Course Wrap-Up
CSE 333

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Final Exam Logistics

- Take-home format via Gradescope
  - No Gradescope-imposed time limit
  - Unlimited access to course resources (videos, slides, your notes)
  - Released **no later than** 4:20pm on Mon, Jun 3
    - If it's released earlier than that, I'll make an Ed announcement

Final Exam: Suggested Plan

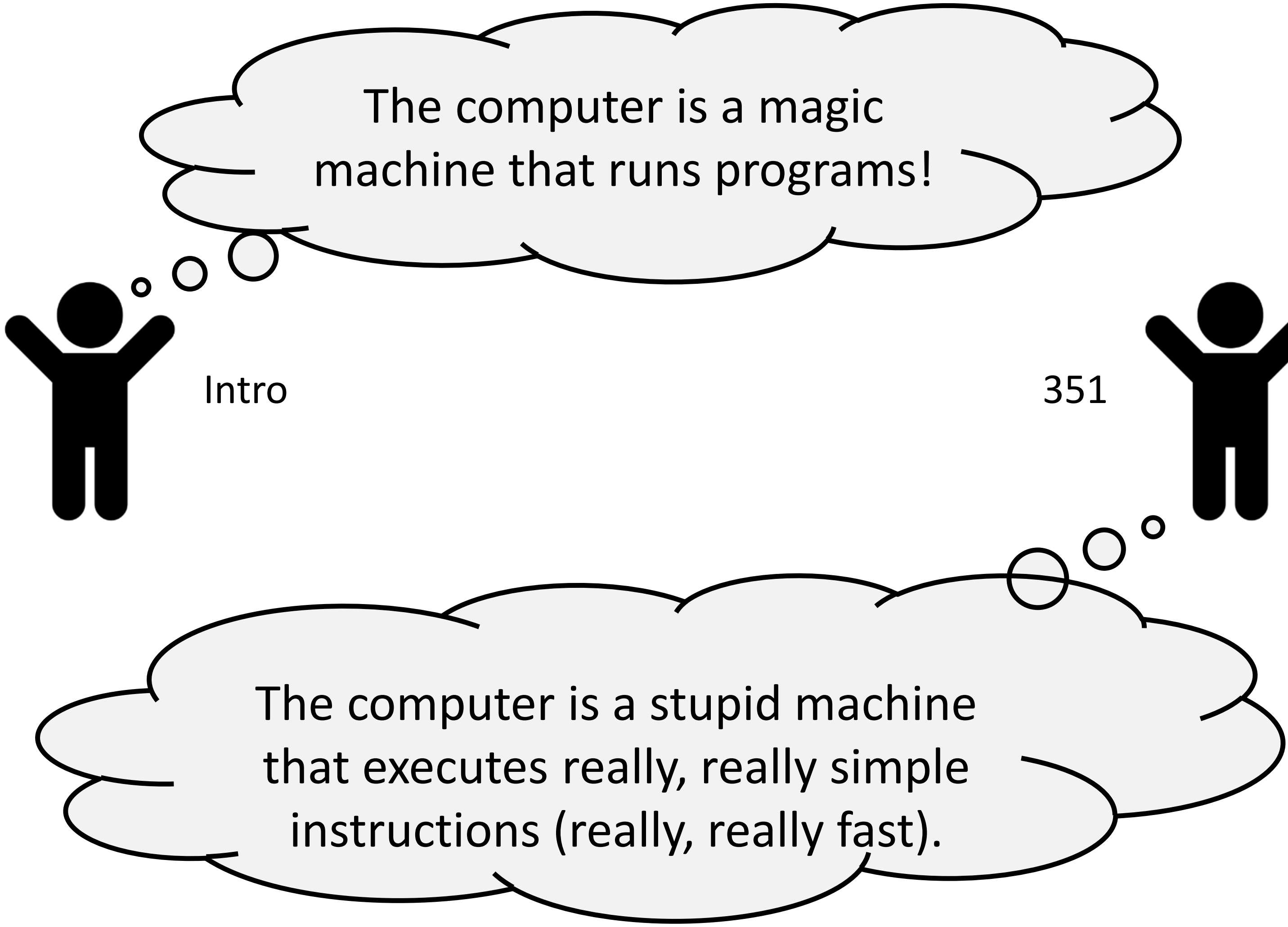
- TAKE A BREAK this weekend!
- Do a general review of areas that you struggled with
  - (eg, pointers, file I/O, etc)
  - Ensure you know how to find the relevant videos, slides, demos, …
- Open the exam on Monday afternoon to take a topic inventory
  - Do a targeted review of those topics on Monday evening
- [optional] meet with your study group
  - Discuss these questions, but don't take notes **about these discussions**
  - Take a 30m break
- Fill out the exam without the benefit of other brains
  - Eg, notes from study group, texts from friends, etc

So what have we been doing for the last 10 weeks?

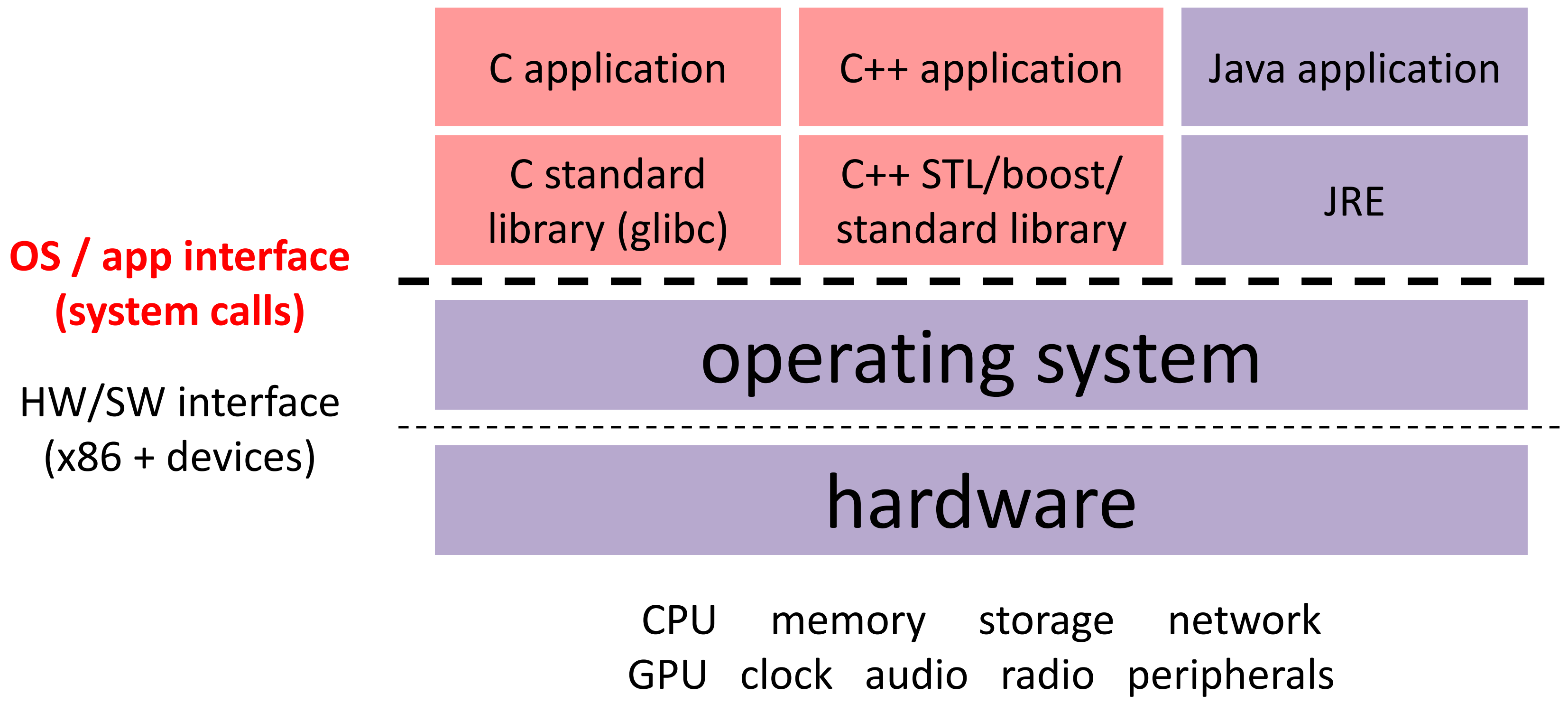
?

Course Goals

- Explore the gap between:


The computer is a magic machine that runs programs!
Intro
351
The computer is a stupid machine that executes really, really simple instructions (really, really fast).

Course Map: 100,000 foot view


C application
C++ application
Java application
C standard library (glibc)
C++ STL/boost/ standard library
JRE
OS / app interface (system calls)
operating system
HW/SW interface (x86 + devices)
hardware
CPU memory storage network
GPU clock audio radio peripherals

Systems Programming

- The programming skills, engineering discipline, and knowledge you need to build a system
  - **Programming:** C / C++
  - **Discipline:** design, testing, debugging, performance analysis
  - **Knowledge:** long list of interesting topics
    - Concurrency, OS interfaces and semantics, techniques for consistent data management, distributed systems algorithms, …
    - Most important: a deep understanding of the “layer below”

Main Topics

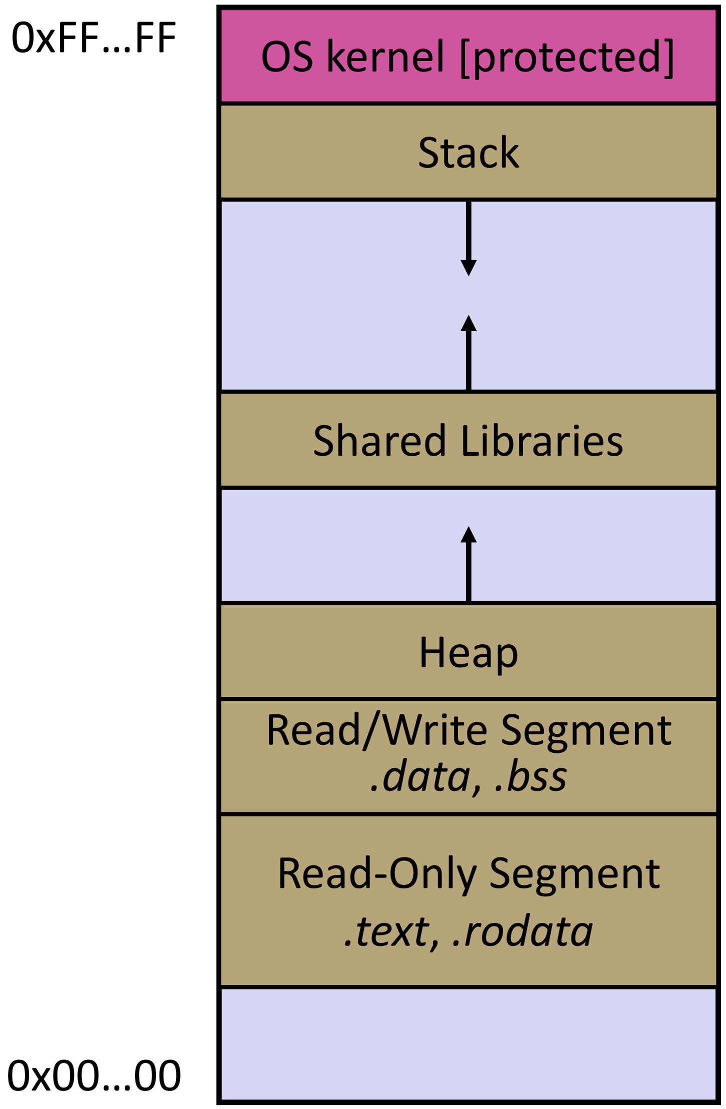
- C
  - Low-level programming language
- C++
  - The 800-lb gorilla of programming languages
  - "better C" + classes + STL + smart pointers + …
- Memory management
- System interfaces and services
- Networking basics – TCP/IP, sockets, …
- Concurrency basics – POSIX threads, synchronization

The C/C++ Ecosystem

- System layers:
  - C/C++
  - Libraries
  - Operating system
- Building Programs:
  - Pre-processor (`cpp`, `#include`, `#ifndef`, …)
  - Compiler: source code → object file (`.o`)
  - Linker: object files + libraries → executable
- Build tools:
  - `make` and related tools
  - Dependency graphs

Program Execution

- What's in a process?
  - Address space
  - Current state
    - SP, PC, register values, etc.
  - Thread(s) of execution
  - Environment
    - Arguments, open files, etc.



Structure of C Programs

- Standard types and operators
  - Primitives, extended types, structs, arrays, typedef, etc.
- Functions
  - Defining, invoking, execution model
- Standard libraries and data structures
  - Strings, streams, etc.
  - C standard library and system calls, how they are related
- Modularization
  - Declaration vs. definition
  - Header files and implementations
  - Internal vs. external linkage
- Handling errors without exception handling
  - `errno` and return codes

C++ (and C++11)

- A “better C”
  - More type safety, stream objects, memory management, etc.
- References and const
- Classes and objects!
  - So much (too much?) control: constructor, copy constructor, assignment, destructor, operator overloading
  - Inheritance and subclassing
    - Dynamic vs. static dispatch, virtual functions, vtables and vptrs
    - Pure virtual functions and abstract classes
    - Subobjects and slicing on assignment
- Copy semantics vs. move semantics

C++ (and C++11)

- C++ Casting
  - What are they and why do we distinguish between them?
  - Implicit conversion/construction and `explicit`
- Templates – parameterized classes and functions
  - Similarities and differences from Java generics
  - Template implementation via expansion
- STL – containers, iterators, and algorithms
  - `vector`, `list`, `map`, `set`, etc.
  - Copying and types
- Smart Pointers
  - `unique_ptr`, `shared_ptr`, `weak_ptr`
  - Reference counting and resource management

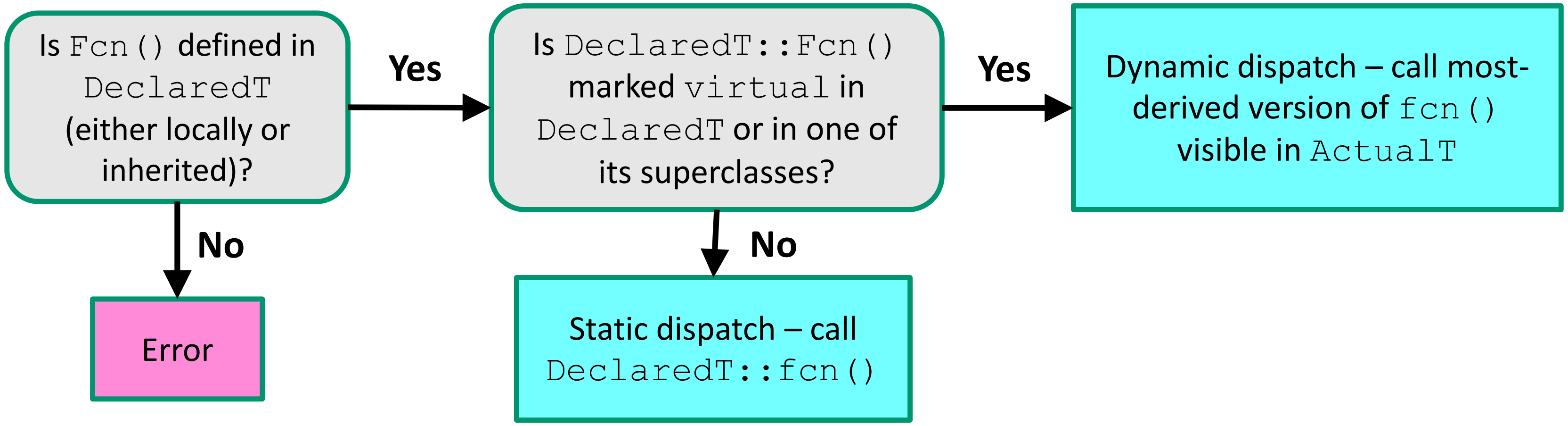
Dynamic Dispatch, Virtual Functions, &c

- *The* most frequent question on ed as the exam approaches, based on past experience.
- How to solve it? Understand the difference between static compile-time types (declared types) and actual type of the object referenced by a pointer.
- Understand which functions are virtual and which aren't
  - And remember that virtual is sticky, applies to all inherited / overridden function in subclasses
- Then follow the chart (from lec. 19) ….

Mixed Dispatch

- Which function is called is a mix of both compile time and runtime decisions as well as *how* you call the function
  - If called on an object (*e.g.* `obj.Fcn()`), usually optimized into a hard-coded function call at compile time
  - If called via a pointer or reference:

```
DeclaredT *ptr = new ActualT;
ptr->Fcn();  // which version is called?
```


Is Fcn() defined in DeclaredT (either locally or inherited)?
Yes
Is DeclaredT::Fcn() marked virtual in DeclaredT or in one of its superclasses?
Yes
Dynamic dispatch – call most-derived version of fcn() visible in ActualT
No
Error
No
Static dispatch – call DeclaredT::fcn()

Memory

- Object scope and lifetime
  - *Static*, *automatic*, and *dynamic* allocation / lifetime
- Pointers and associated operators (`&`, `*`, `->`, `[]`)
  - Can be used to link data or fake "call-by-reference"
- Dynamic memory allocation
  - **`malloc`**/**`free`** (C), **`new`**/**`delete`** (C++)
  - Who is responsible? Who owns the data? What happens when (not if) you mess this up? (dangling pointers, memory leaks, …)
- Tools
  - Debuggers (`gdb`), monitors (`valgrind`)
  - Most important tool: thinking!

Networking

- Conceptual abstraction layers
  - Physical, data link, network, transport, session, presentation, application
  - Layered *protocol* model
    - We focused on IP (network), TCP (transport), and HTTP (application)
- Network addressing
  - MAC addresses, IP addresses (IPv4/IPv6), DNS (name servers)
- Routing
  - Layered packet payloads, security, and reliability

Network Programming

Client side

1) Get remote host IP address/port
2) Create socket
3) Connect socket to remote host
4) Read and write data
5) Close socket

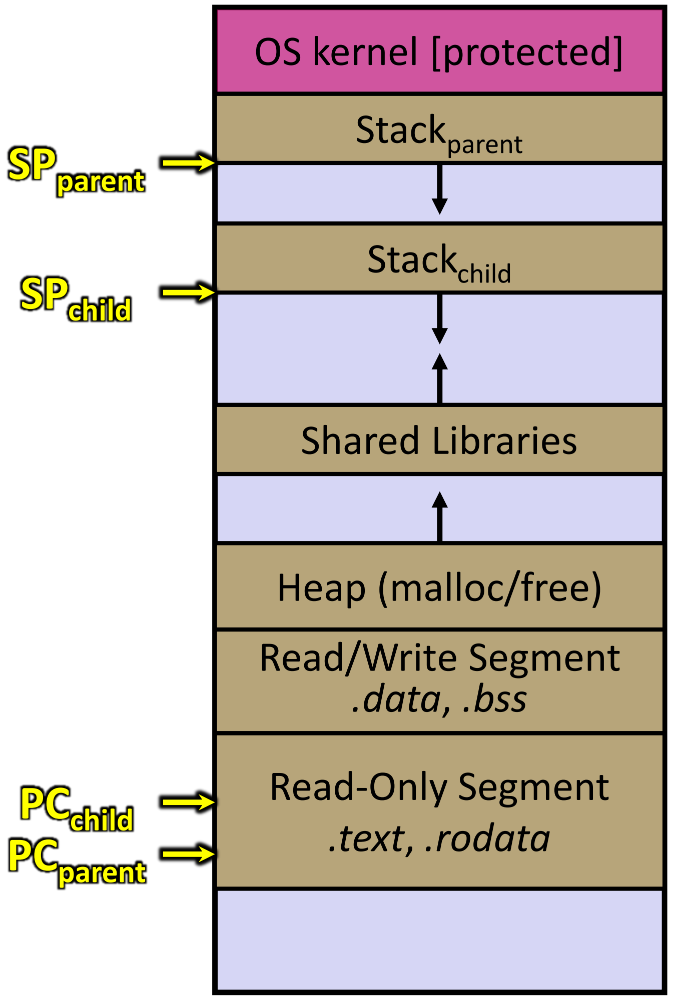
Server side

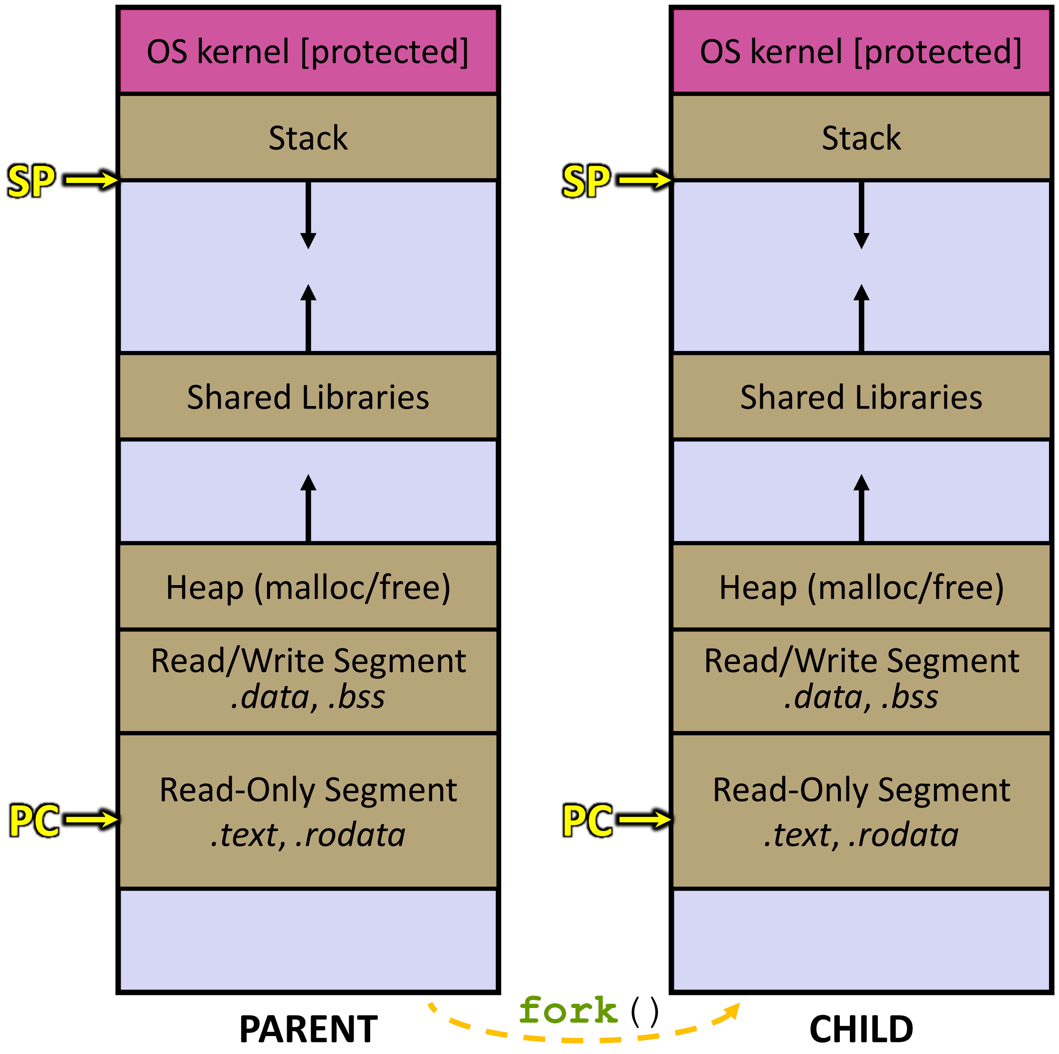
1) Get local host IP address/port
2) Create socket
3) Bind socket to local host
4) Listen on socket
5) Accept connection from client
6) Read and write data
7) Close socket

Concurrency

- Why or why not?
  - Better throughput, resource utilization (CPU, I/O controllers)
  - Tricky to get right – harder to code and debug
- Threads – "lightweight"
  - Address space sharing; separate stacks for each thread
  - Standard C/C++ library: pthreads
- Processes – "heavyweight"
  - Isolated address spaces
  - Forking functionality provided by OS
- Synchronization
  - Data races, locks/mutexes, how much to lock…

Processes vs Threads on One Slide





Phew! That’s it!

- But that’s a lot!!

- Take a look back and congratulate yourself on what you’ve accomplished in a 10-week quarter!

Courses: What's Next?

- **CSE401:** Compilers (pre-reqs: 332, 351)
  - *Finally* understand why a compiler does what it does
- **CSE451:** Operating Systems (pre-reqs: 332, 333)
  - How do you manage all of the computer's resources?
- **CSE452:** Distributed Systems (pre-reqs: 332, 333)
  - How do you get large collections of computers to collaborate (correctly!)?
- **CSE461:** Networks (pre-reqs: 332, 333)
  - The networking nitty-gritty: encoding, transmission, routing, security
- **CSE455:** Computer Vision
- **CSE457:** Computer Graphics

This doesn’t happen without lots of help…

- Thanks to a fantastic staff – it can’t work without them!!
  - Deeksha Vatwani Hannah Jiang Jen Xu
  - Leanna Nguyen Nam Nguyen Sayuj Shahi
  - Tanay Vakharia Wei Wu Yiqing Wang
  - Zohar Le

- And thanks to the folks who put the course together:
  - Steve Gribble, John Zahorjan, Hal Perkins, Justin Hsia, me, Aaron Johnston, Travis McGaha, many others

And thanks to…

You

It’s been great to share new ideas and skills with everyone. You should be proud of what you’ve done. Please take care of yourself, watch your health, stay active, and help yourself, your friends, your community.

Congratulations and best wishes!

You’ve learned a *lot* – go out and build great things!

Come by and say hello in the future – I’d love to know what you’ve been up to after CSE 333!

That's all Folks!