Lecture 01: Introduction

CS343 – Operating Systems

Branden Ghena – Fall 2024

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

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

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: Microcontroller System Design
    - CS397: Wireless Protocols for the IoT

Things I love

Cosmere

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

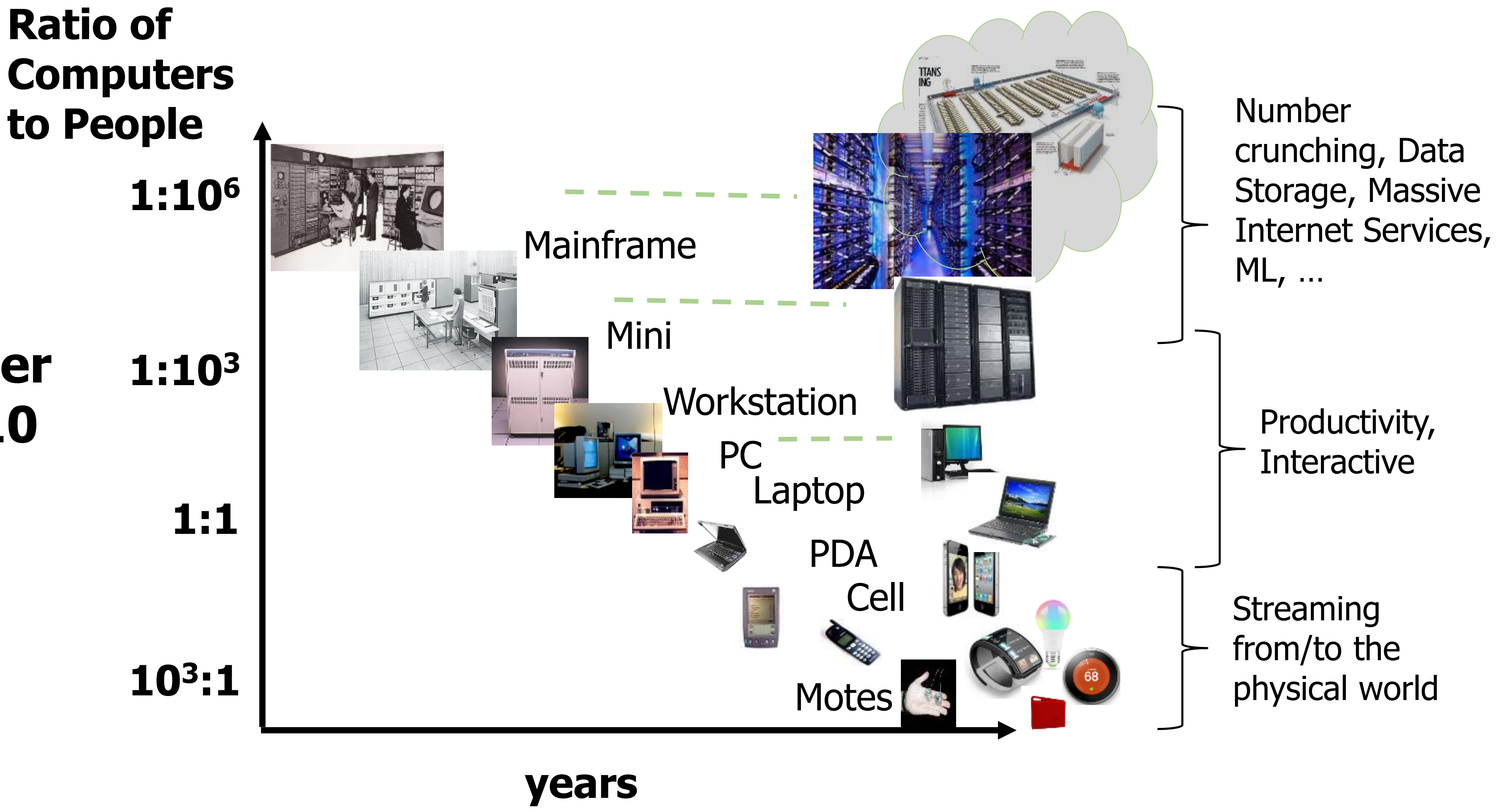
- Explore trends in OS history

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?

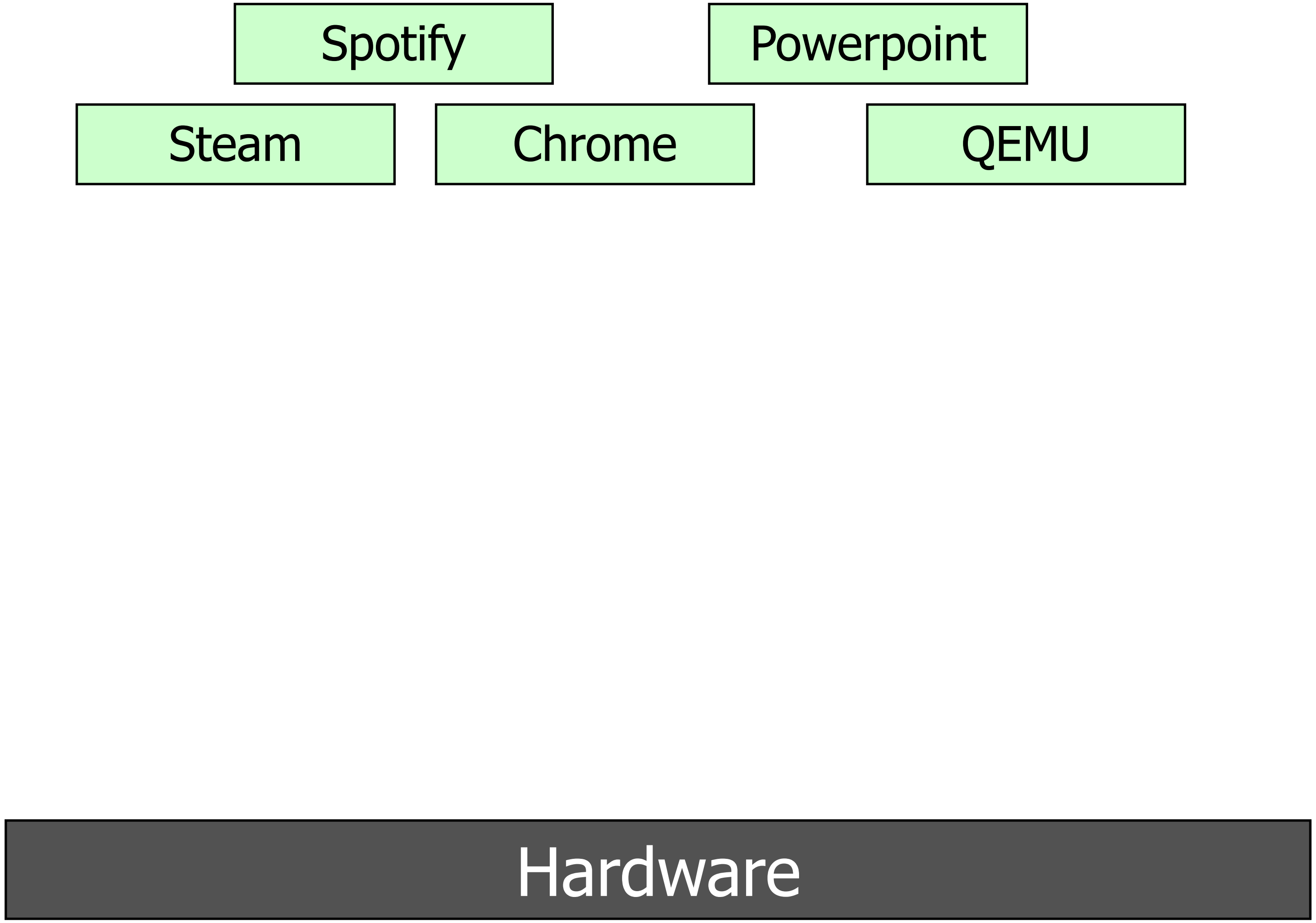
  2. Manage **sharing of resources** across many applications
     - Why: protect applications, enforce fair access
     - Challenges: What are the mechanisms and what are the policies?

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

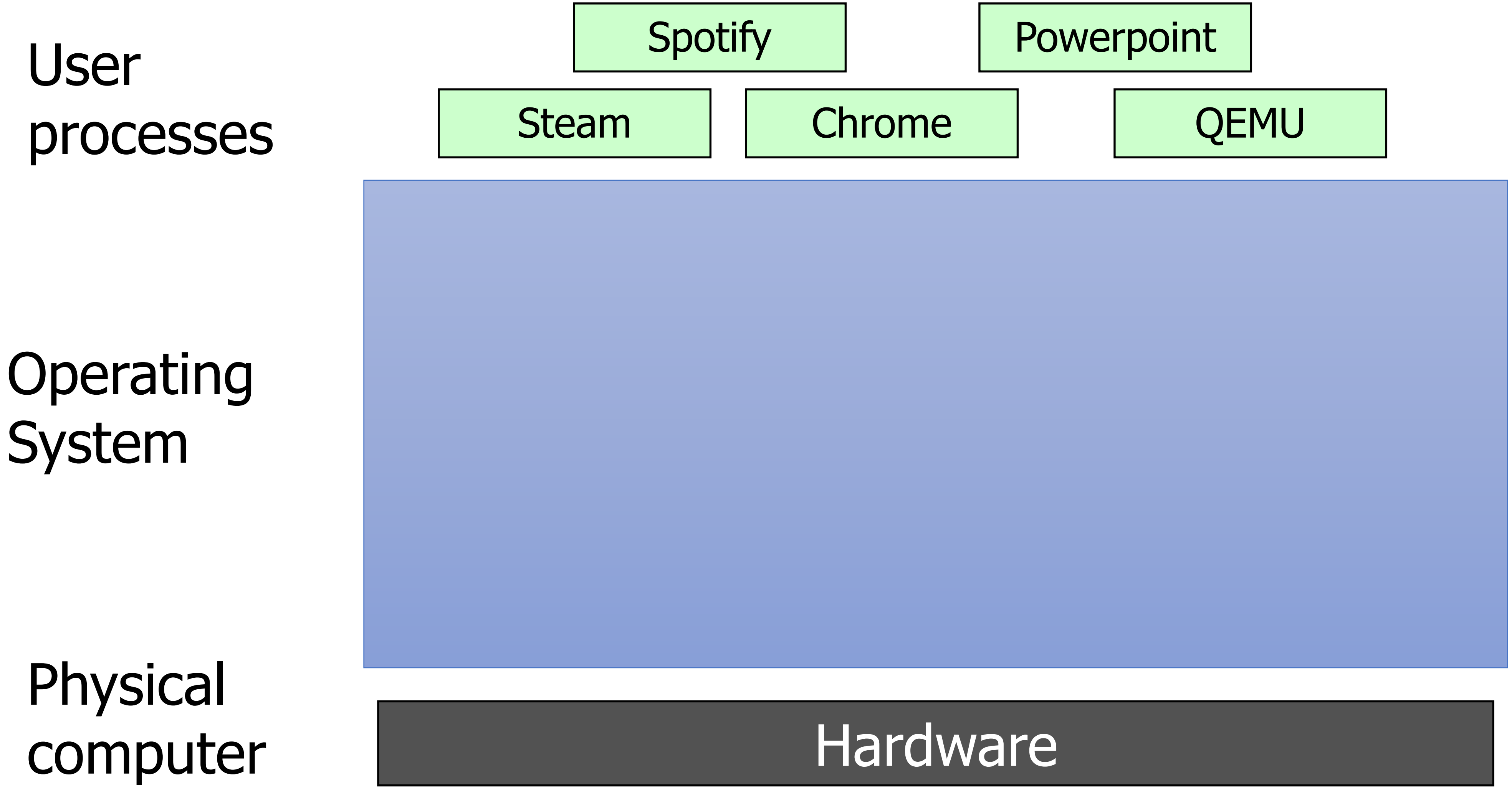
What is an operating system?

User processes

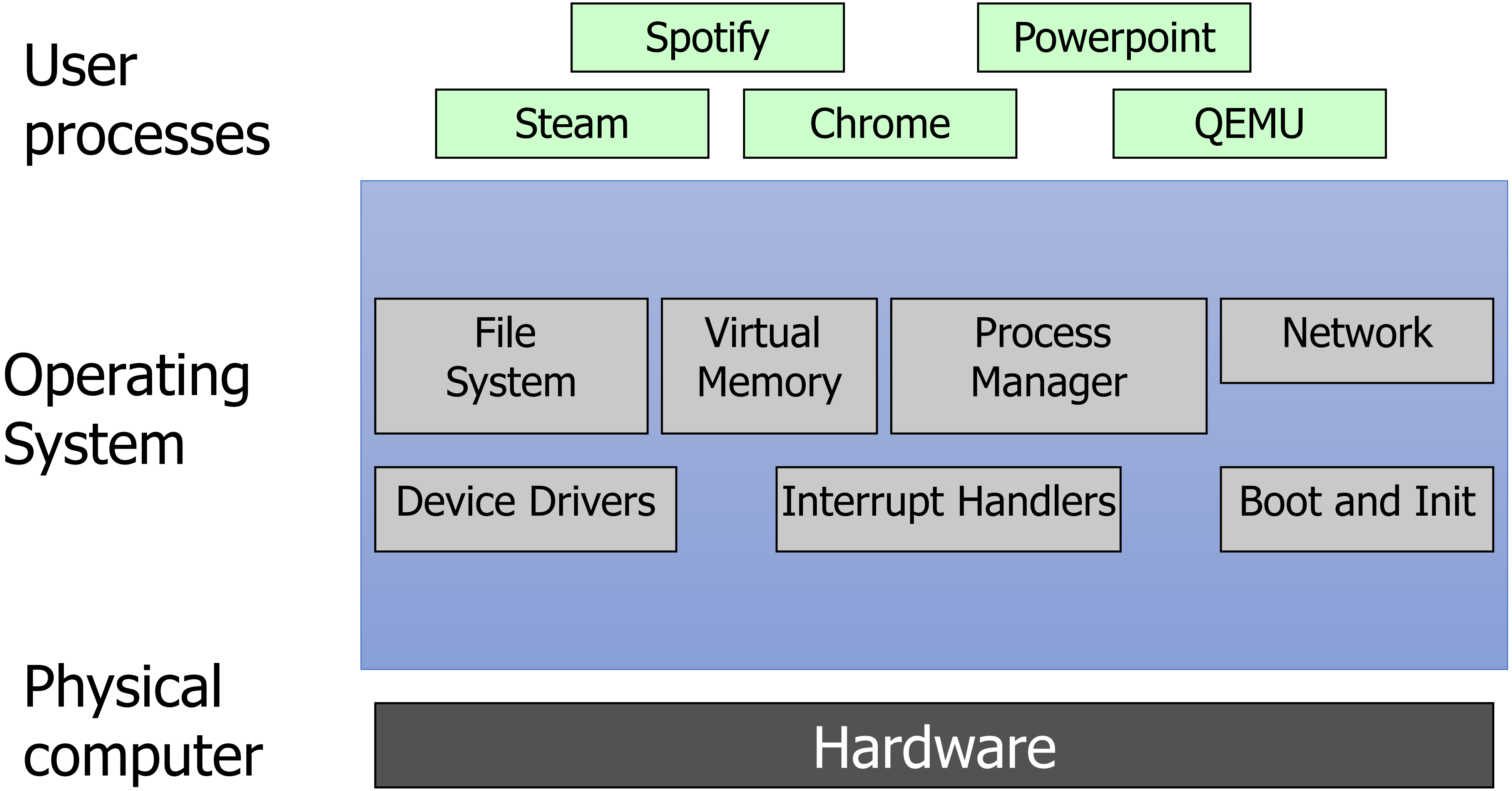
Physical computer



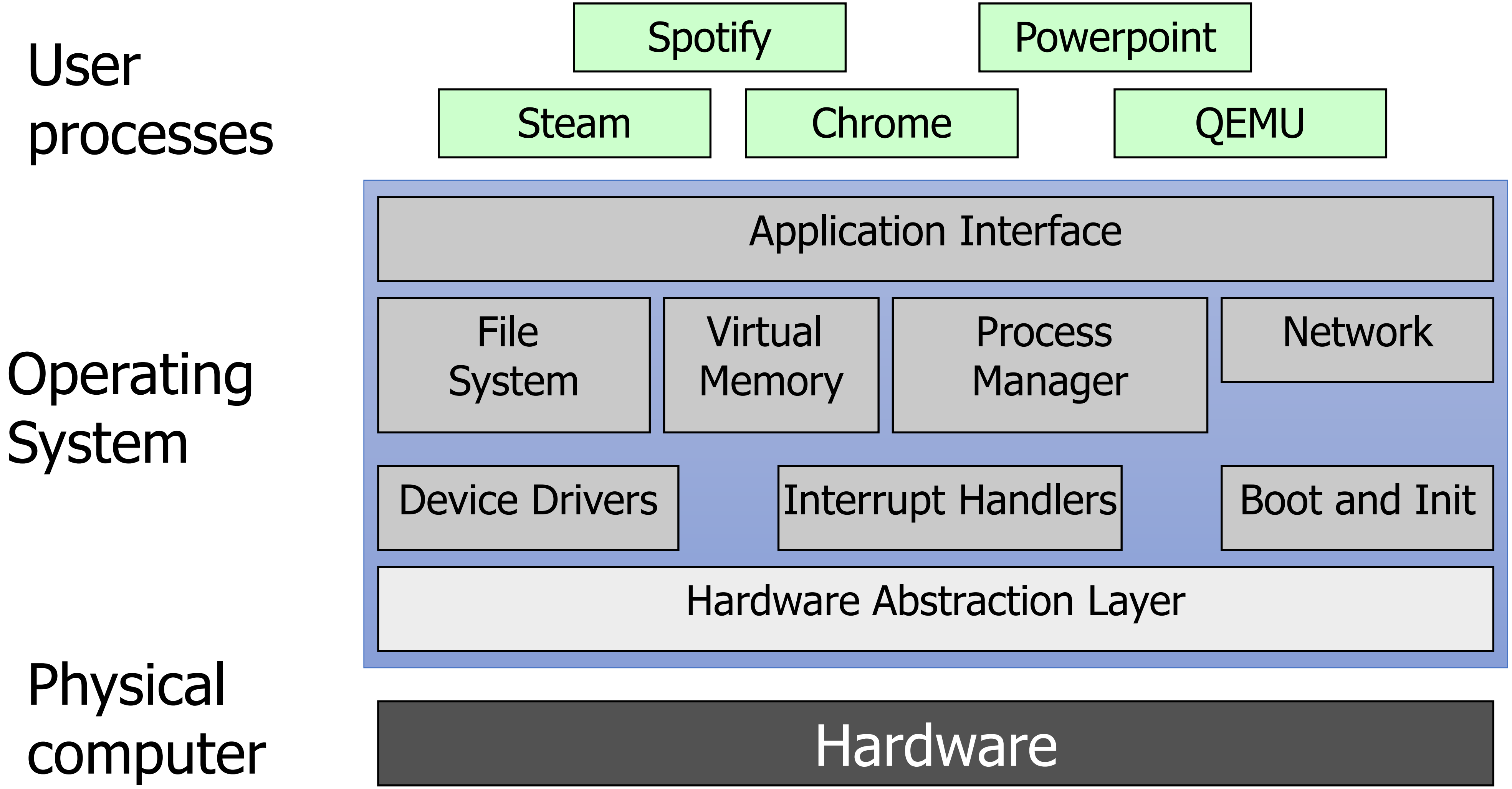
What is an operating system?



What is an operating system?



What is an operating system?



What's part of the OS?

- **OS** **kernel** – the part of the OS code that has full control of the system

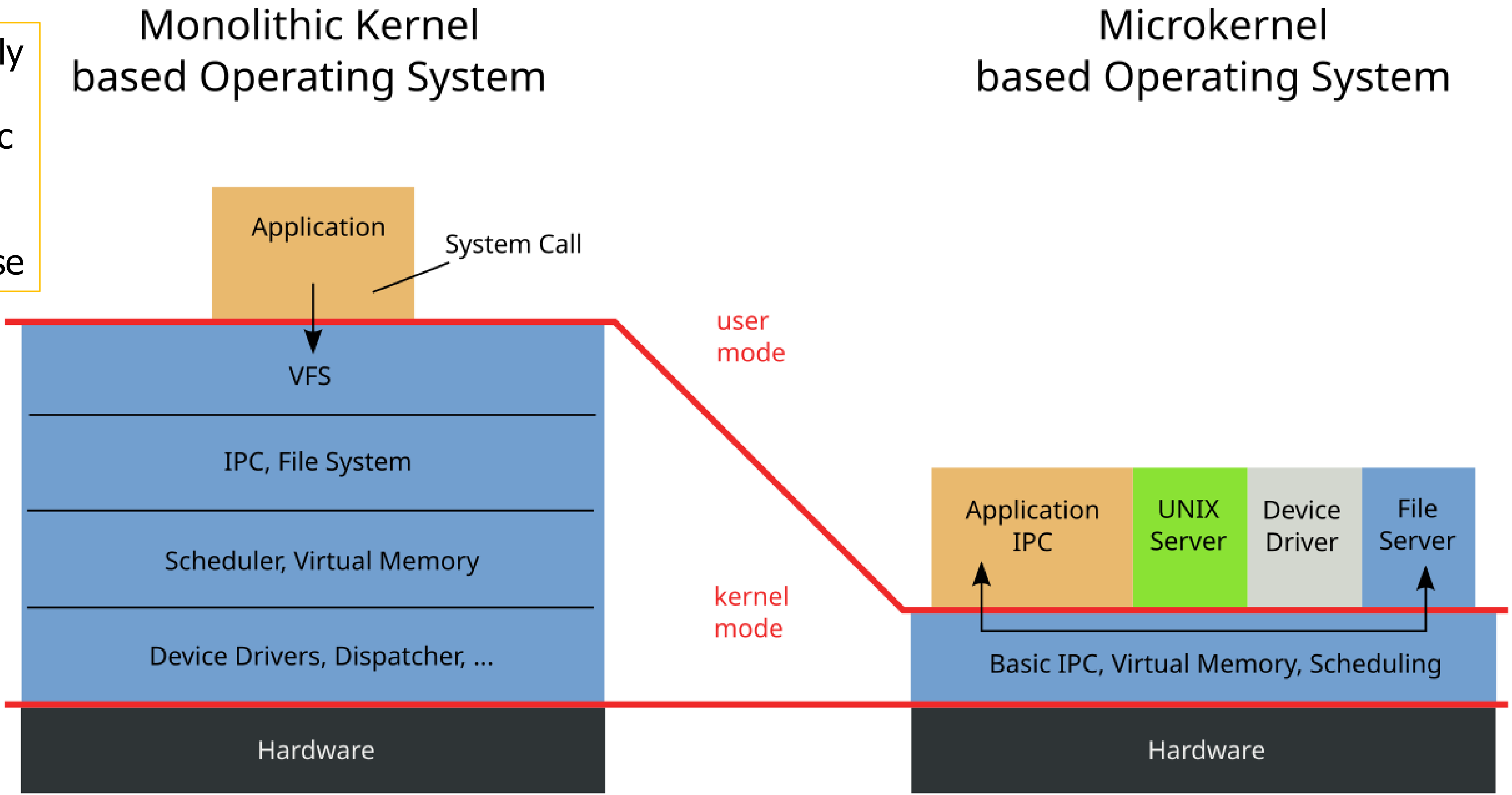
- Process scheduling (who uses CPU)
- Memory allocation (who uses RAM)
- Accesses hardware devices
  - Outputs graphics
  - Reads/writes to network
  - Read/write to disks
  - Handles boot-up and power-down

- **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,

Kernel design choices can vary

We usually focus on Monolithic kernel design in this course



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 still run without operating systems

- “Bare-metal” embedded systems
  - Many downsides:

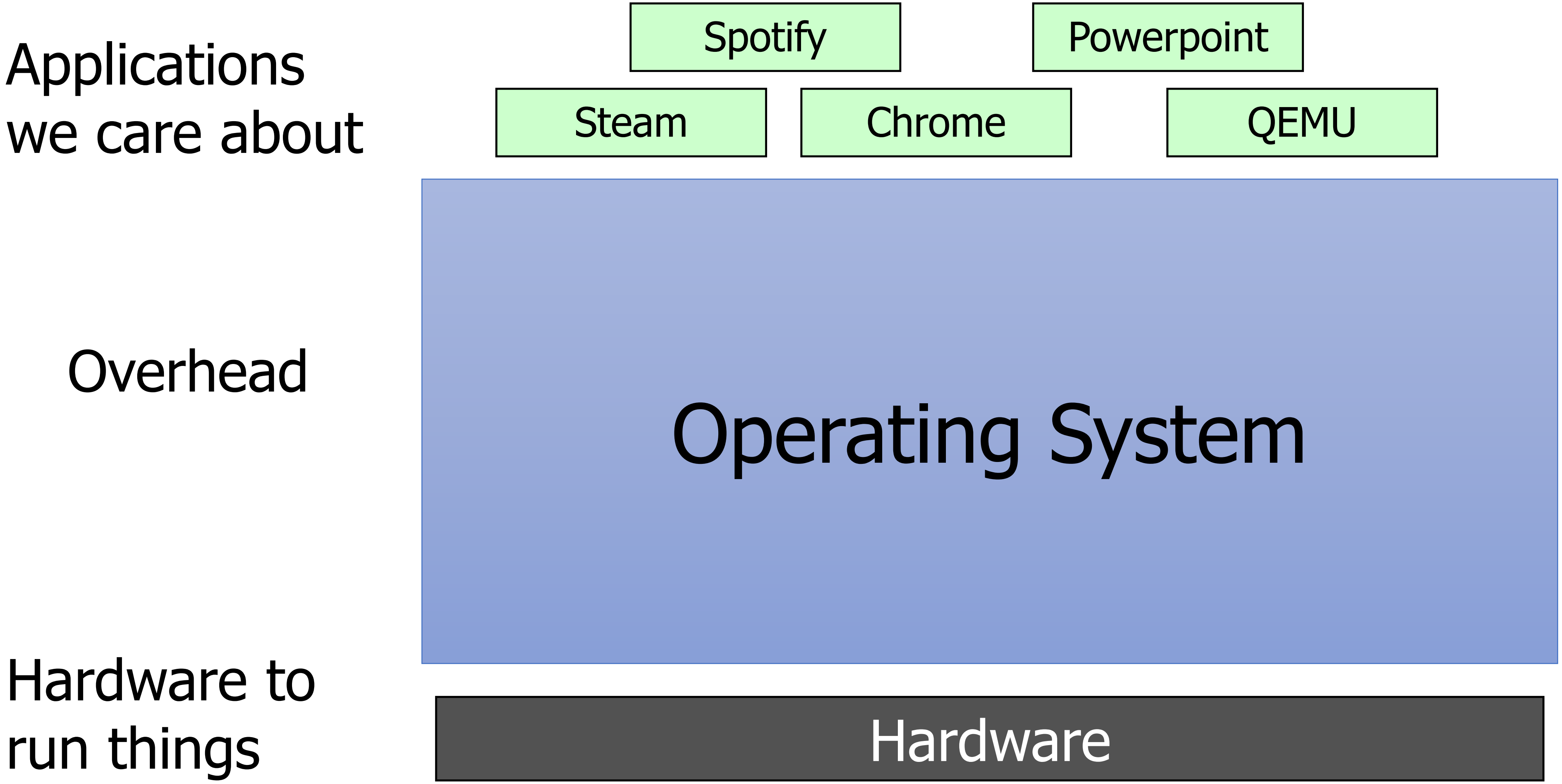
  - Application must handle things for themselves
    - Boot and initialization
    - All hardware it wants to interact with

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

  - No malloc, no segfaults
    - Instead invalid memory accesses likely crash the whole system
    - Imagine if each CS211 segfault resulted in the EECS server rebooting…

- Upside: can be a VERY highly efficient system

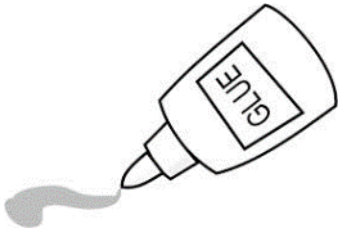
Operating Systems are middle-management



Roles of an Operating System give the overhead value

- 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

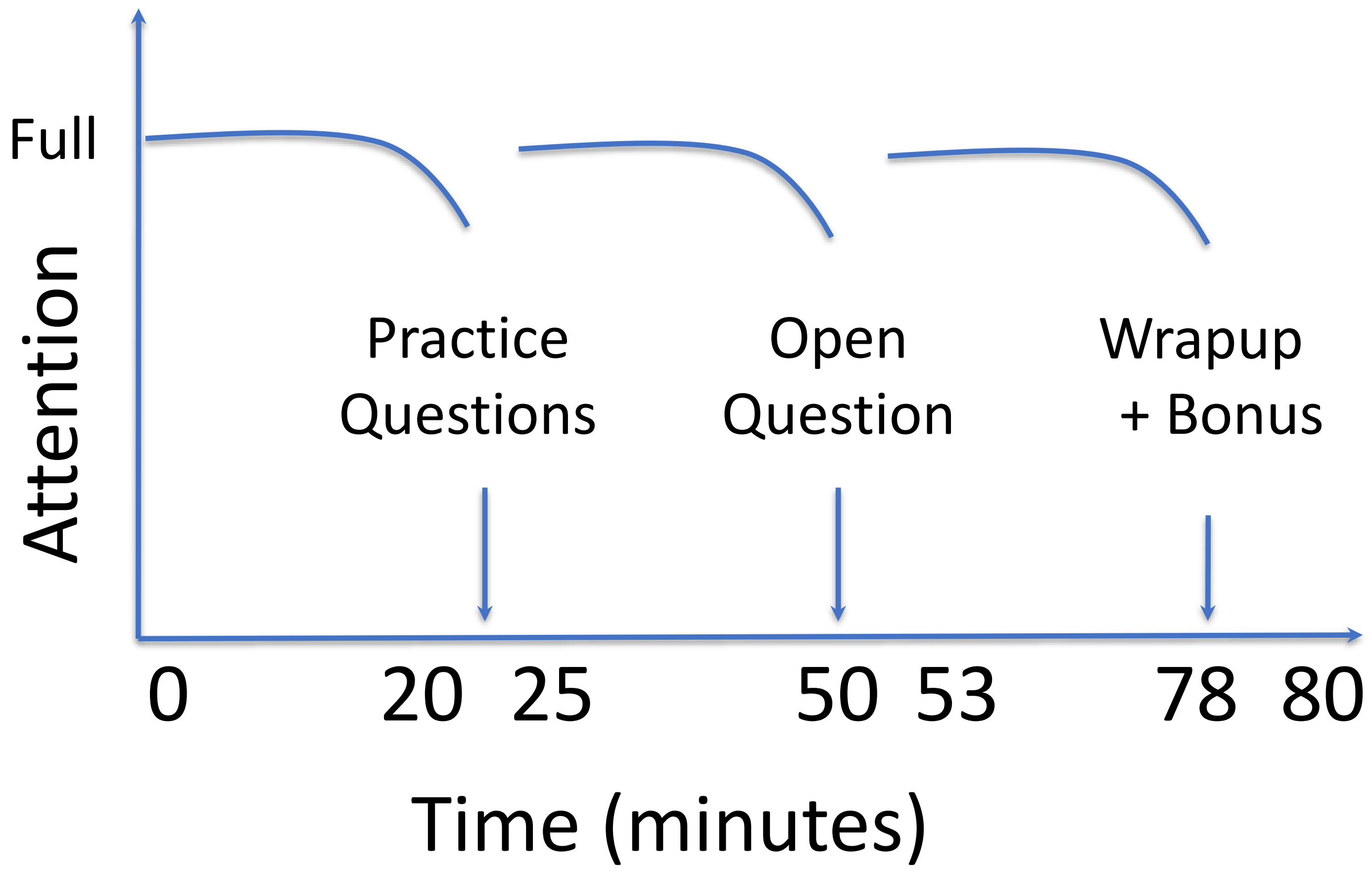


- Glue
  - Common services
    - Storage, Window system, Networking
  - Sharing, Authorization
  - Look and feel

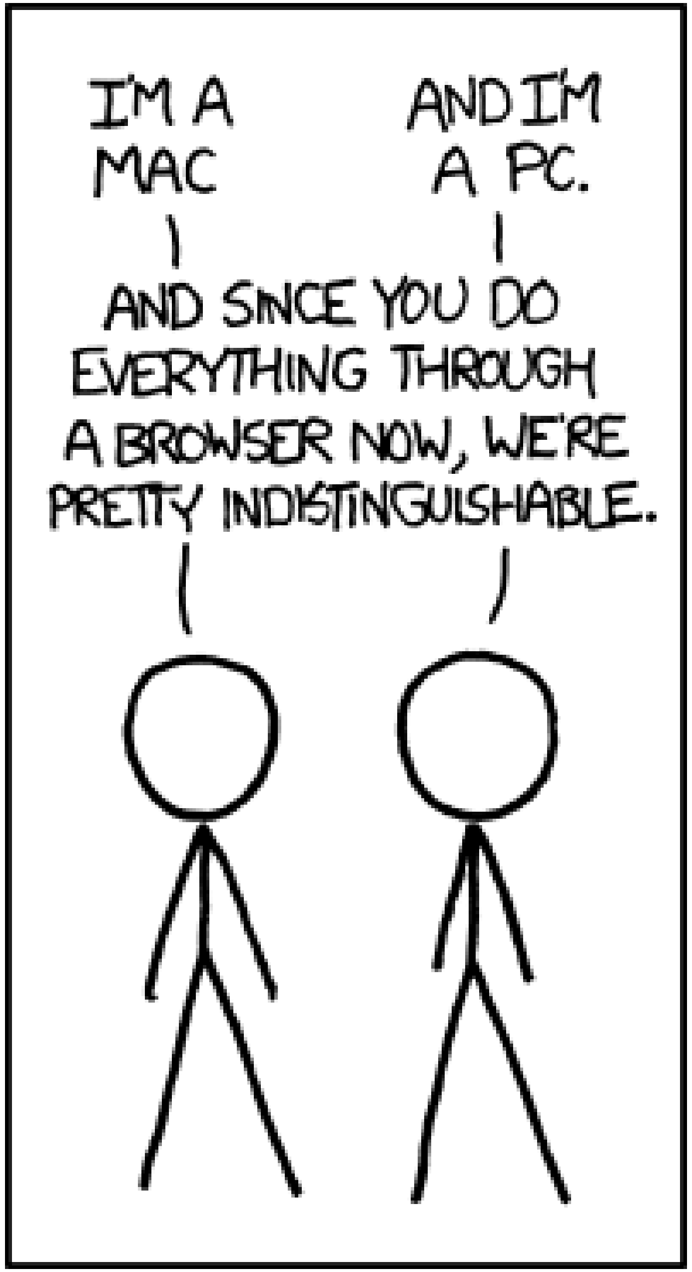
Example: File Systems

- 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, file explorer

Architecture of a lecture



Break + xkcd



https://xkcd.com/934/

Open question:

Are modern web browsers basically operating systems?

Outline

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

Course staff

- Teaching Assistant
  - Connor Selna
    - PhD student in systems
- Peer Mentors (8)
  - Blake Hu
  - Emily Wei
  - Ethan Havemann
  - Jason Lu
  - Kevin Hayes
  - Max Glass
  - Natalie Hill
  - Robert Pritchard

Their role: support student questions via office hours and Piazza

We’ll have lots of weekly office hours blocks for you to get help from them

Course Details – how to learn stuff

- Lectures: here Tuesdays and Thursdays
  - Provides background on materials
  - Attend and ask questions!
  - Panopto tab on Canvas should have best-effort recordings (a few hours later)
  - I also post the slides right before class to the Canvas homepage

- 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

- Office Hours: will start next week

Asking questions

- Class and office hours are always an option!
  - I usually have time after class to answer a bunch of questions
  - Right after a break is a great time for questions too

- Piazza: (similar to Campuswire)
  - 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 Piazza instead!
  - Let me know if you don't have access. I'll update the roster

Course grade

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

- Exact number to letter mapping is a little flexible
  - But this course is NOT curved
  - Only flexible in your favor

Midterm exams

- Test on your knowledge of course material (like a 213 exam)
  - 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: October 22^{nd} (Tuesday)
  - Week before the drop deadline
- Second midterm, exam week: December 11^{th} (Wednesday)
  - Make sure you can be here in-person for it!

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
    - Pair programming more often results in code written right the first time

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 10/03)
  - Must do alone
  - All-or-nothing grading
  - (Doesn't take very long usually)

- Normally teams of 2 or 3 students
  - Find partners now!
  - We'll put out a survey soon for those who don't know anyone

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 Piazza)

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 five days late with only a two-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, not something you asked AI to create

- 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 & Piazza are for your benefit

Break + First Tasks

1. 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

2. Take a break, chat with your neighbors, look at your phone, reset your brain for a minute

3. Getting Started Lab should be up on Thursday

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 managing Input/Output (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

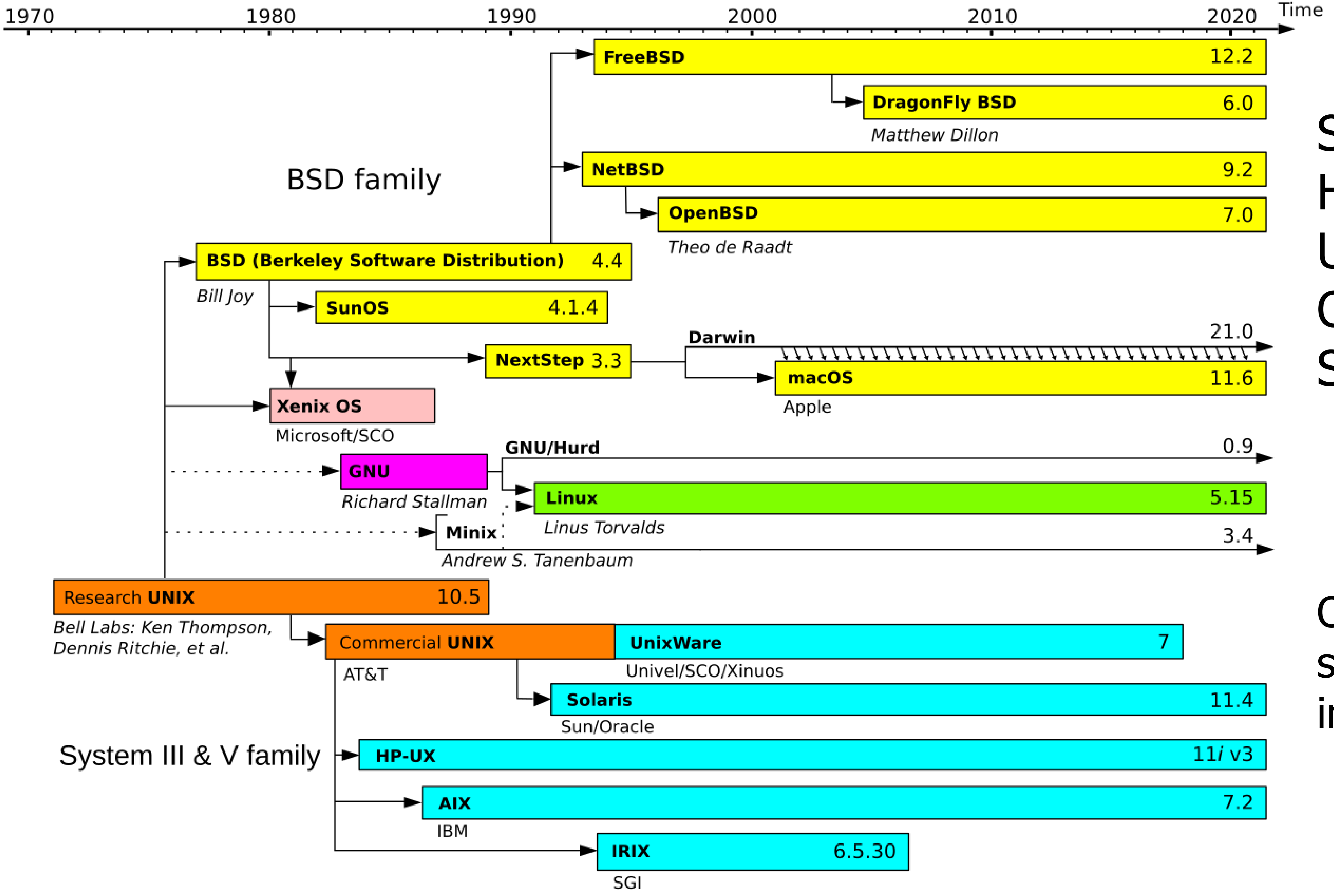
- OS responsibility
  - Schedule jobs
  - Monitor I/O

- 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

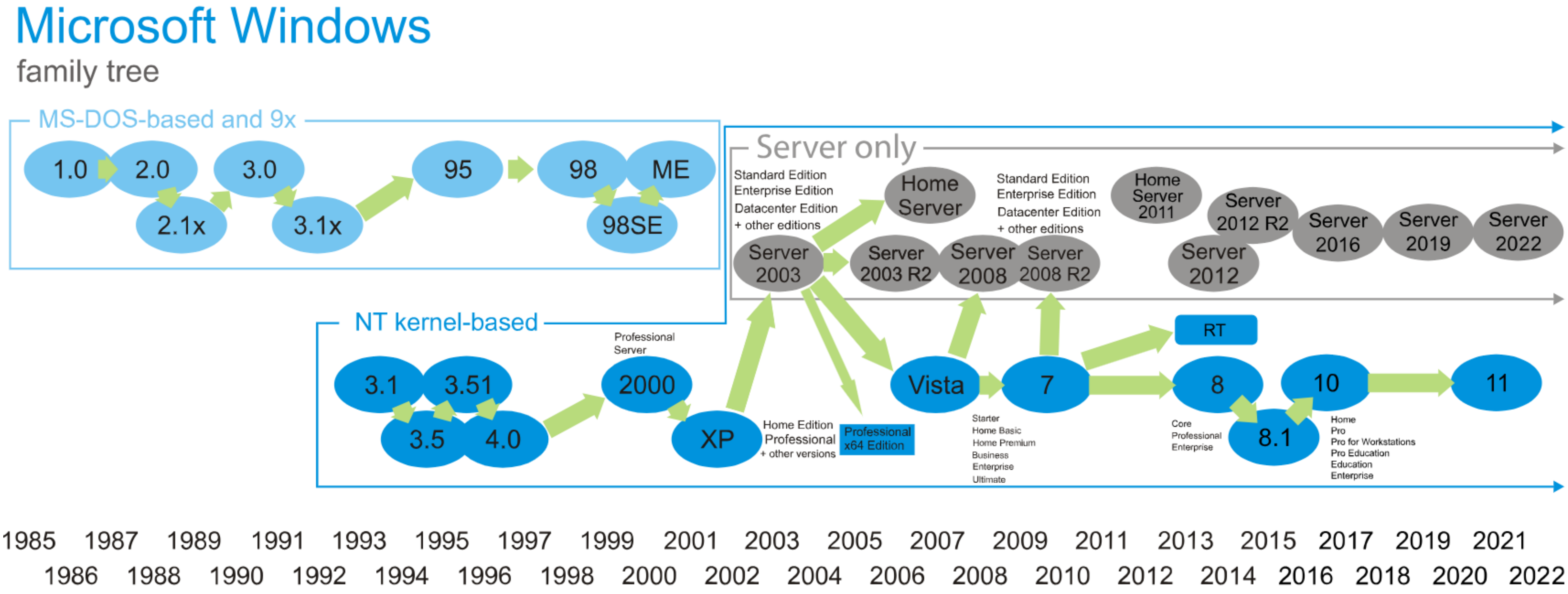


Simplified History of Unix-like Operating Systems

Operating systems are very interconnected

Legacy of Windows

- Entirely separate from Unix family tree
- DOS was the original kernel, followed by NT
  - Server has a separate OS, based on NT with some updates from it



Later evolution of computer systems – PC

- 1980s-00s: Personal Computers (IBM PC, Macintosh)
  - Graphical user interfaces were developed
  - Mainframe OS concepts (like networking) were applied to PCs
  - Magnetic disk (hard drive) capacity becomes 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
    - Computers are bought for Excel or for Lotus 1-2-3

Later evolution of computer systems – Mobile and Cloud

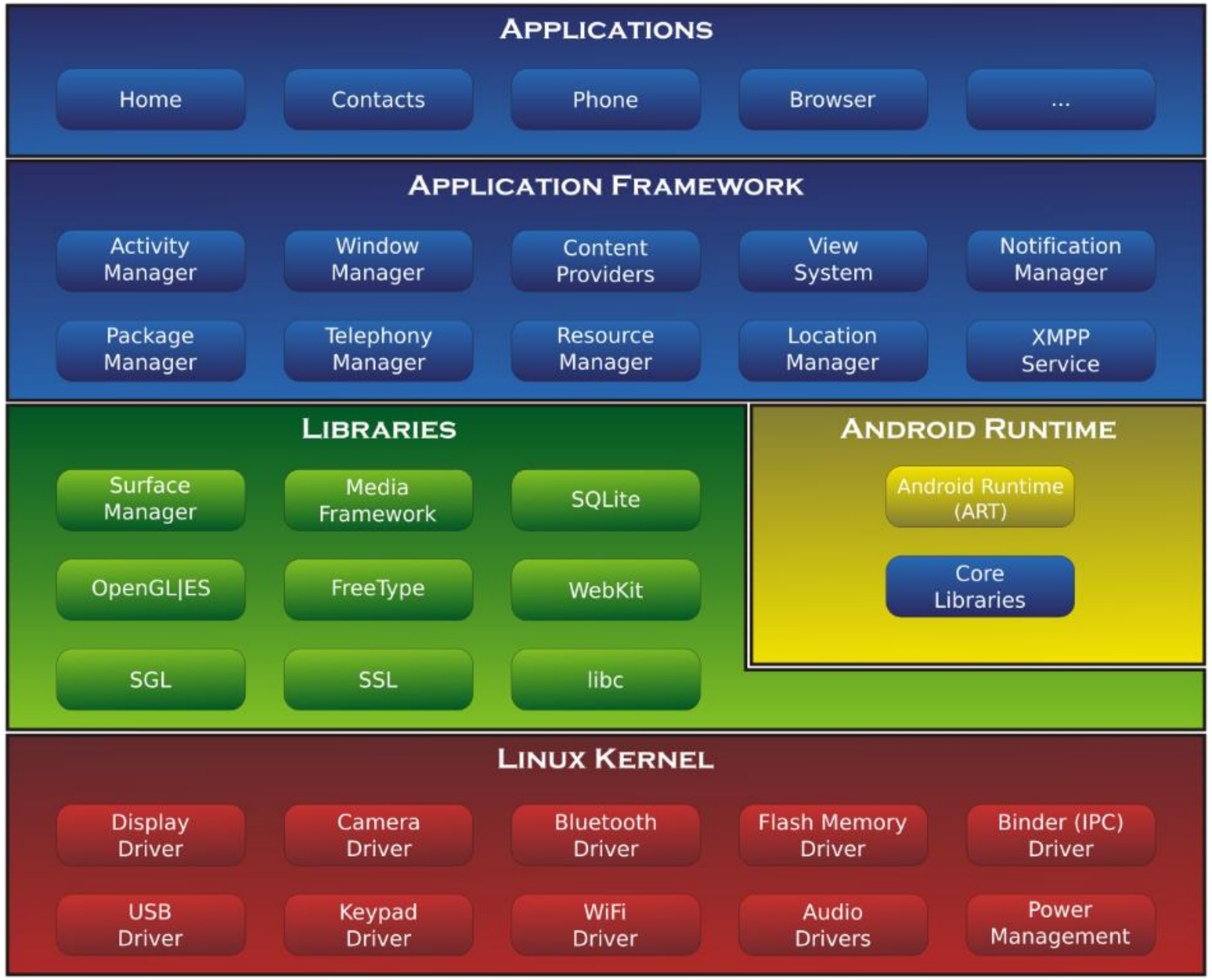
- 2000s-20s: Mobile and pervasive computing, Cloud Computing
  - Slow hardware is once again common (phones & wearables)
  - OS manages sensitive information like location and internet behavior
  - Fast flash storage is common.
  - Server hardware is shared by many different cloud computing customers

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

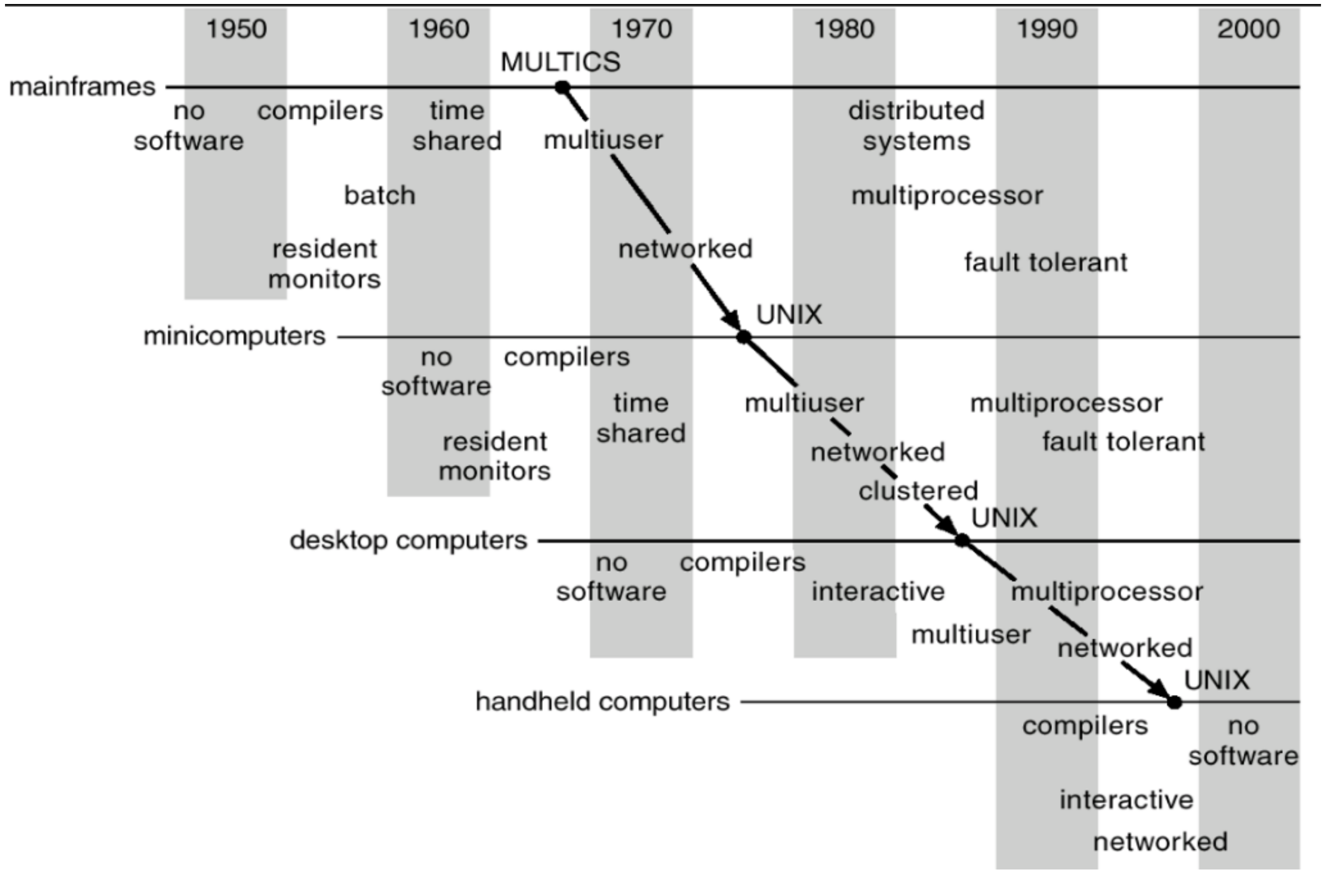
An example: Android Operating System

- 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 2024, a **smart watch** has 1 GB RAM, 32 GB SSD storage, two CPU cores, and a real OS.

Some future OS directions

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

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

3. 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?
- Logistics
- Operating Systems History
- **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

- Systems Design and Implementation
  - Maybe you won’t ever build an OS (maybe you will!)
  - But you might work on other large, backend systems that will deal with similar concerns. This is good practice!

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