Lecture 01: Introduction

CS343 – Operating Systems

Branden Ghena – Spring 2022

Some slides borrowed from:
Stephen Tarzia (Northwestern), Jaswinder Pal Singh (Princeton), and UC Berkeley CS162

Northwestern

Welcome to CS343!

- In brief: how does the operating system work and why?

- Role of the Operating System
  - **Manages** hardware resources
  - Provides **abstractions** to support processes

- Major topics
  - Concurrency
  - Scheduling
  - Devices
  - Virtual Memory
  - File Systems

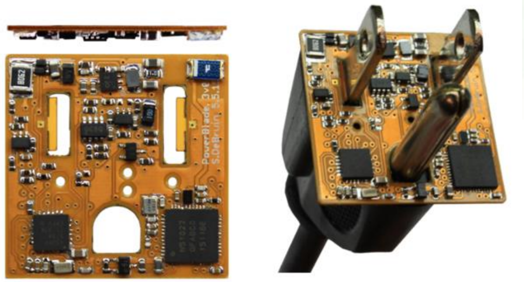
COVID Update - Spring 2022 Edition

- Masks in class are no longer mandatory
  - You’re still welcome to wear one if you want, but I won’t make you
  - I’ll still be wearing one

- If you are sick, do not come to class
  - Even if there’s an exam that day!!
  - We will be flexible with deadlines as necessary
  - Lectures are being recorded automatically

Branden Ghena (he/him)

- Assistant Faculty of Instruction
- Education
  - Undergrad: Michigan Tech
  - Master’s: University of Michigan
  - PhD: University of California, Berkeley
- Research
  - Resource-constrained sensing systems
  - Low-energy wireless networks
  - Embedded operating systems
- Teaching
  - Computer Systems
    - CS211: Fundamentals of Programming II
    - CS213: Intro to Computer Systems
    - CS343: Operating Systems
    - CE346: Microprocessor System Design
    - CS397: Wireless Protocols for the IoT



Things I love

Today's Goals

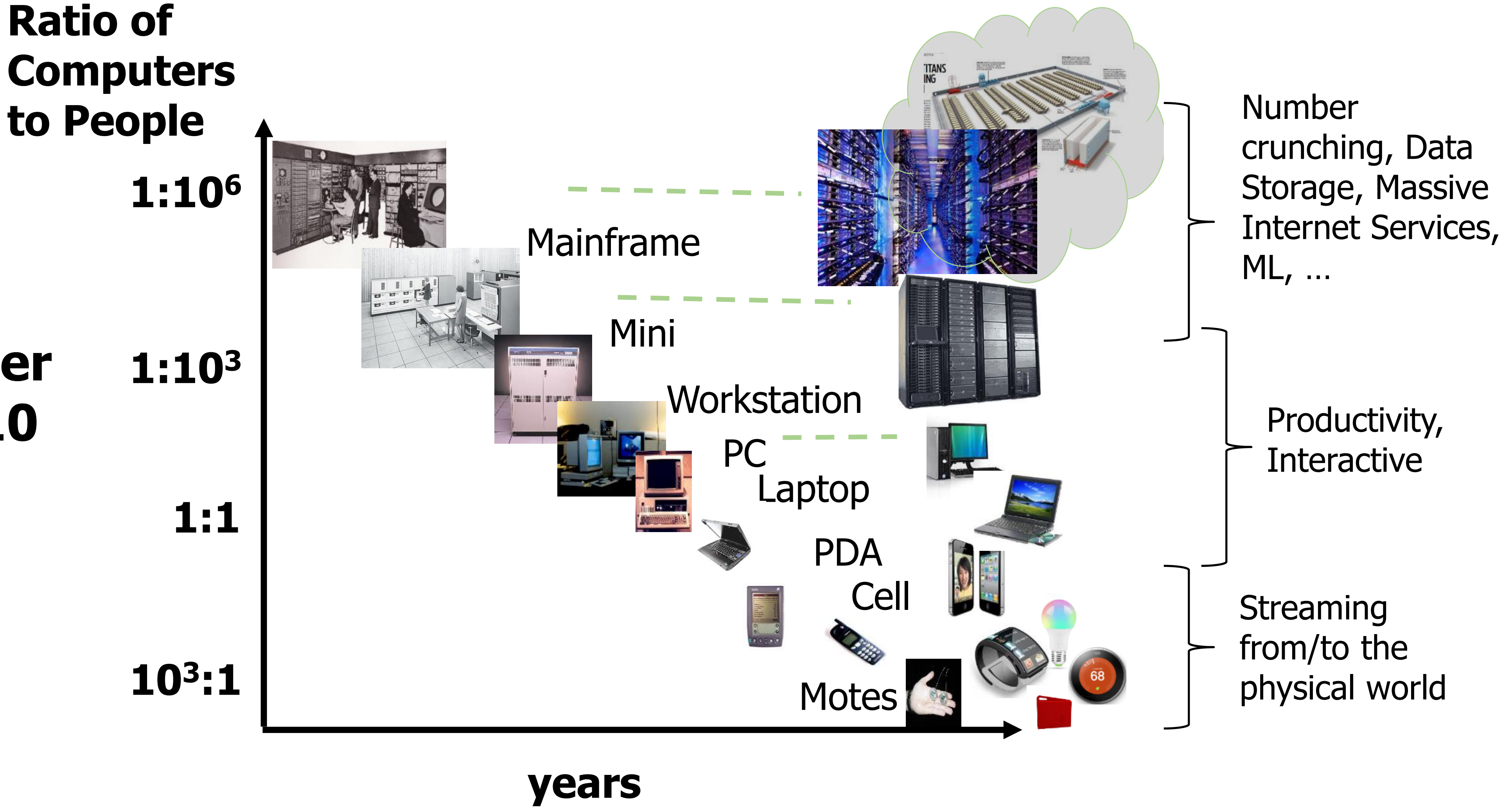
- Discuss the role of an Operating System
- Introduce theme and goals of the course
- Describe how this class is going to function
- Explore trends in OS history

Outline

- **What is an OS?**
- Logistics
- Operating Systems History
- CS343 Focus

Computers come in incredible diversity

Bell's Law: New computer class every 10 years



Computing timescales are increasingly large

Jeff Dean (Google AI): "Numbers Everyone Should Know"

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns

Operating systems are at the heart of these challenges

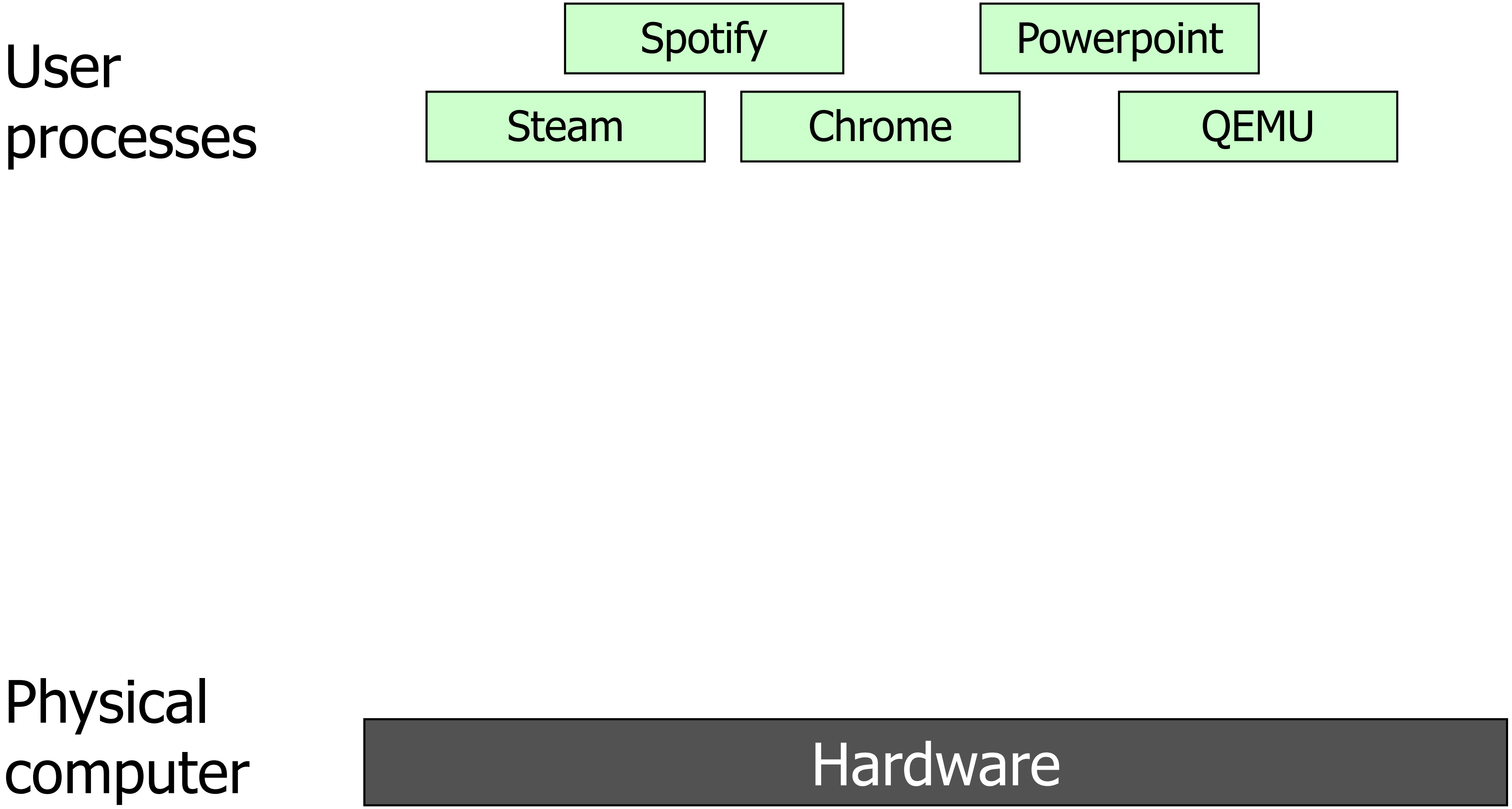
- OSes make advancing technology available to rapidly evolving applications. They do so with two major goals:

  1. Provide **abstractions** to applications to enable hardware compatibility
     - Why: allow reuse of common features, avoid low-level details
     - Challenges: What are the correct abstractions?

  2. Manage **sharing of resources** across many applications
     - Why: protect applications, enforce fair access
     - Challenges: What are the mechanisms and what are the policies?

- Good operating systems do these quickly, efficiently, and securely

What is an operating system?



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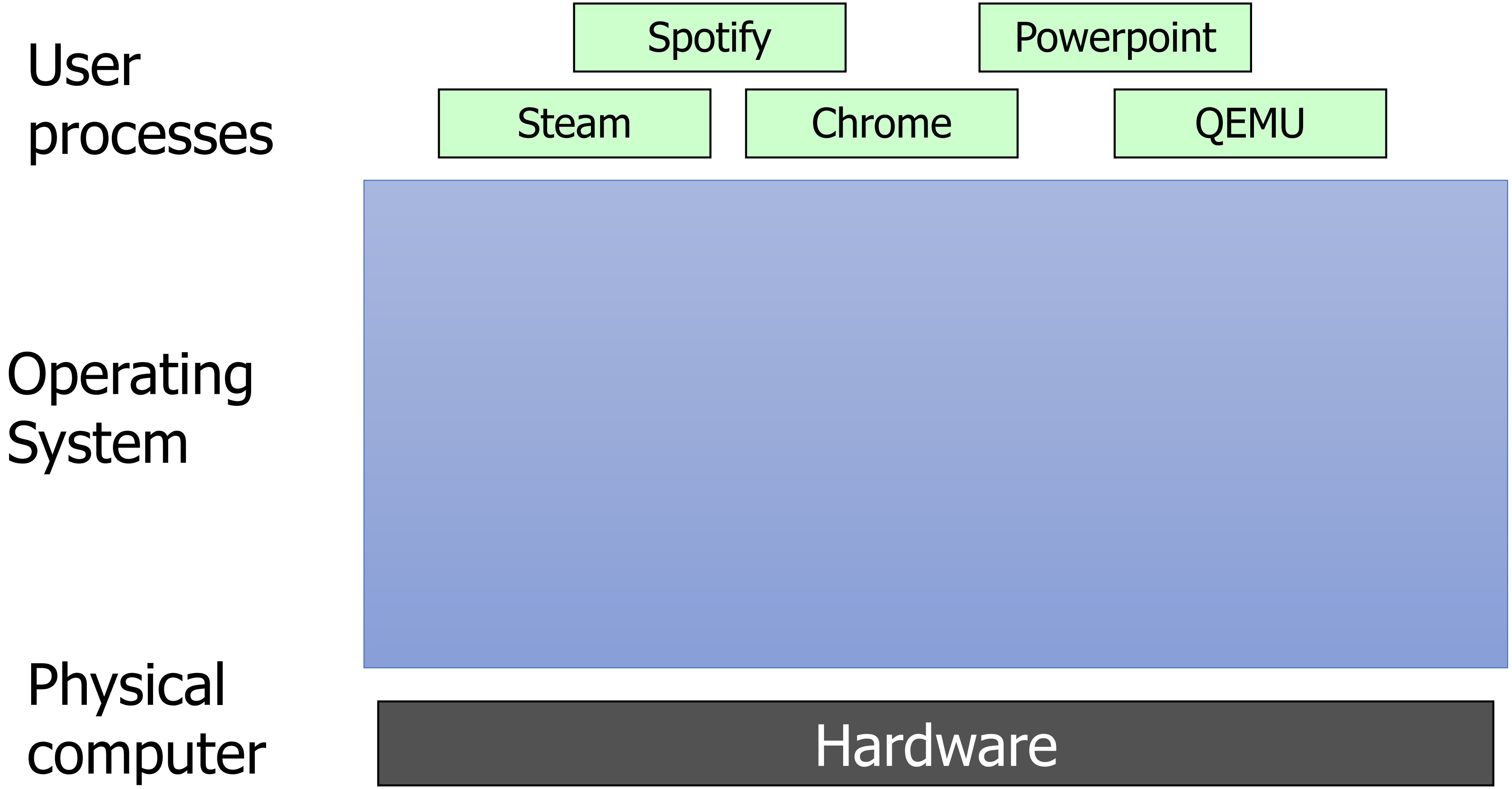

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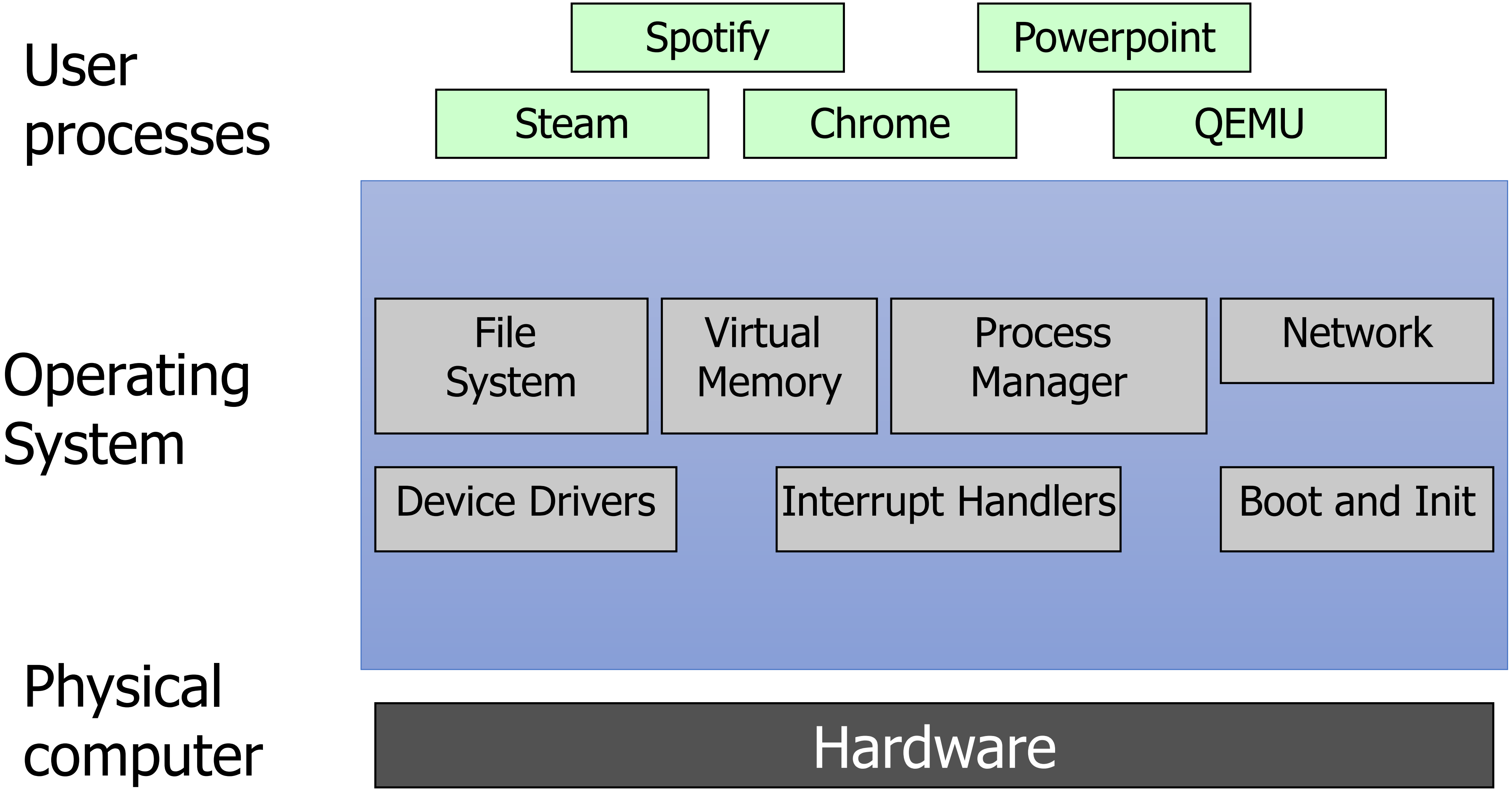

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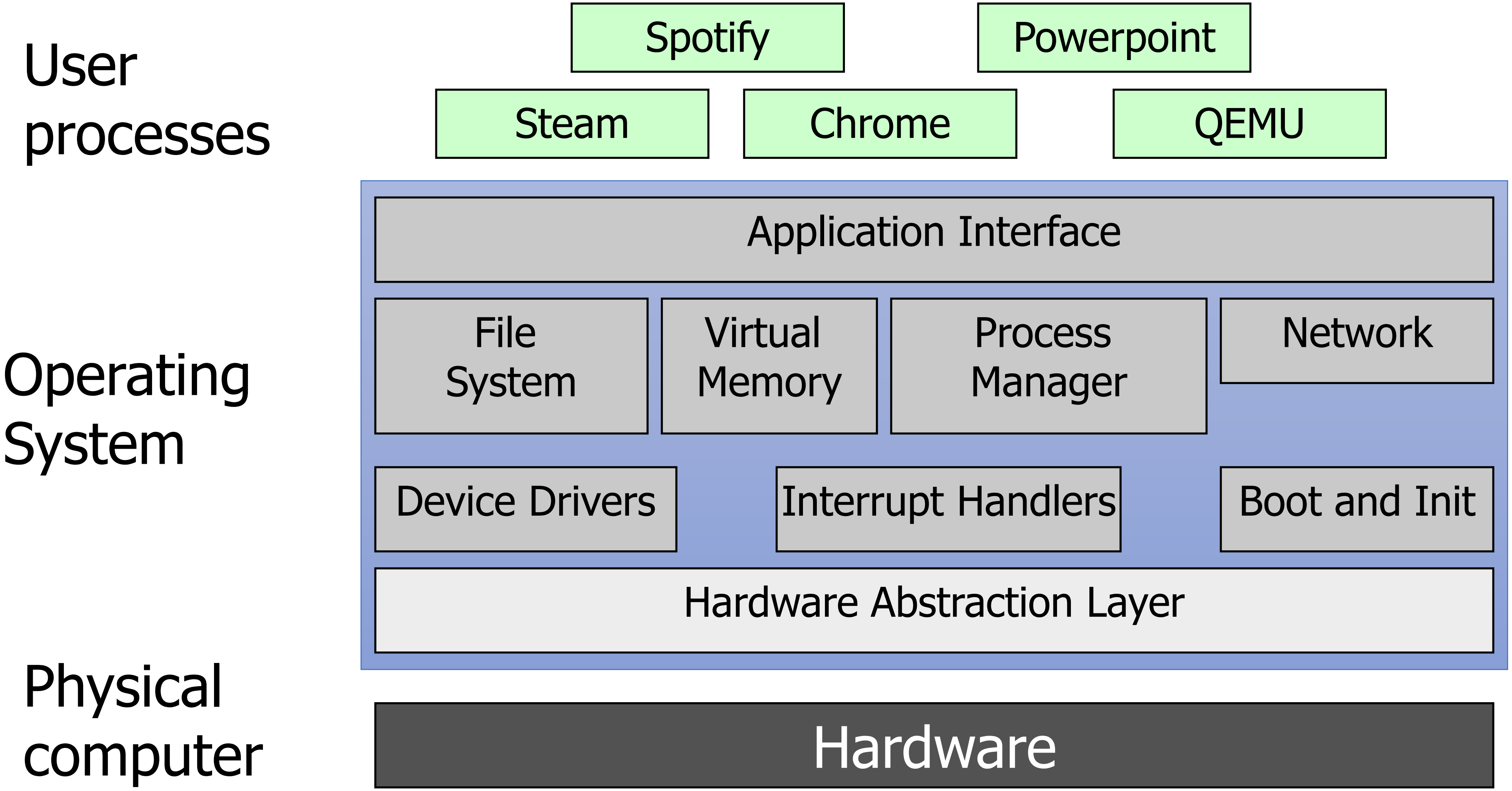


What’s part of the OS?

- **OS kernel** – the only code without security restrictions

- Process scheduling (who uses CPU)
- Memory allocation (who uses RAM)
- Accesses hardware devices
  - Outputs graphics
  - Reads/writes to network
  - Read/write to disks
  - Handles boot-up and power-down

- **OS distribution** – the kernel + lots of other useful stuff

- GUI / Window manager
- Command shell
- Software package manager
  - “app store”, yum, apt, brew
- Common software libraries
- Useful apps:
  - Text editor, compilers, web browser, web server, SSH, anti-virus, file-sharing, media libraries,

Before operating systems

- User could only run one program at a time.
- Had to insert the program disk before booting the machine.
- Program had to control the hardware directly
  - This is a nuisance because hardware is complicated
  - Program will only be compatible with one set of hardware
- An example (at right): 1983 “King’s Quest” game for IBM PC Jr.

Embedded systems often run without operating systems

- “Bare-metal” embedded systems
- Application must handle:
  - Boot and initialization
  - All hardware it wants to interact with

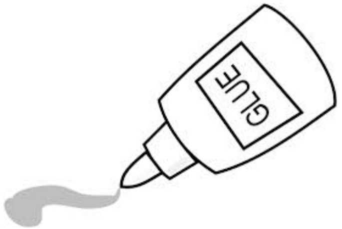
- Applications are not portable
  - Rewrite, mostly from scratch, for new microcontroller

- No malloc, no segfaults
  - Instead invalid memory accesses likely crash the whole system

What is an Operating System?

- Referee
  - Manage protection, isolation, and sharing of resources
  - Resource allocation and communication

- Illusionist
  - Provide clean, easy-to-use abstractions of physical resources
    - Infinite memory, dedicated machine
    - Higher level objects: files, users, messages
    - Masking limitations, virtualization

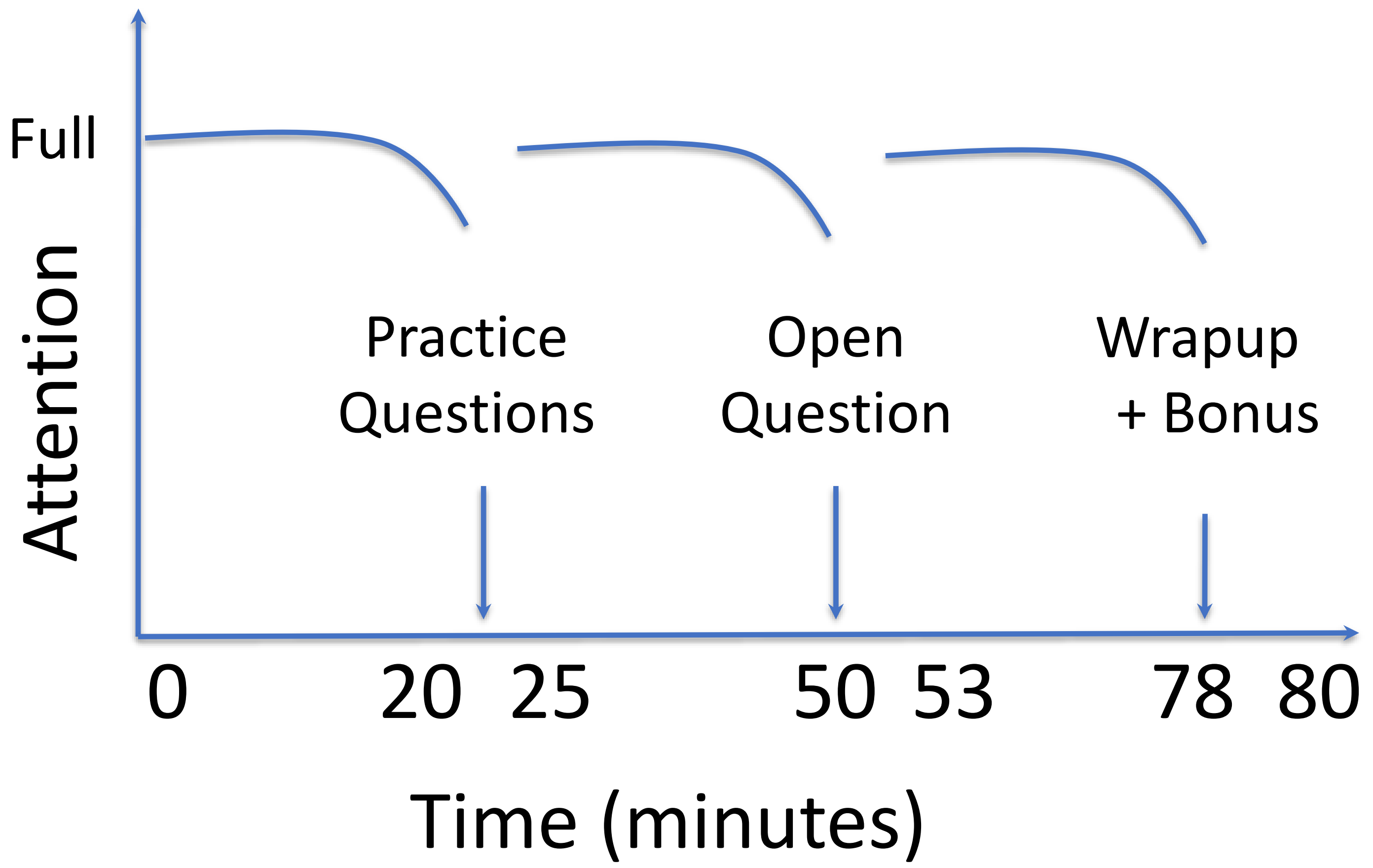


- Glue
  - Common services
    - Storage, Window system, Networking
  - Sharing, Authorization
  - Look and feel

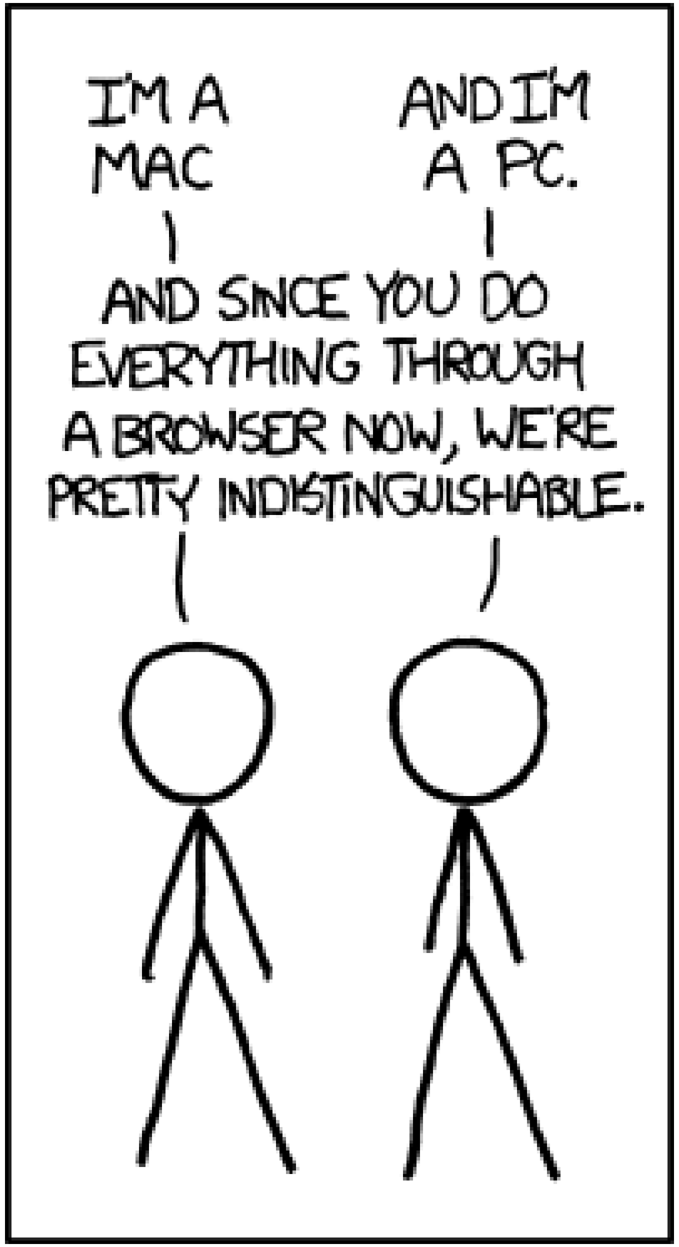
Example: File Systems

- Referee
  - Prevent users from accessing other's files without permission
- Illusionist
  - Files can grow infinitely large
  - Where a file exists in memory or disk isn't important!
- Glue
  - Default file system types, named directories

Architecture of a lecture



Break + xkcd



Open question:

Are modern web browsers basically operating systems?

https://xkcd.com/934/

Outline

- What is an OS?
- **Logistics**
- Operating Systems History
- CS343 Focus

Course staff

- Teaching Assistant
    - Mohammad Kavousi
        - PhD student working with Peter Dinda
        - TA experience across several systems courses

- Peer Mentors (4)
    - Alexander Redding
    - Huaxuan Chen
    - Li Kang Tan
    - Parveen Dhanoa

    - All recently took CS343 as students

Their role: support student questions via office hours and campuswire

Lecture

- 9:30-10:50 am, Tuesdays and Thursdays
  - Pancoe Abbot Auditorium

- Provides background on materials
  - And an immediate chance for you to ask questions

- Textbook:
  - Modern Operating Systems (4th Edition), Tanenbaum and Bos
  - Very useful reference. Lecture will be relatively in sync with it
  - Other references are in the syllabus

Asking questions

- Class and office hours are always an option!

- Campuswire: (similar to piazza)
  - Post questions
  - Answer each other’s questions
  - Find lab partners
  - Information from the course staff
  - Post private info just to course staff

- Please do not email me! Post to Campuswire instead!
  - I’ll be updating roster again a few times

Labs

- These are a significant amount of the learning in this class
  - Hands-on experience with the topics we're talking about
  - Labs primarily involve written code in C
  - Can be quite a bit of work

- Work on these in groups of up to three students
  - Preferably two or three
  - Goal: collaboration, not splitting labs
    - If you don't work on it, you're not going to learn from it

Lab logistics

- Getting Started Lab
  - Learn how everything works
- Producer-Consumer Lab
  - Concurrency and locks
- Queuing/Scheduling Lab
  - OS application scheduling
- Device Driver Lab
  - Driver for a GPU
- Paging Lab
  - Memory management

- Getting started lab is special
  - One week deadline (due 04/07)
  - Must do alone
  - All-or-nothing grading
- Normally teams of 2 or 3 students
  - Find partners now!
  - We'll put out a survey for those who don't know anyone

Midterm exams

- Test on your knowledge of course material
  - In-person, on paper
  - I’ll allow a notes sheet

- Not cumulative. Two midterms on two halves of the class

- First midterm will be during class time: April 28th
- Second midterm will be during exam week: June 9th
  - **Warning:** Thursday of exam week
  - Plan ahead. No exceptions for people who are on internships

Course grade

- 20% Midterm (first half of the course)
- 20% Final (second half of the course)
- 60% Labs
  - 05% Getting Started Lab (individual)
  - 10% Producer-Consumer Lab
  - 10% Queuing/Scheduling Lab
  - 15% Device Driver Lab
  - 15% Paging Lab

- This class is NOT curved
  - Standard 93% A, 90% A-, 87% B+, etc. applies

Late policy

- You can submit labs late

- 20% penalty to maximum grade per day late
  - Example: three days late means maximum grade is 40%

- We will be flexible with deadlines for problems outside of your control
  - Sick, family emergency, broken computer
  - Contact me (via Campuswire)

Slip days

- Slip days let you turn in a homework late and receive no penalty

- Each student gets **3 slip days**
  - Apply to **labs**
  - You don’t need to tell us you’re using them, we’ll just automatically apply them at the end of the year
  - Be sure to coordinate about them on partner assignments

- Examples:
  - Turn in Scheduling Lab three days late
  - Turn in Scheduling Lab two days late and Paging lab one day late
  - Turn in Paging Lab four days late with only a one-day penalty

Academic integrity

- This is something I take very seriously

- Collaboration good; plagiarism bad
  - You should know where that line is, and be nowhere near it
  - When in doubt, ask the instructor *before* you do something you're not sure about

- At no point should you see someone else's solutions
  - Not your colleagues', not your friends', not your cousin's, not something you found online

- I report everything suspicious to the dean

Expectations

- Give yourself time to complete labs
  - Dealing with C code
  - Handling a large code base
  - Dealing with concurrency!!
  - You'll learn a lot through the challenge
- Don't fall behind on lecture materials
  - Material builds on itself, like in CS213
- Use course staff to help you out
  - Office hours & Campuswire are for your benefit

Break + First Tasks

1. Getting Started Lab
   - Makes sure you've got everything set up to do all the labs
   - Should be available later today
   - Get this done on time

2. Find partner(s) for assignments
   - We'll put out a form in the next few days if you don't know people in the class

Outline

- What is an OS?
- Logistics
- **Operating Systems History**
- CS343 Focus

Computer History

- Check out the textbook!
  - In-depth history
  - Entertaining writing with *just* the right amount of sarcasm

- This isn’t a computer history course
  - But there is a good reason to understand the lineage of the techniques we explore in this course

Early evolution of computing systems – Batch

- 1955: Batch systems
  - Collect a bunch of program punch cards and write them all one magnetic tape.
  - Run the tape through the mainframe to execute all the jobs in sequence.

- OS responsibility
  - Libraries for I/O

- Problems
  - I/O is VERY slow. 80-90% of total time just waiting.

Early evolution of computing systems – Multiprogramming

- 1960s: Multiprogramming (IBM OS/360)
  - Keep multiple runnable jobs in memory at once.
  - Allows overlap I/O of one job with computing of another.
    - Uses asynchronous I/O and interrupts or polling to detect I/O completion
- OS responsibility
  - Schedule jobs
  - Monitor I/O
- Problems
  - Still need to submit all jobs in advance

Early evolution of computing systems – Timesharing

- 1960s-70s: Timesharing (MULTICS, Unix)
  - Multiple user terminals connected to one machine
  - Allows *interactive* use of machine to be efficient (because another user’s job can run while you’re thinking).

- OS responsibility
  - Multiple users (with permissions!)
  - Scheduling processes
  - Application interface
  - Shell tools

Later evolution of computer systems – PC

- 1980s-90s: Personal Computers (IBM PC, Macintosh)
  - Graphical user interfaces were developed
  - Mainframe OS concepts (like networking) were applied to PCs
  - Magnetic disks (hard drives) become huge, but still slow

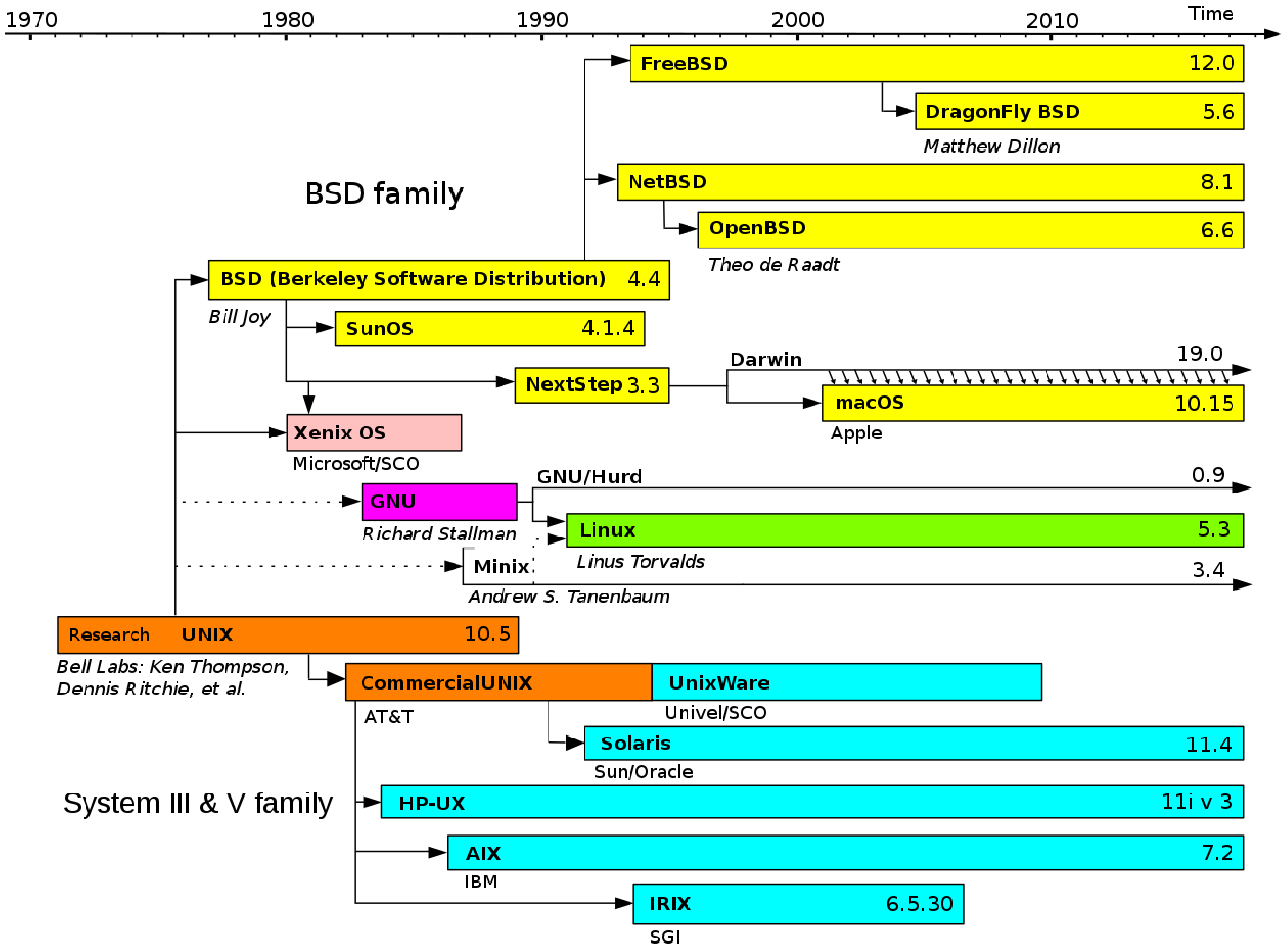
- OS responsibility
  - Look and feel of a system, particularly for non-experts
  - Tools that were distributed with the OS had significant business results

Later evolution of computer systems – Mobile and Cloud

- 2000s-10s: Mobile and pervasive computing, Cloud Computing
  - Slow hardware is once again common (phones & wearables)
  - OS manages sensitive information like location and internet behavior
  - Fast flash storage is common.
  - Server hardware is shared by many different cloud computing customers

- OS responsibility
  - Diverse hardware drivers
  - Security
  - Massive parallelism

Simplified History of Unix-like Operating Systems

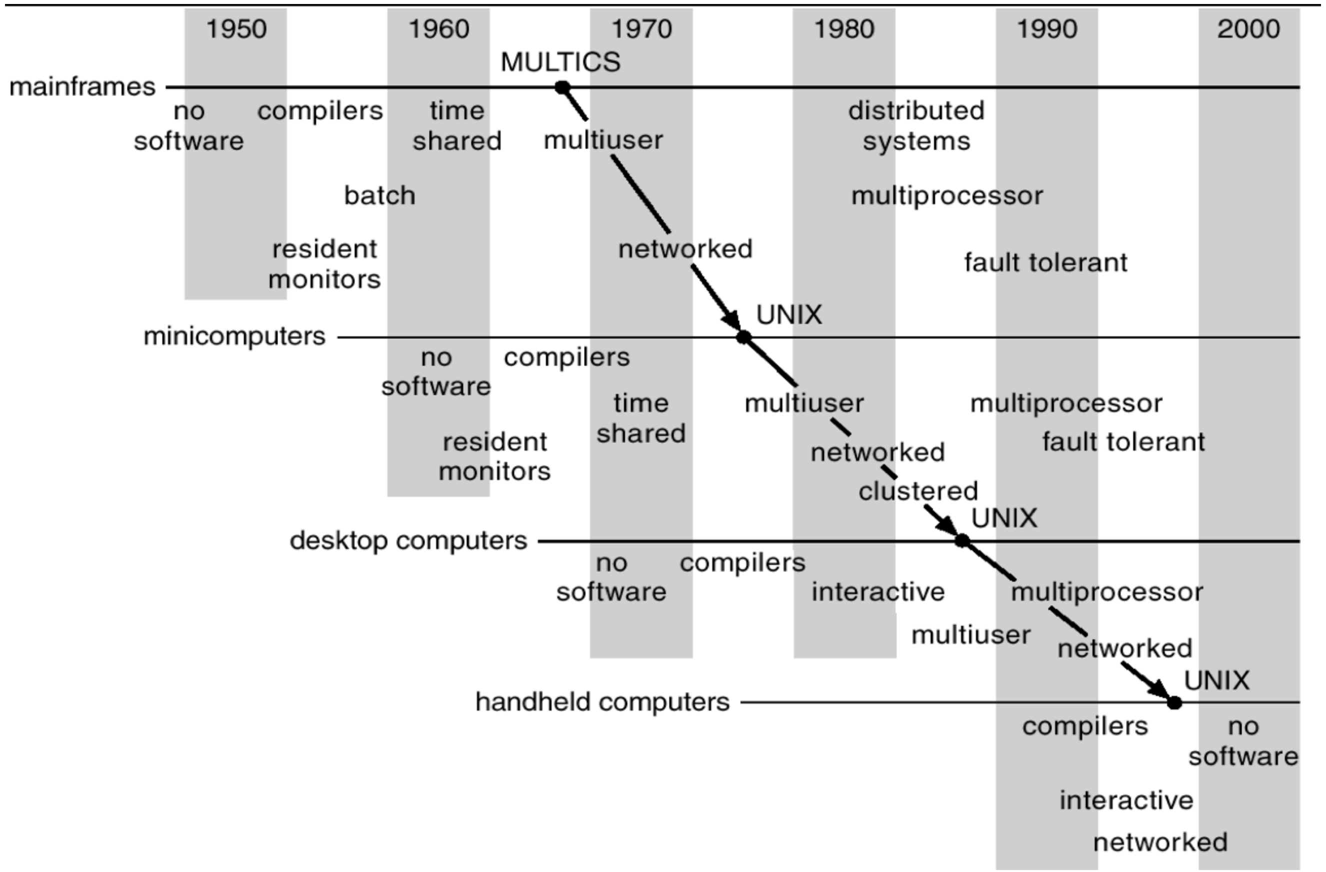


Operating systems are very interconnected

Android Operating System

- Kernel - Linux
  - With modifications particularly in power management
  - And additional drivers
- Distribution
  - Look and feel of “Android”
  - App framework
  - Some of this changes per vendor (Samsung vs Google)

Operating systems have evolved with hardware in a cycle



- Sophisticated operating systems first arose on mainframes.
- OS ideas migrated to smaller machines as those machines became more powerful.
- In 2019, a **smart watch** has 1 GB RAM, 16 GB SSD storage, two CPU cores, and a real OS.

Future OS directions

- Manage increasingly specialized hardware
  - Post-Moore's law, general-purpose CPUs loose out to special-purpose chips
  - OS must maintain abstractions while enabling capabilities

- Energy as another resource
  - Already considered in laptop/smartphone worlds
  - Increasingly important to data center operations as well

- Very small-scale, ubiquitous devices
  - Computers are becoming part of everything around us
  - How do we develop applications for those devices and coordinate them?

Outline

- What is an OS?
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- **CS343 Focus**

Schedule for first half of the course

1. Concurrency
   - Dealing with the realities of modern-day computing
   - Sources, Control, Challenges

2. Scheduling
   - Managing CPU utilization
   - Workload, Queuing, Real-time

Schedule for second half of the course

3. Device Drivers
   - Management and abstraction of devices
   - Interrupts, DMA, Abstractions

4. Virtual Memory
   - Management and abstraction of memory
   - Paging, Allocation, Security

5. File Systems
   - Management and abstraction of data
   - Principles, Examples

Why do we care about OS?

- Performance
  - Speed is influenced by
    - Parallelism, resource contention, memory management
    - Generally OS overhead
- Security
  - Process and data isolation when actually all running together
  - The biggest security vulnerabilities break abstractions
    - Meltdown and Spectre

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