Course Wrap-Up

CSE 333 Summer 2020

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Administrivia

- hw4 due tomorrow (8/20)
  - Submissions accepted until Sunday (8/23)
  - If you want to use late day(s), you **MUST** let staff know. Make a private post on ed or send an email to staff letting us know you want to use late day(s).

- Course evaluations due Friday night
  - Please fill these out! <3

- Grades for various assignments have been posted. **PLEASE CHECK THESE** and contact staff if something seems incorrect!!!

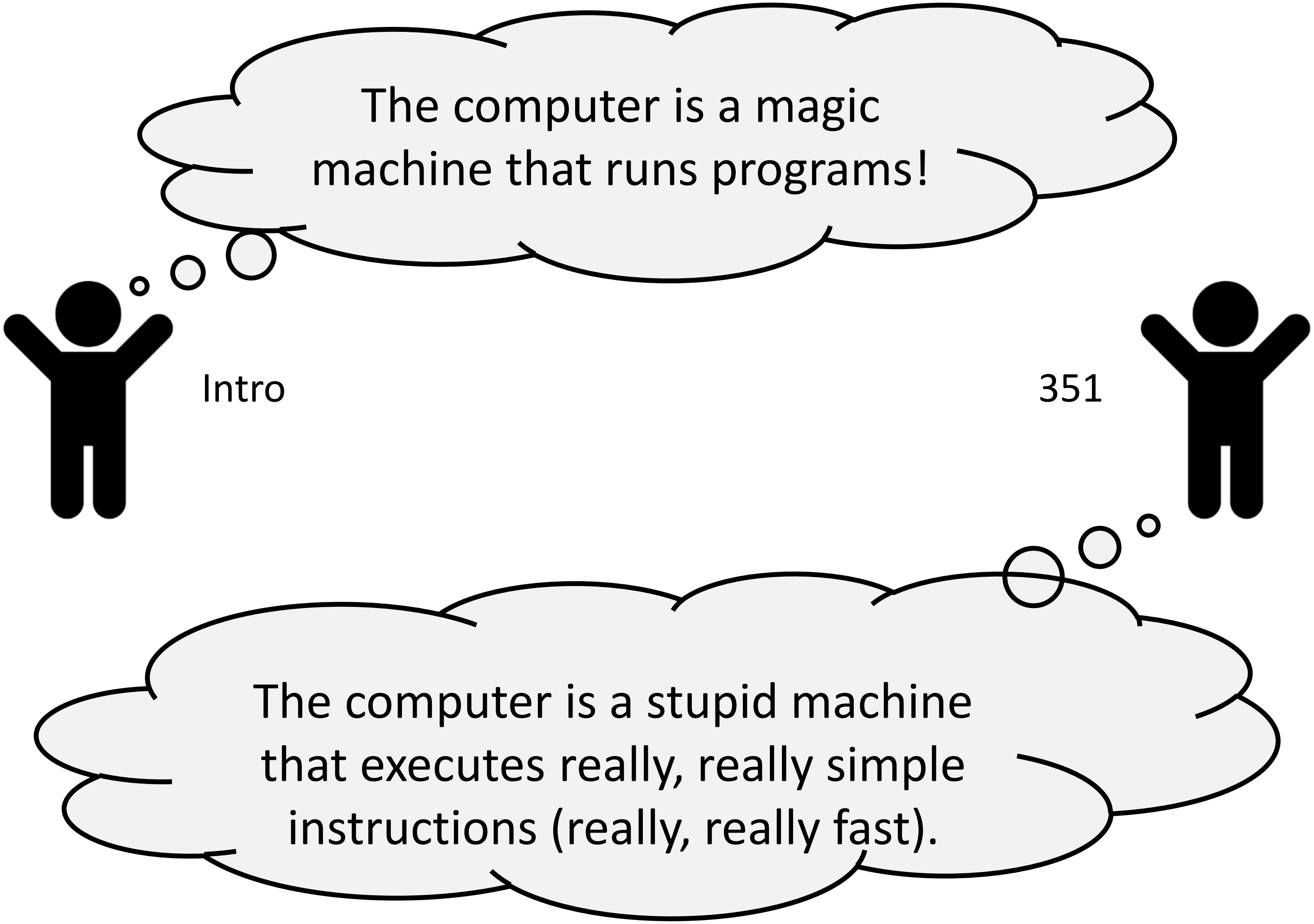
So what have we been doing for the last 9 weeks?

?

Ideally you would know everything I am talking about in this lecture, but the red stars indicate things you really should leave the course knowing ☆

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).

Lecture Outline

- **Systems Programming: The What**
- Systems Programming: The Why

Systems Programming: The What

- 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

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

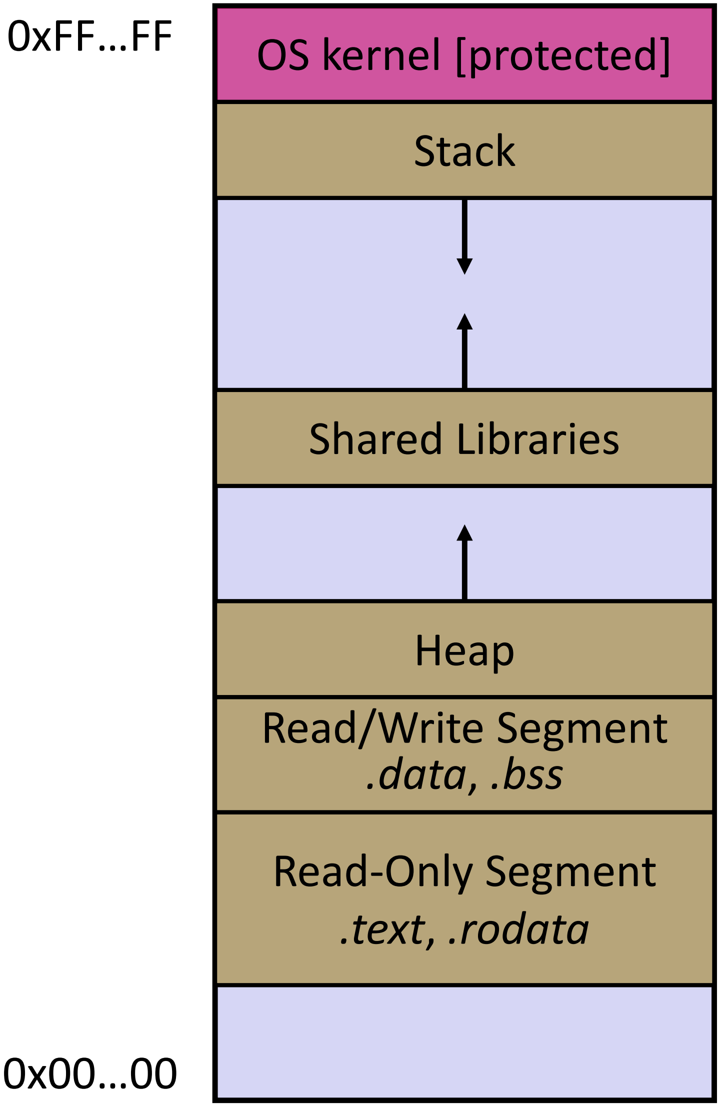
C++ (and C++11)

- 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 implementations 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

Program Execution

Mostly review from 351....

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



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!

The Operating System

- Operating System has more permissions
  - User must ask OS to handle restricted operations
  - Only OS can directly interact with hardware, read from disk, …
- System Calls
  - OS provides an interface for User Processes to request the OS to complete a protected operation.
  - Library calls (fread/fwrite/…) will also have to go through the OS via system calls.
- I/O
  - Reading/Writing to disk takes a LONG time
    - (relative to other operations)
  - Strategies like buffering should be used to minimize number of disk accesses.

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

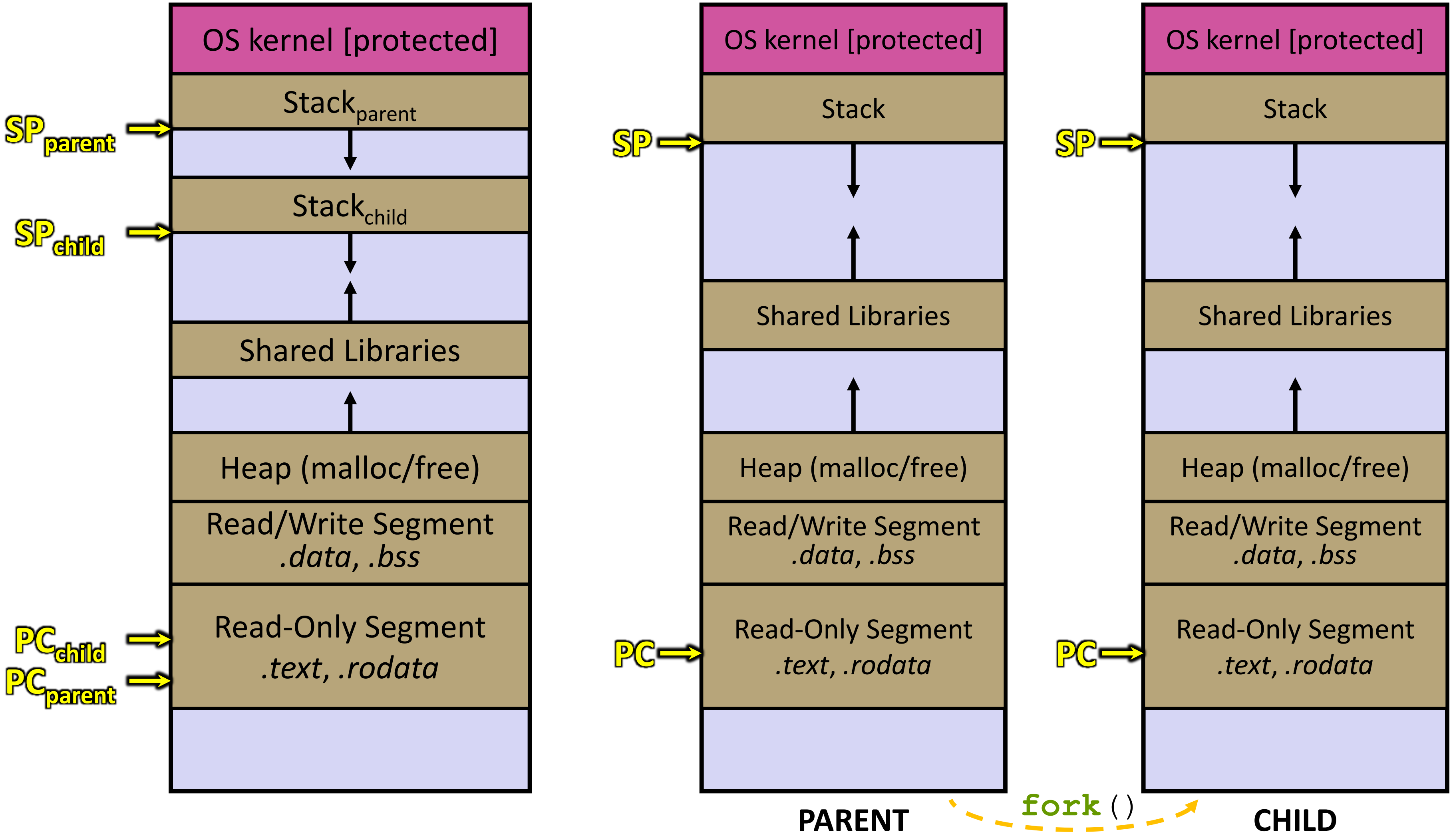
1) Get local host IP address/port
2) Create socket
3) Bind socket to local host
4) Listen on socket
5) Accept connection from client
6) Read and write data
7) Close socket

- Error handling
- Blocking vs. non-blocking calls

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



Poll Everywhere

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What is your Favourite Topic In CSE 333?

Lecture Outline

- Systems Programming: The What
- **Systems Programming: The Why**

Systems Programming: The Why

- The programming skills, engineering discipline, and knowledge you need to build a system
  1) Understanding the "layer below" makes you a better programmer at the layer above
  2) Gain experience with working with and designing more complex "systems"
  3) Learning how to handle the unique challenges of low-level programming allows you to work directly with the countless "systems" that take advantage of it

So What is a System?

- "A **system** is a group of interacting or interrelated entities that form a unified whole. A system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning."
  - https://en.wikipedia.org/wiki/System
  - Still vague, maybe still confusing

- But hopefully you have a better idea of what a system in CS is now
  - What kinds of systems have we seen…?

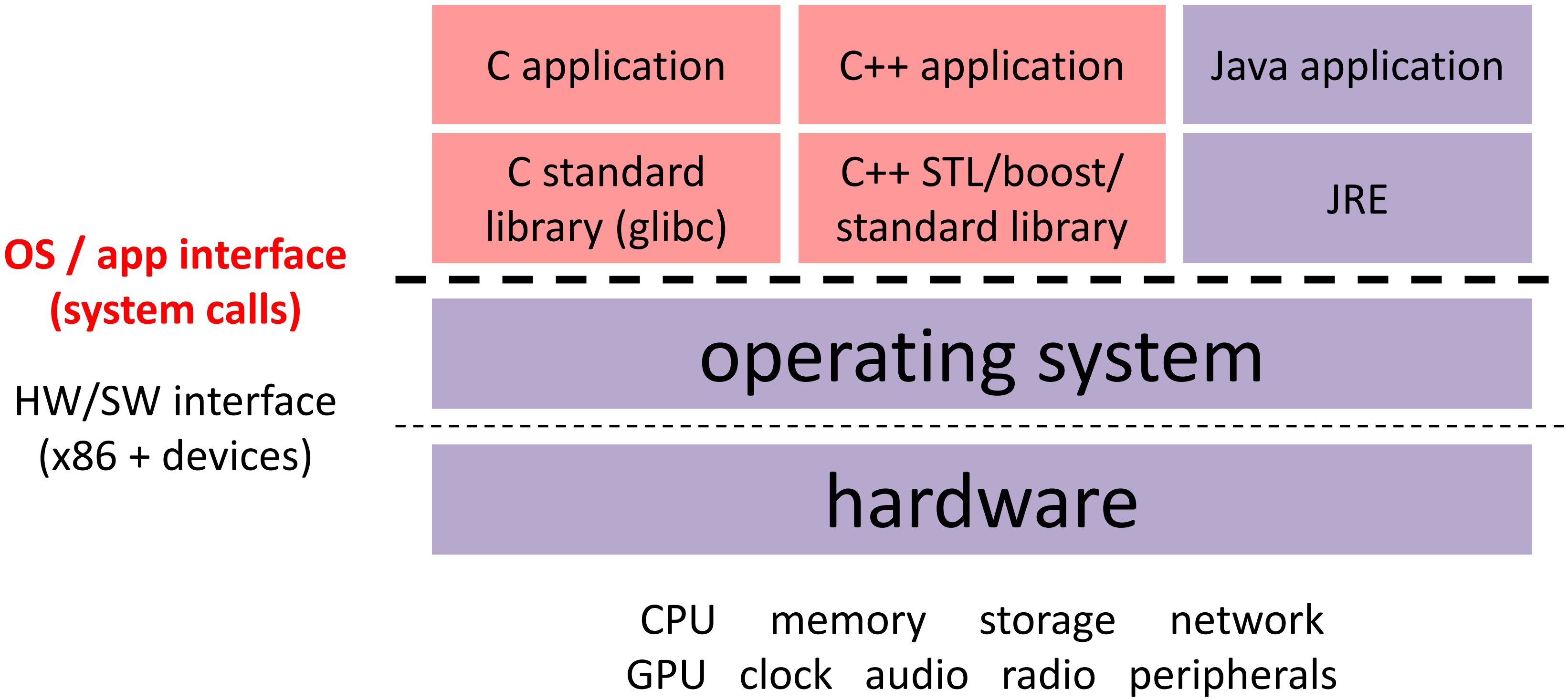
Software System

- Writing complex software systems is *difficult*!
  - Modularization and encapsulation of code
  - Resource management
  - Documentation and specification are critical
  - Robustness and error handling
  - Must be user-friendly and maintained (not write-once, read-never)

- **Discipline:** cultivate good habits, encourage clean code
  - Coding style conventions
  - Unit testing, code coverage testing, regression testing
  - Documentation (code comments, design docs)
  - If programmer discipline is interesting to you, take CSE 331!

The Computer as a System

- Modern computer systems are increasingly complex!
  - Networking, concurrency/parallelism, distributed systems
  - Buffered vs. unbuffered I/O



A Network as a System

- A networked system relies heavily on its connectivity
  - Depends on materials, physical distance, network topology, protocols
- 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

Congratulations!

- Look how much we learned!
- Lots of effort and work, but lots of useful takeaways:
  - Debugging practice and metacognition (`gdb`, bug journals)
  - Reading documentation
  - Tools (`git`, `valgrind`, makefiles)
  - C and C++ familiarity, including multithreaded and networked code
- No exam to study for, but go forth and build cool systems!
- Tomorrow’s Lecture: Future Classes, Course Thanks, and AMA!