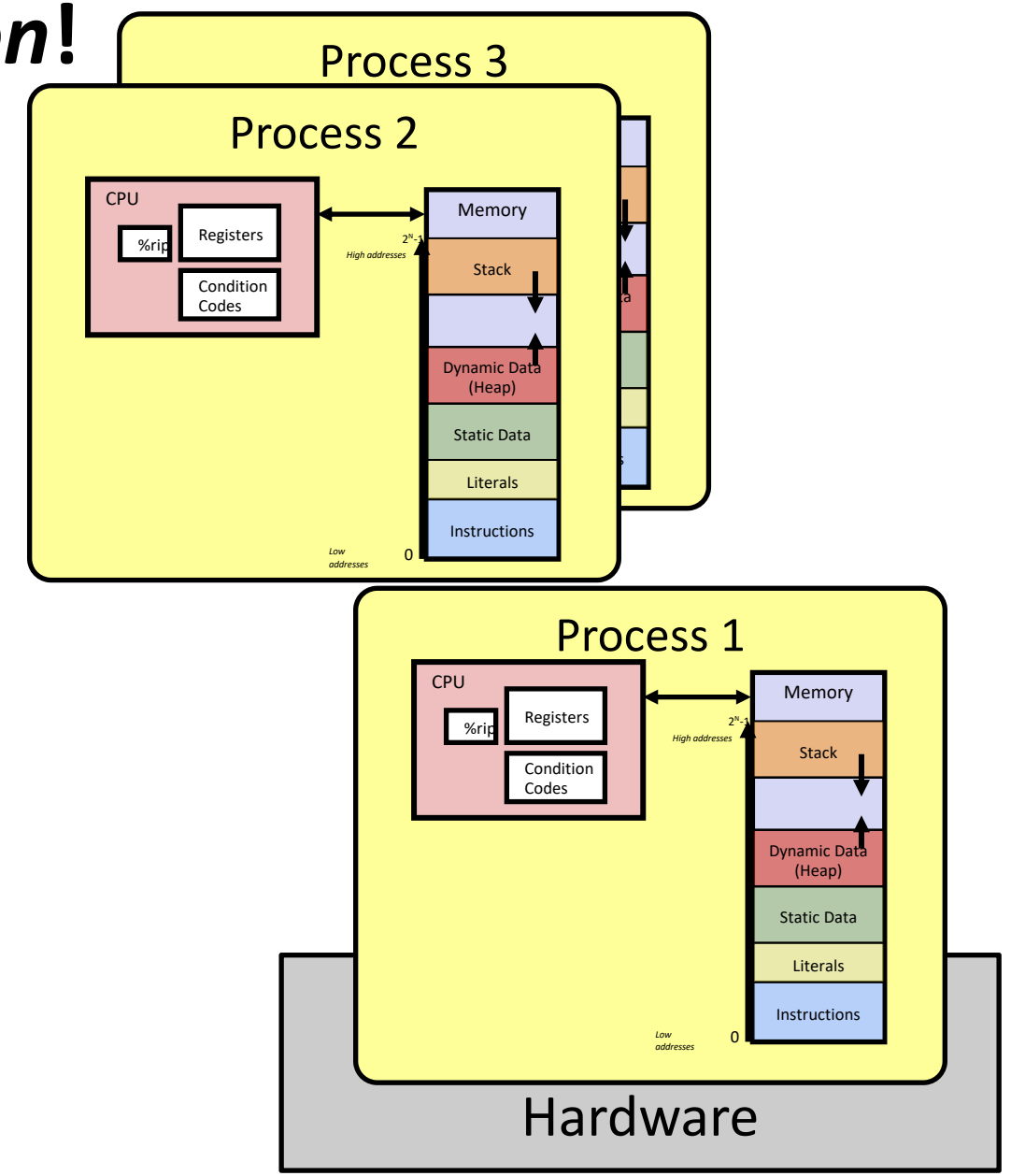


But remember… it's all an *illusion*!



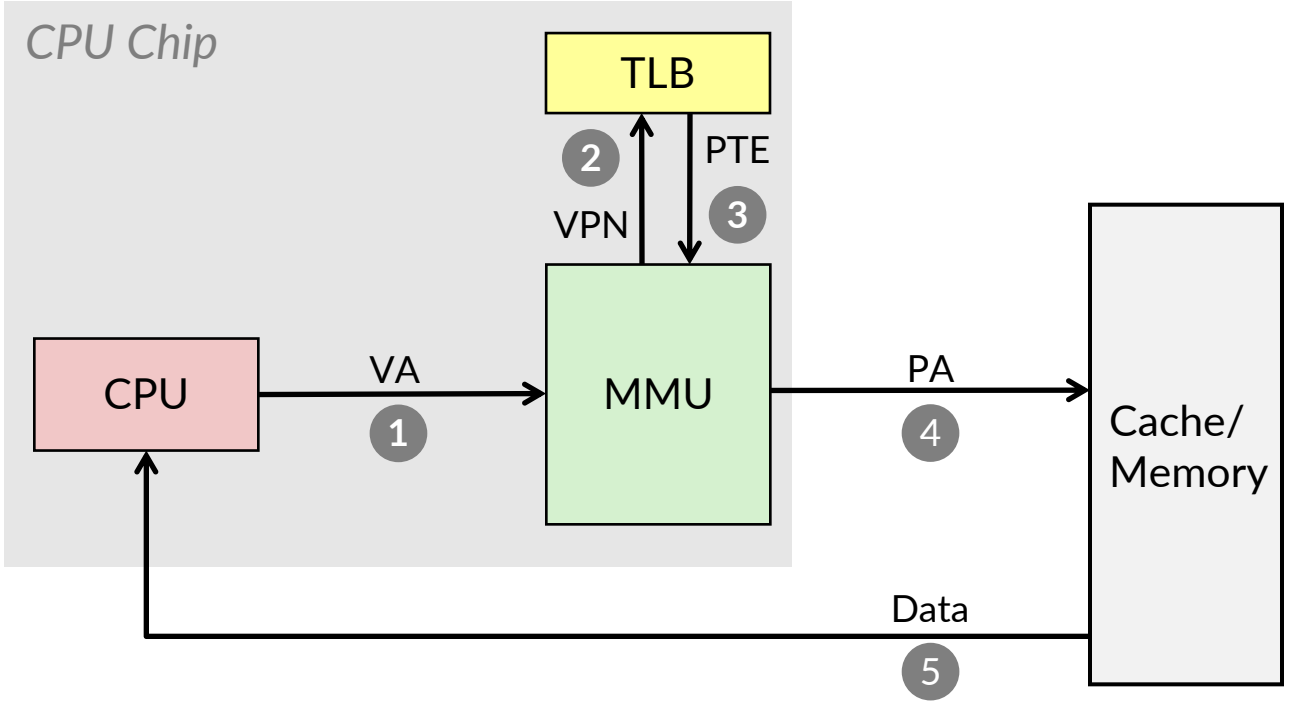
- Context switches
  - Don't really have CPU to yourself
- Virtual Memory
  - Don't really have 2^{64} bytes of memory all to yourself
  - Allows for *indirection* (remap physical pages, sharing…)

But remember… it's all an *illusion*!



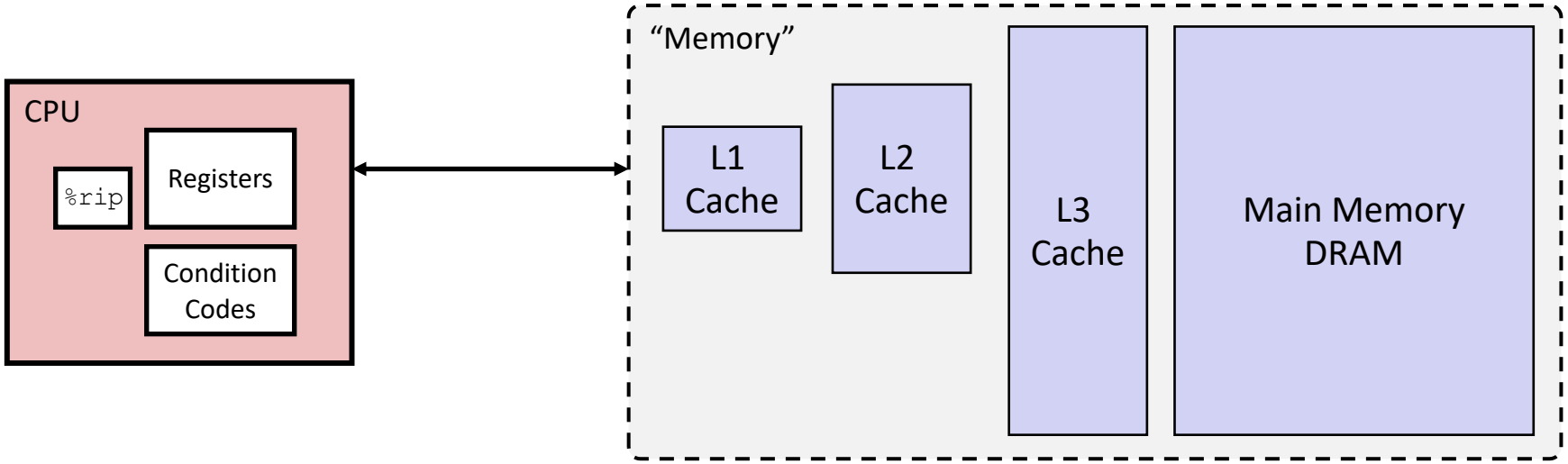
- `fork`
  - Creates copy of the process
- `execv`
  - Replace with new program
- `wait`
  - Wait for child to die (to *reap* it and prevent *zombies*)

Virtual Memory



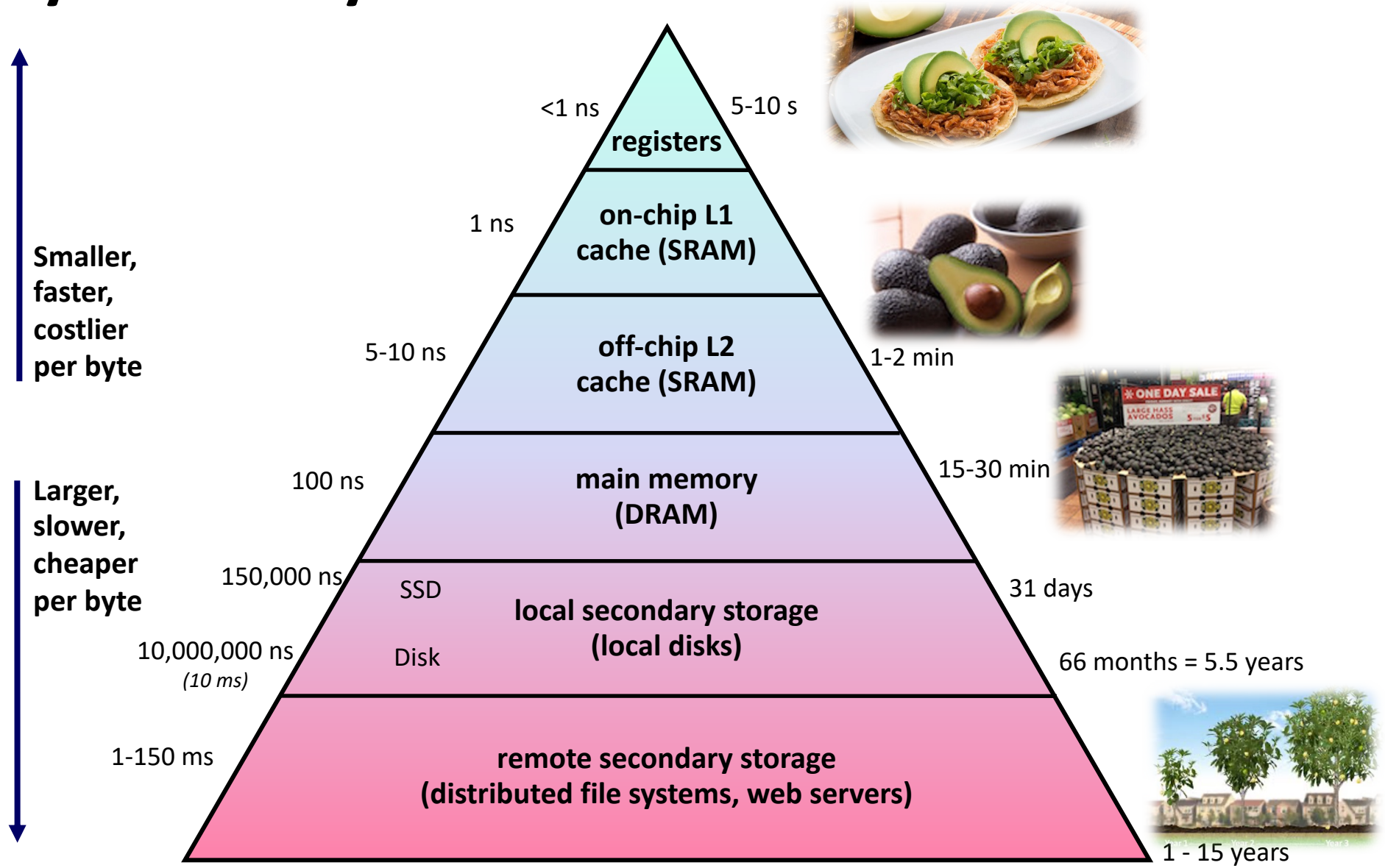
- Address Translation
  - Every memory access must first be converted from virtual to physical
  - **Indirection***:* just change the address mapping when switching processes
  - Luckily, TLB (and page size) makes it pretty fast

But Memory Itself 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 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/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

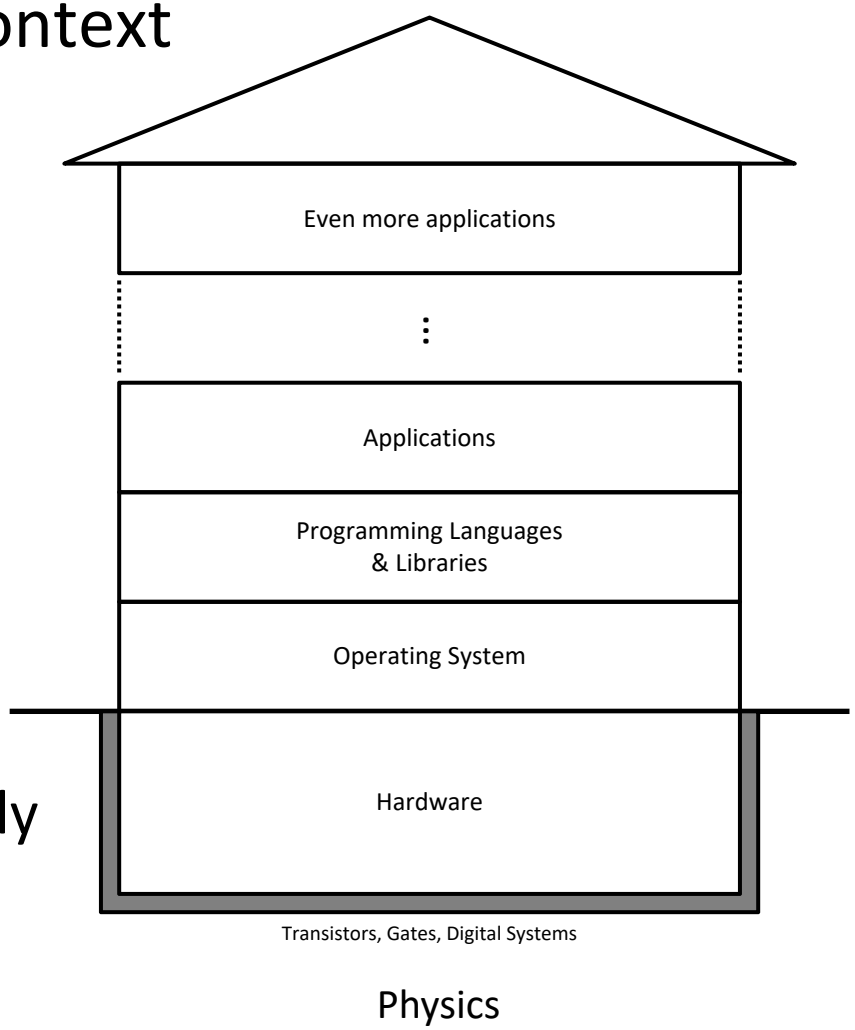
- We know Java as a programming language
  - Need to work our way down to the 0s and 1s of computers
  - Try not to lose anything in translation!
  - We encountered C language, assembly language, and machine code (for the x86 family of CPU architectures)

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
    - 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 scaling
  - Need to reexamine your heading and vision periodically
    - Check your metrics and definition of success



Thinking Critically About Ideologies: Efficiency

- C is close to the hardware: lack of abstraction makes it **fast** but also **difficult to use**
  - Buffer overflows, segmentation faults, memory bugs, etc.
  - "Minimalistic" and "rugged" or "bloated" and "spoiled"
    - We need people in systems with both perspectives!
- Automation of "boring, repetitive work"
  - Augmentation is highly valued and exclusive
  - "Boring, repetitive work" is more available but tenuous; want to be rid of it!

Thinking Critically About Ideologies: Scaling

- Large tech companies operate on a global scale.
- But scaling is really, really difficult…
  …and when you do it wrong, there are global consequences.
- Co-design required: when designing a solution for the world, need to **involve** lots of people all over the world
  - What does "organizing the world" (Google) mean? Organizing it for whom? To what end?
- Computers make it technically easier to scale globally, but that doesn't make us otherwise uniquely suited
  - "Move fast and break things" doesn't scale well...

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)
- 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

Course Perspective

- CSE 351 provides you the tools you need to continue your journey into computer science
- You may have learned that you love low-level stuff!
  Here is what to take next:
  - Systems Programming (333), Operating Systems (451), Compilers (401), Embedded Systems (474)
  - Pick up an Arduino, and hack away on your own projects!
- You might never want to touch C again…but maybe something else struck your fancy!
  - Programming Languages (341), Distributed Systems (452), Machine Learning (446)
  - Create a website! Pick up a Raspberry Pi, hook up some LEDs, program it in Python!

Course Perspective

- Wherever your next steps take you…
  - You belong in computer science **because** of who you are, not despite it. **Your** perspective is unique and valuable.
  - The areas of computer science that you like to spend time in don't make you any "less" of a programmer.
  - You get to decide what works best for you.

- But also, take some time away from the computer 😁
  - The world is huge, and your laptop's screen is only, like, 14"
  - Take classes outside of CSE – you might even make connections!

Can You Now Explain These to a Friend?

- Which of the following did you actually find the most interesting to learn about?

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)

Courses: What's Next?

- Staying near the hardware/software interface:
  - **CSE 369/EE 271:** Digital Design – basic hardware design using FPGAs
  - **CSE 474/EE 474:** Embedded Systems – software design for microcontrollers
- Systems software:
  - **CSE 341/CSE 413:** Programming Languages
  - **CSE 332/CSE 373:** Data Structures and Parallelism
  - **CSE 333/CSE 374:** Systems Programming – building well-structured systems in C/C++
- Looking ahead:
  - **CSE 401:** Compilers (pre-reqs: 332)
  - **CSE 451:** Operating Systems (pre-reqs: 332, 333)
  - **CSE 461:** Networks (pre-reqs: 332, 333)
  - **CSE 484:** Computer Security (pre-reqs: 332, 351)
  - **CSE 590E**: Computer Science Education Seminar

Courses: What's Next?

- Something completely different!
- From past & present TAs
  - MUSIC 116: Elementary Music Theory
  - GWSS 374: Transgender Studies
  - PHIL 118: Persuasion Or Manipulation? The Ethics And Psychology Of Influence
  - LING 269: Swearing and Taboo Language
  - DIS ST 230: Introduction to Disability Studies
  - ESRM 190: Environmental Science Special Topics
  - LING 200: Intro to Linguistics
  - DESIGN 150: What Is Design: Practices, Principles, And Perspectives
  - EDUC 251: Seeking Educational Equity and Diversity
  - MUSIC 162: American Popular Song

Thanks for a great quarter!

- Huge thanks to your awesome TAs!

- Don’t be a stranger!
  - Next year my teaching schedule is Au: CSE 121, Wi: CSE 122, Sp: CSE 391
  - I’m always looking for TAs, so be sure to apply for any of these courses!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Ask Me Anything