CSE 451: Operating Systems
Autumn 2019

Module 1
Course Introduction

John Zahorjan
zahorjan@cs.washington.edu

Today's agenda

- Administrive Details
  - Course overview
    - course staff
    - general structure
    - the text(s)
    - policies
    - your to-do list
- OS overview
  - Trying to make sense of the topic

Course overview

- Operationally, everything you need to know will be on the course web page:

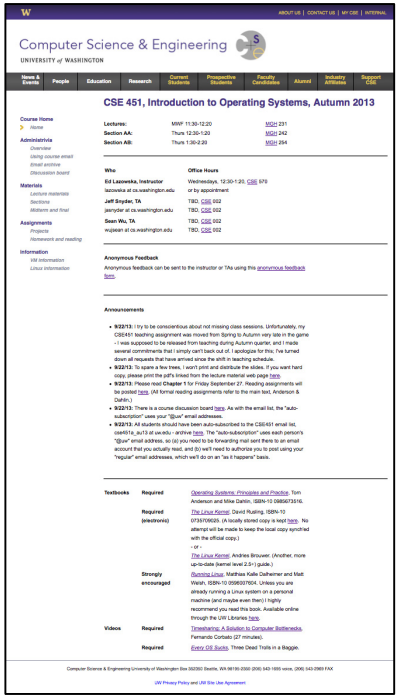
  http://www.cs.washington.edu/451/

- Or on the course email:

  cse451a_au19@uw.edu

- Or on the course discussion board:

  see course home page



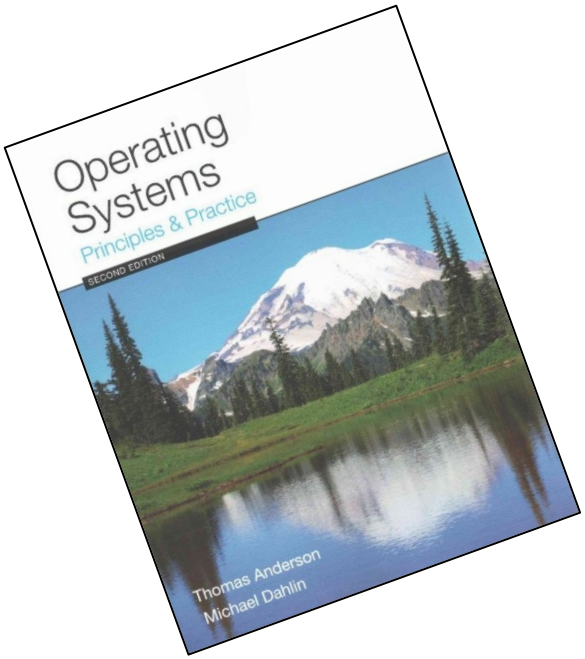
Course Staff (and non-staff)

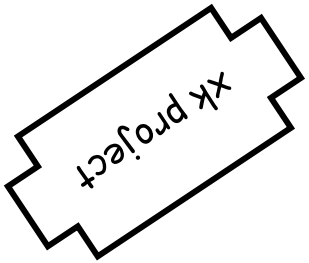
- Course staff
  - John Zahorjan
  - Will Ceriale
  - Porter Jones
  - Jonathan Jusuf
  - Arthur Liang
  - Tom Lou
- 78+ of you

Course Structure

- General Course Structure
  - PROJECTS
  - Lectures
    - Read the text prior to class
  - Sections
    - will focus on projects
  - Homework
    - may have exercises to cover material not emphasized by projects

Course Issue





Policy vs. Mechanism

- Policy is what you're trying to achieve
  - All users should get about the same amount of CPU time per second
    - Warning: that's a crude example, more of a goal than a policy. Actual policies later in the course.
- Mechanism is how you achieve that
  - The OS sets a hardware timer and switches tasks when it expires
- Roughly, class/reading is about policy, the projects are about mechanism

- The text
  - Really outstanding – written by current experts
    - Allows you to actually figure out how things work
  - Think of it as helping you to understand, and dig deeper than, the lecture, section, and project material
- Other resources
  - Many online; some of them are essential
- Policies
  - Collaboration vs. cheating
  - Projects: late policy

The Project(s)

- Start your projects early
- Projects
  - Start them early
  - Five of them
  - Start them early
  - Teams of two. You're likely to be happier if you form a team on your own than if we form one for you!
  - Do not start your project late. You will regret it.
  - Start them early

Late Policy

- There is one
- It's some balancing act of these principles
  - You know better than we do what all your responsibilities are
  - We owe it to you (and your partner!) to provide sufficient incentive to stay on schedule that you don't get yourself in trouble
- Don't get yourself in trouble!

Course Registration

- If you want to get into the class, you need to follow some procedure (that I hope you know!)
  - *The advisors run the show*

What is an Operating System?

- Answers:
  - I don't know.
  - Nobody knows.
  - The book claims to know – read Chapter 1.
  - They’re programs – big hairy programs
    - The Linux source has over 15M lines of C
    - Windows has way, way more…

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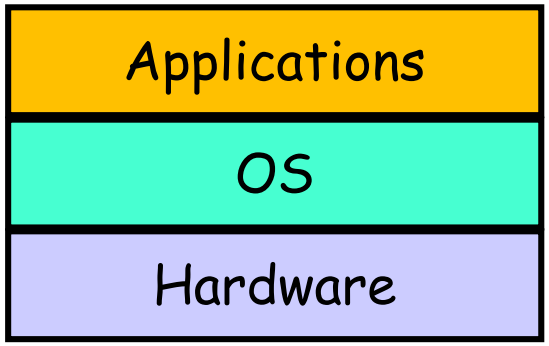
- Answers:
  - I don't know.
  - Nobody knows.
  - The book claims to know – read Chapter 1.
  - They’re programs – big hairy programs
    - The Linux source you'll be compiling has over 1.7M lines of C

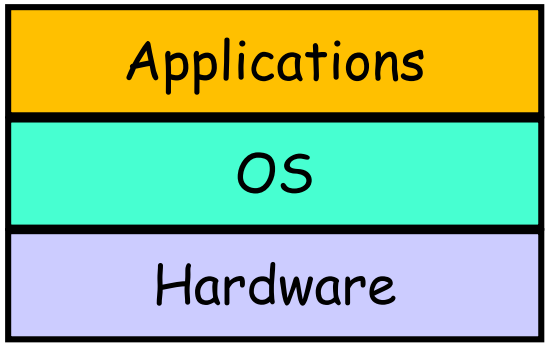
Okay. What are some functions/goals of an OS?

The Traditional Graphic



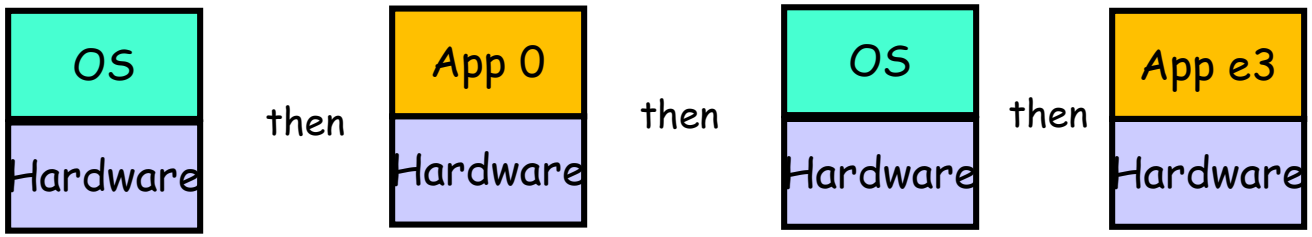
- This depiction invites you to think of the OS as a library
- (This depiction invites you to think of the hardware as a library...)

What's Right With That Picture



- The OS *is* between you (the app) and the hardware
  - Your application cannot manipulate the hardware, it has to ask (politely)
  - This is the basis of security
- The OS *is (partly)* a library
  - Some functionality is in the kernel because it turns out to be fastest to put it there, not because it absolutely has to be there

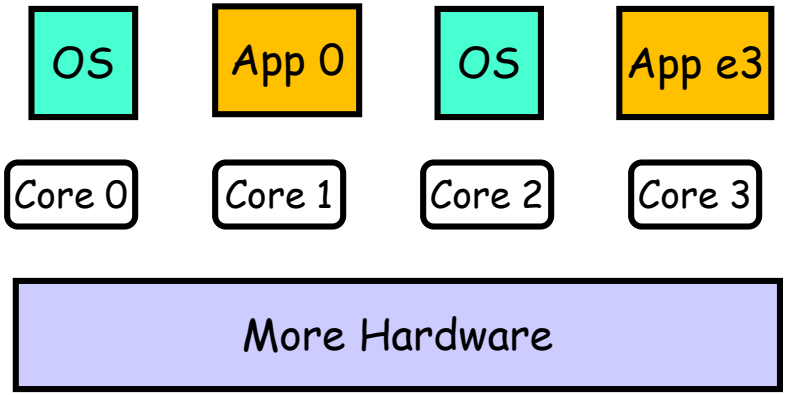
What's Wrong With That Picture



- The OS *isn't* between you and (some of) the hardware
  - When you're running, your code uses some of the hardware directly
    - Which hardware?
    - Why (not interpose the OS between you and that hardware)?
    - Why not have separate hardware for the OS and the apps?
- The OS *isn't* a library
  - You don't tell it when to run, it tells you when to run
  - You don't tell it what code to run, it makes up its own mind

What's Wrong With That Last Picture

- It's from 2004
  - Why take turns when we can all go at once?



Understanding Execution from the Software Point of View

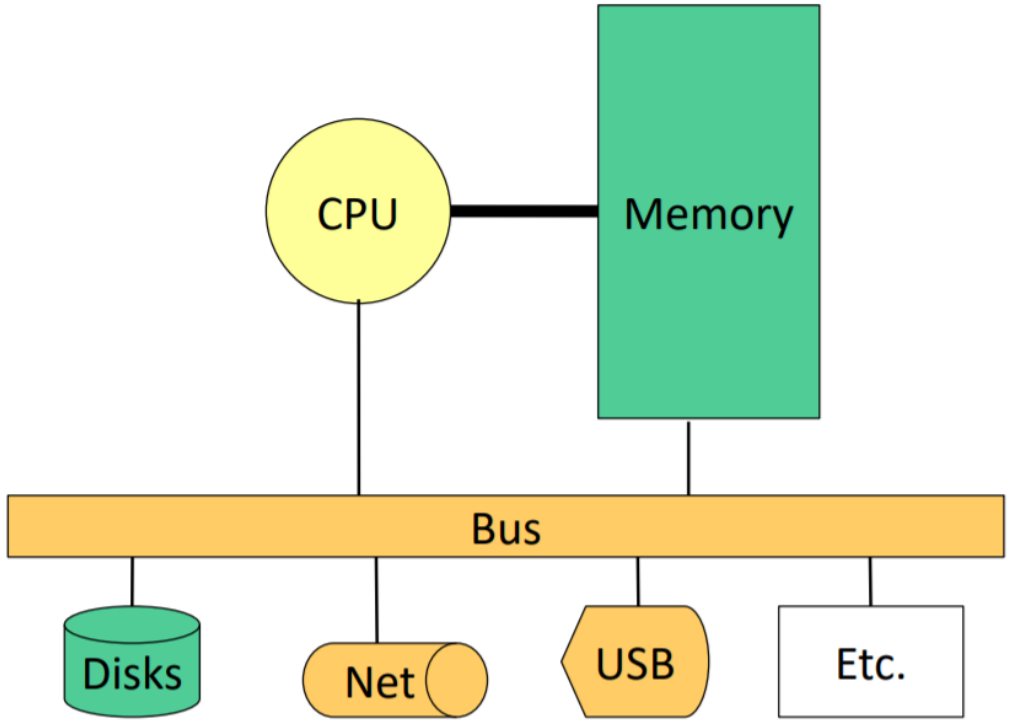
- I have values in local and global variables and you can't touch them. (You don't even exist.)
- I execute this instruction, then I execute the next instruction, sometimes I loop, sometimes I call, but it's all me and my code (unless I explicitly invoke some library code written by someone else)
- Okay, I know your program is running at the same time, but I don't care because you have no effect on me and I have no effect on you
  - *(This is one of the primary goals/abstractions of the OS)*

Understanding Execution from the Hardware Point of View

- Tick, tick, tick, ...
- Fetch an instruction, execute an instruction
  - Each instruction may modify some machine *state*
    - Update some value(s)
- From this point of view, there are no programs, there is no OS or application, there is just the current state of the machine and the next state
- *(However, the hardware is designed to enable us to write OS's and applications and do other useful things)*

The Abstract View of Hardware

Hardware: Logical View



The xk View of Hardware (Partial)

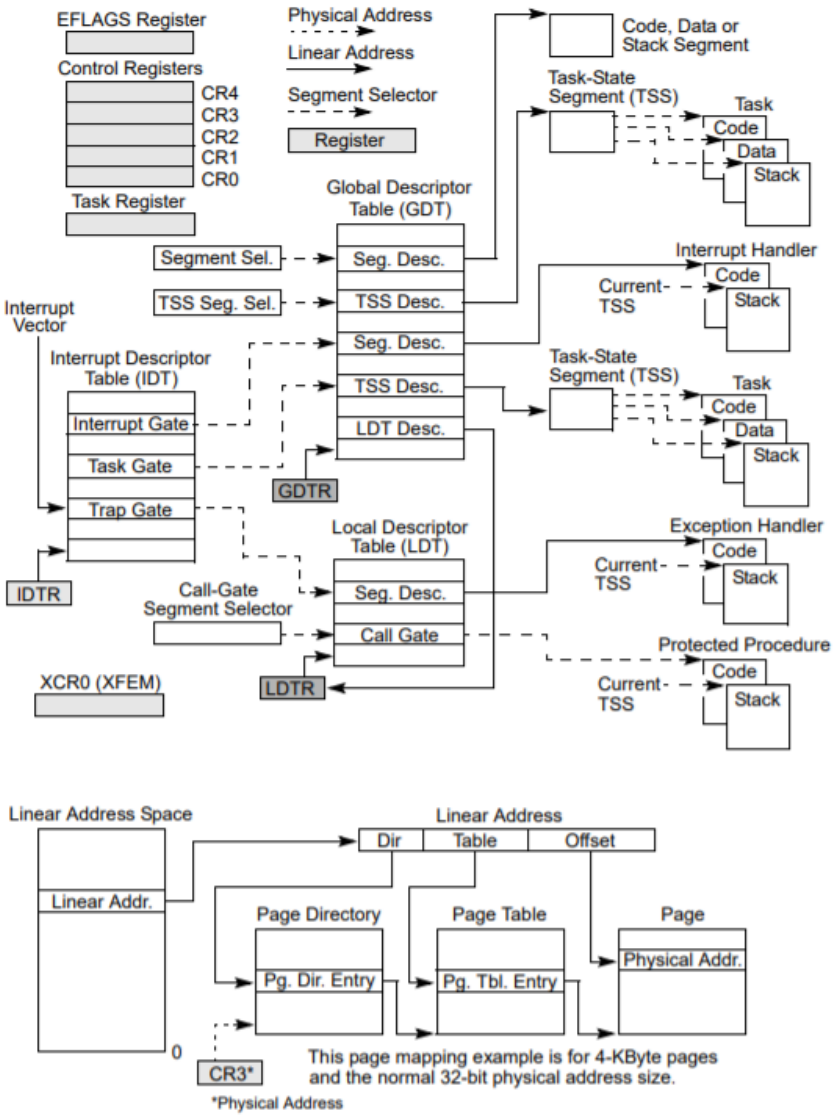


Figure 2-1. IA-32 System-Level Registers and Data Structures

The OS and Hardware

- An OS mediates programs' access to hardware resources (*sharing* and *protection*)
  - computation (CPU)
  - volatile storage (memory) and persistent storage (disk, etc.)
  - network communications (TCP/IP stacks, Ethernet cards, etc.)
  - input/output devices (keyboard, display, sound card, etc.)
- The OS abstracts hardware into logical resources and well-defined interfaces to those resources (*ease of use*)
  - processes (CPU, memory, instruction execution)
  - files (disk)
  - sockets (network)
  - streams (keyboard, display, sound card, etc.)

The text says an OS is …

- A Referee
  - Mediates resource sharing
- An Illusionist
  - Masks hardware limitations
- Glue
  - Provides common services

Why bother with an OS?

- Application benefits
  - programming simplicity
    - see high-level abstractions (files) instead of low-level hardware details (device registers)
    - abstractions are reusable across many programs
  - portability (across machine configurations or architectures)
    - device independence: 3com card or Intel card?
- User benefits
  - safety
    - program “sees” its own virtual machine, thinks it “owns” the computer
    - OS protects programs from each other
    - OS multiplexes resources across programs
  - efficiency (cost and speed)
    - share one computer across many users
    - concurrent execution of multiple programs

The Major OS Issues

- **structure**: how is the OS organized?
- **sharing**: how are resources shared across users?
- **naming**: how are resources named and what is the scope?
- **protection**: how is one user/process protected from another?
- **security**: how is the integrity of the OS and its resources ensured?
- **performance**: how do we avoid making it all slow?
- **availability**: can you always access the services you need?
- **reliability**: what happens if something goes wrong (either with hardware or with a program)?
- **extensibility**: can we add new features?
- **communication**: how do programs exchange information, including across a network?

More OS Issues…

- **concurrency**: how are simultaneous activities (computation and I/O) created and controlled?
- **scale**: what happens as demands or resources increase?
- **persistence**: how do you make data last longer than program executions?
- **distribution**: how do we allow a computation to span machine boundaries?
- **accounting**: how do we keep track of resource usage, and perhaps charge for it?
- **auditing**: can we reconstruct who did what to whom?

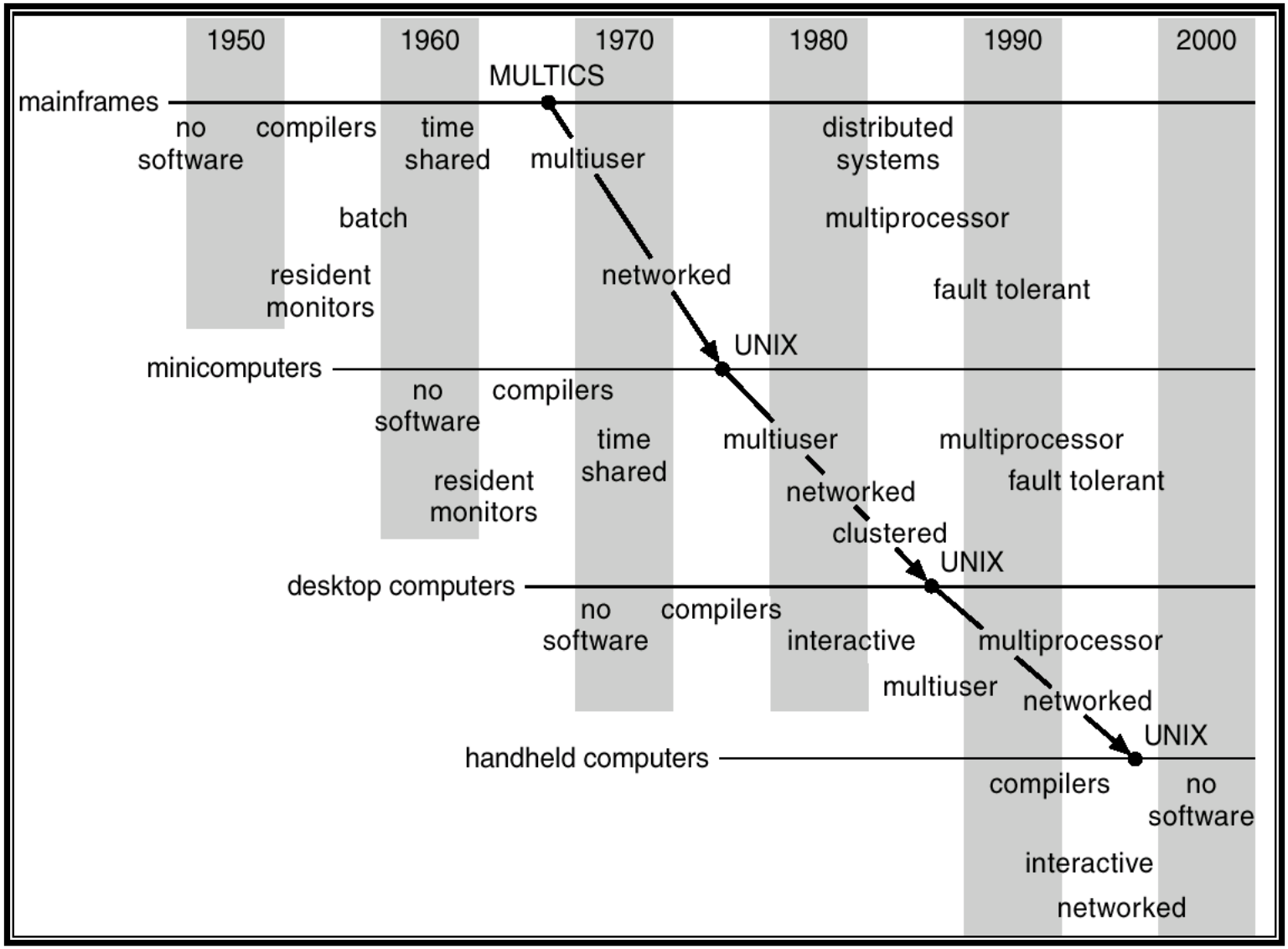
There are tradeoffs – not right and wrong!

(Ok, some things are clearly wrong, but there is no right.)

Hardware/Software Changes Over Time

- 1960s: mainframe computers (IBM)
- 1970s: minicomputers (DEC)
- 1980s: microprocessors and workstations (SUN), local-area networking, the Internet
- 1990s: PCs (rise of Microsoft, Intel, Dell), the Web
- 2000s:
  - Internet Services / Clusters (Amazon)
  - General Cloud Computing (Google, Amazon, Microsoft)
  - Mobile/ubiquitous/embedded computing (iOS, Android)
- 2010s: sensor networks, "data-intensive computing," computers and the physical world ("pervasive computing")
- 2020: it's up to you!!

Progression of concepts and form factors



Has it all been discovered?

- New challenges constantly arise
  - embedded computing (e.g., home assistants)
  - sensor networks (very low power, memory, etc.)
  - peer-to-peer systems
  - ad hoc networking
  - scalable server farm design and management (e.g., Google)
  - software for utilizing huge clusters (e.g., MapReduce, Bigtable)
  - overlay networks (e.g., PlanetLab)
  - finding bugs in system code (e.g., model checking)
  - high value real time systems (autonomous vehicles)
- Old problems constantly re-define themselves
  - the evolution of smart phones recapitulated the evolution of PCs, which had recapitulated the evolution of minicomputers, which had recapitulated the evolution of mainframes
  - but the ubiquity of PCs re-defined the issues in protection and security, as phones are doing once again

Protection and security as an example

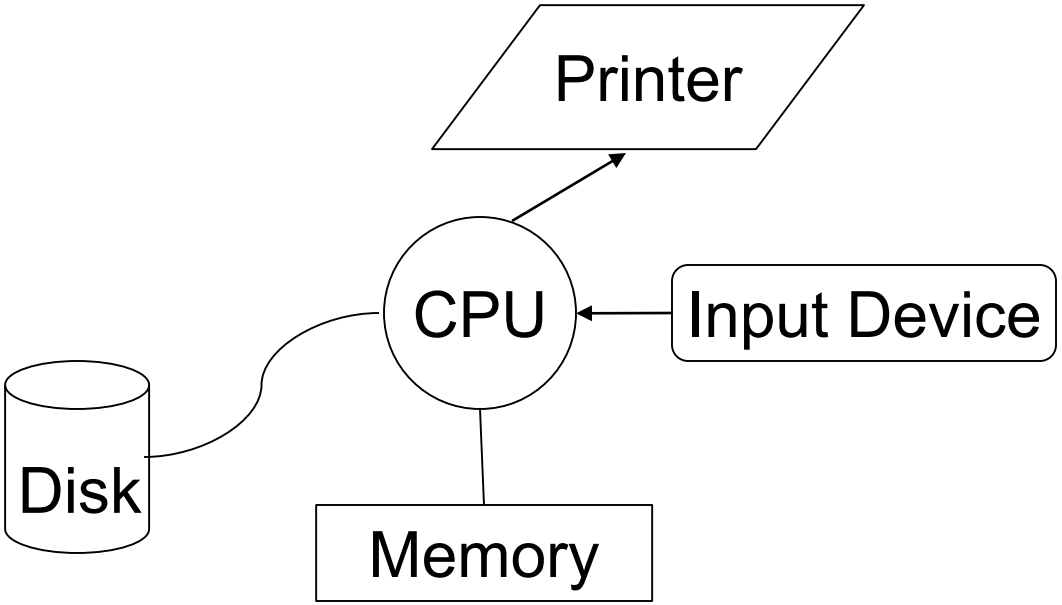
- none
- OS from my program
- your program from my program
- my program from my program
- access by intruding individuals
- access by intruding programs
- denial of service
- distributed denial of service
- spoofing
- spam
- worms
- viruses
- stuff you download and run knowingly (bugs, trojan horses)
- stuff you download and run obliviously (cookies, spyware)
- web tracking

In the Beginning...

- 1943
  - T.J. Watson (created IBM):
    " I think there is a world market for maybe five computers."

- Fast forward … 1950
  - There are maybe 20 computers in the world
    - They were unbelievably expensive
    - Imagine this: machine time is more valuable than person time!
    - Ergo: *efficient use of the hardware is paramount*
  - Operating systems are born
    - (Why?)
    - They carry with them the vestiges of these ancient forces

The Primordial Computer



The OS as a Linked Library

- In the very beginning…
  - OS was just a library of code that you linked into your program; programs were loaded in their entirety into memory, and executed
    - "OS" had an "API" that let you control the disk, control the printer, etc.
  - Interfaces were literally switches and blinking lights
  - When you were done running your program, you'd leave and turn the computer over to the next person

- *Recapitulation: Paul Allen writing a bootstrap loader for the Altair as the plane was landing in New Mexico*

Seattle Trivia (Wikipedia “Altair Basic”, edited)

Bill Gates recalls that, when he and Paul Allen read about the Altair in the January 1975 issue of Popular Electronics, they understood that the price of computers would soon drop to the point that selling software for them would be a profitable business. They contacted MITS founder Ed Roberts, told him that they were developing an interpreter, and asked whether he would like to see a demonstration. This followed the common engineering industry practice of a trial balloon, an announcement of a non-existent product to gauge interest.

Gates and Allen had neither an interpreter nor even an Altair system on which to develop and test one. However, Allen had written an Intel 8008 emulator for their previous venture. He adapted this emulator based on the Altair programmer guide, and they developed and tested the interpreter on Harvard's PDP-10. Harvard officials were not pleased when they found out, but there was no written policy that covered the use of this computer.

The finished interpreter, including its own I/O system and line editor, fit in only four kilobytes of memory, leaving plenty of room for the interpreted program. In preparation for the demo, they stored the finished interpreter on a punched tape that the Altair could read, and Paul Allen flew to Albuquerque.

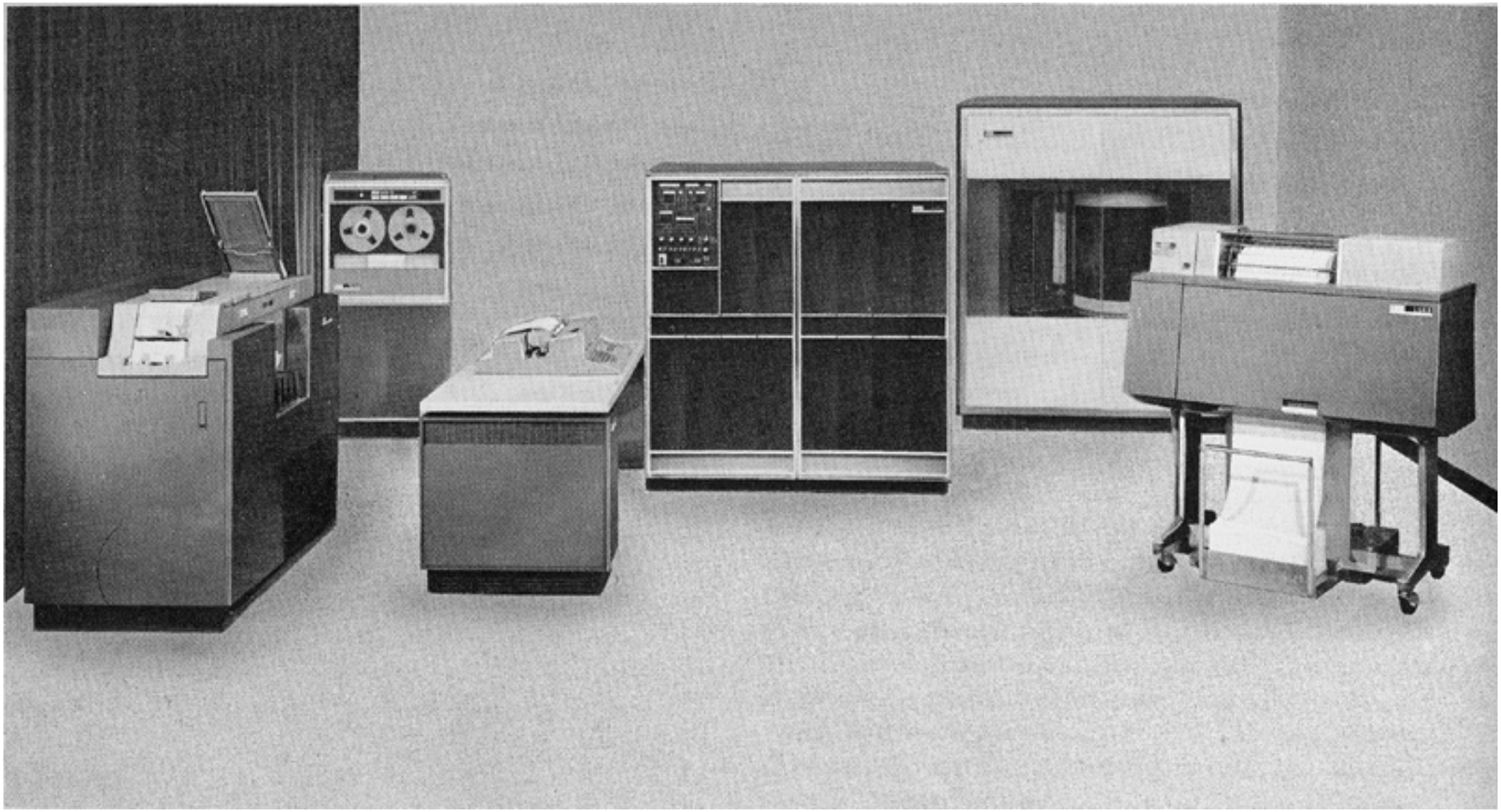
On final approach, Allen realized that they had forgotten to write a bootstrap program to read the tape into memory. Writing in 8080 machine language, Allen finished the program before the plane landed. Only when they loaded the program onto an Altair and saw a prompt asking for the system's memory size did Gates and Allen know that their interpreter worked on the Altair hardware. Later, they made a bet on who could write the shortest bootstrap program. Gates won.

Asynchronous I/O

- The disk was really slow
- The CPU was really expensive
- Add hardware so that the disk could operate without tying up the CPU
  - Disk controller
- Hotshot programmers could now write code that:
  - Starts an I/O
  - Goes off and does some computing
  - Checks if the I/O is done at some later time
- Upside
  - Helps increase (expensive) CPU utilization by overlapping CPU and I/O
- Downsides
  - It's hard to get right
  - The benefits are job specific

The OS as a “Resident Monitor”

- Everyone was using the same library of code
- Why not keep it in memory?
- While we’re at it, make it capable of loading Program 4 while running Program 3 and printing the output of Program 2
  - SPOOLing – Simultaneous Peripheral Operations On-Line
- What new requirements does this impose?

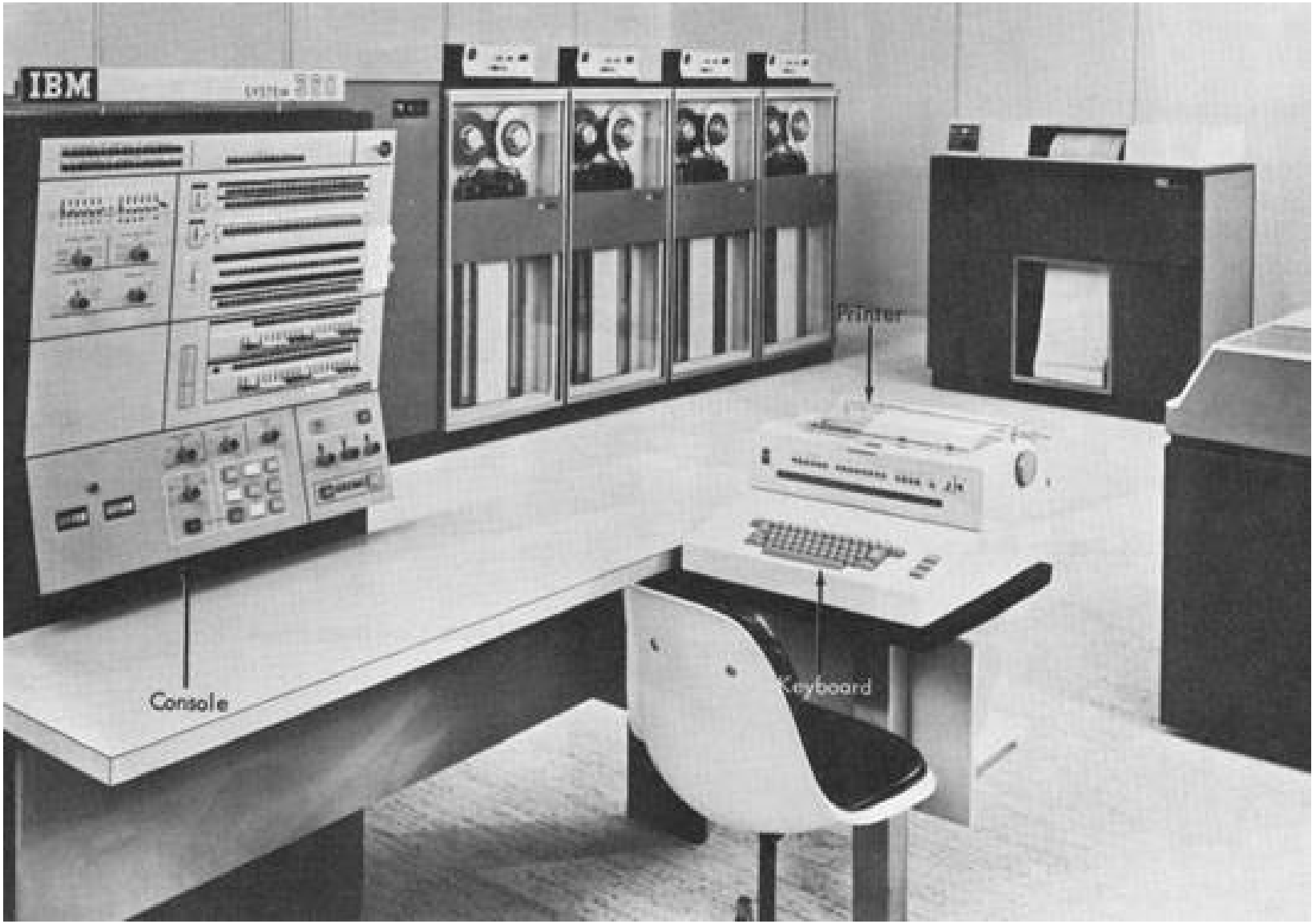


IBM 1401

Multiprogramming

- To further increase system utilization, multiprogramming OSs were invented
  - keeps multiple runnable jobs loaded in memory at once
  - overlaps I/O of one job with compute of another
  - Don't need asynchronous I/O within individual jobs to keep CPU busy
    - Life of application programmer becomes simpler
  - OS *blocks* process waiting for an I/O completion
  - How do we tell when devices are done?
    - Interrupts
    - Polling

- What new requirements does this impose?



IBM System 360

(An aside on protection)

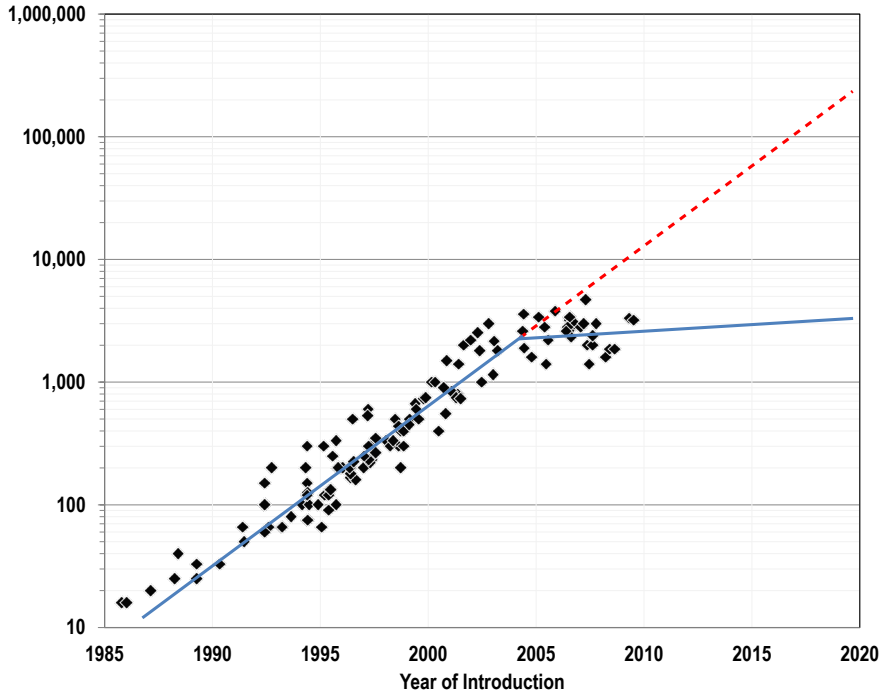
- Applications/programs/jobs execute directly on the CPU, but cannot touch anything except “their own memory” without OS intervention

- Applications can’t be allowed direct access to hardware, e.g., disk
  - Why not?

- Applications are allowed constrained direct use of CPU
  - Why?
  - Constrained how?

(An aside on concurrency)

- Transistor density continues to increase (Moore's Law), but individual cores aren't getting faster – instead, we're getting more of them (the number doubles on roughly the old 18-month cycle)



- The burden is on the programmer to use an ever increasing number of cores

- A lot of this course is about concurrency
  - It used to be a bit esoteric
  - It has now become one of the most important things you'll learn

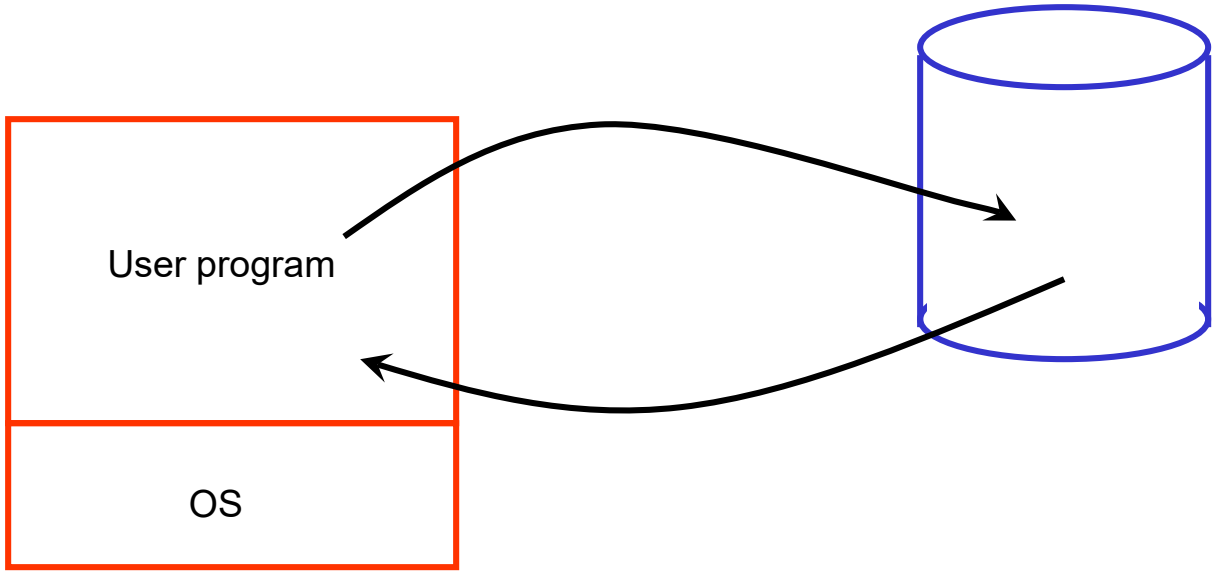
Timesharing

- To support interactive use, create a timesharing OS:
  - multiple terminals into one machine
  - each user has illusion of entire machine to him/herself
  - optimize *response time*, perhaps at the cost of *throughput*

- Timeslicing
  - divide CPU (equally) among the users
  - if job is truly interactive (e.g., editor), then can jump between programs and users faster than users can generate load
  - permits users to interactively view, edit, debug running programs

- MIT CTSS system (operational 1961) was among the first timesharing systems
  - only one user memory-resident at a time (32KB memory!)
- MIT Multics system (operational 1968) was the first large timeshared system
  - nearly all OS concepts can be traced back to Multics!
  - “second system syndrome”

- CTSS as an illustration of architectural and OS functionality requirements



- In early 1980s, a *single* timeshared VAX-11/780 (like the one in the Allen Center atrium) ran computing for *all of* CSE.

- A typical VAX-11/780 was 1 MIPS (1 MHz) and had 1MB of RAM and 100MB of disk.
  - Compare that to your phone

Parallel systems

- Some applications can be written as multiple parallel threads or processes
  - can speed up the execution by running multiple threads/processes simultaneously on multiple CPUs [Burroughs D825, 1962]
  - need OS and language primitives for dividing program into multiple parallel activities
  - need OS primitives for fast communication among activities
    - degree of speedup dictated by communication/computation ratio
  - many flavors of parallel computers today
    - SMPs (symmetric multi-processors)
    - MPPs (massively parallel processors)
    - NOWs (networks of workstations)
    - Massive clusters (Google, Amazon.com, Microsoft)
    - Computational grid (SETI @home)

Personal computing

- Primary goal was to enable new kinds of applications
- Bit mapped display [Xerox Alto,1973]
  - new classes of applications
  - new input device (the mouse)
- Move computing near the display
  - why?
- Window systems
  - the display as a managed resource
- Local area networks [Ethernet]
  - why?
- Effect on OS?

Distributed OS

- Distributed systems to facilitate use of geographically distributed resources
  - workstations on a LAN
  - servers across the Internet
- Supports communications among processes
  - interprocess communication
    - message passing, shared memory
  - networking stacks
- Sharing of distributed resources (hardware, software)
  - load balancing, authentication and access control, …
- Speedup isn't the issue
  - access to diversity of resources is goal

Client/server computing

- Mail service
- File service
- Calendar service
- Compute server
- Game service
- Web service
- Streaming service
- Backup/Sync service
- etc.

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- **naming**: how are resources named (by users, by programs)?
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