Operating Systems
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Introduction

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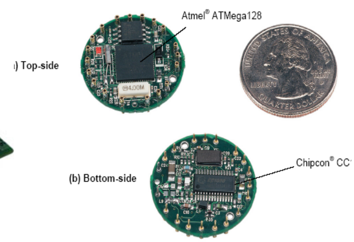
Computing systems are everywhere

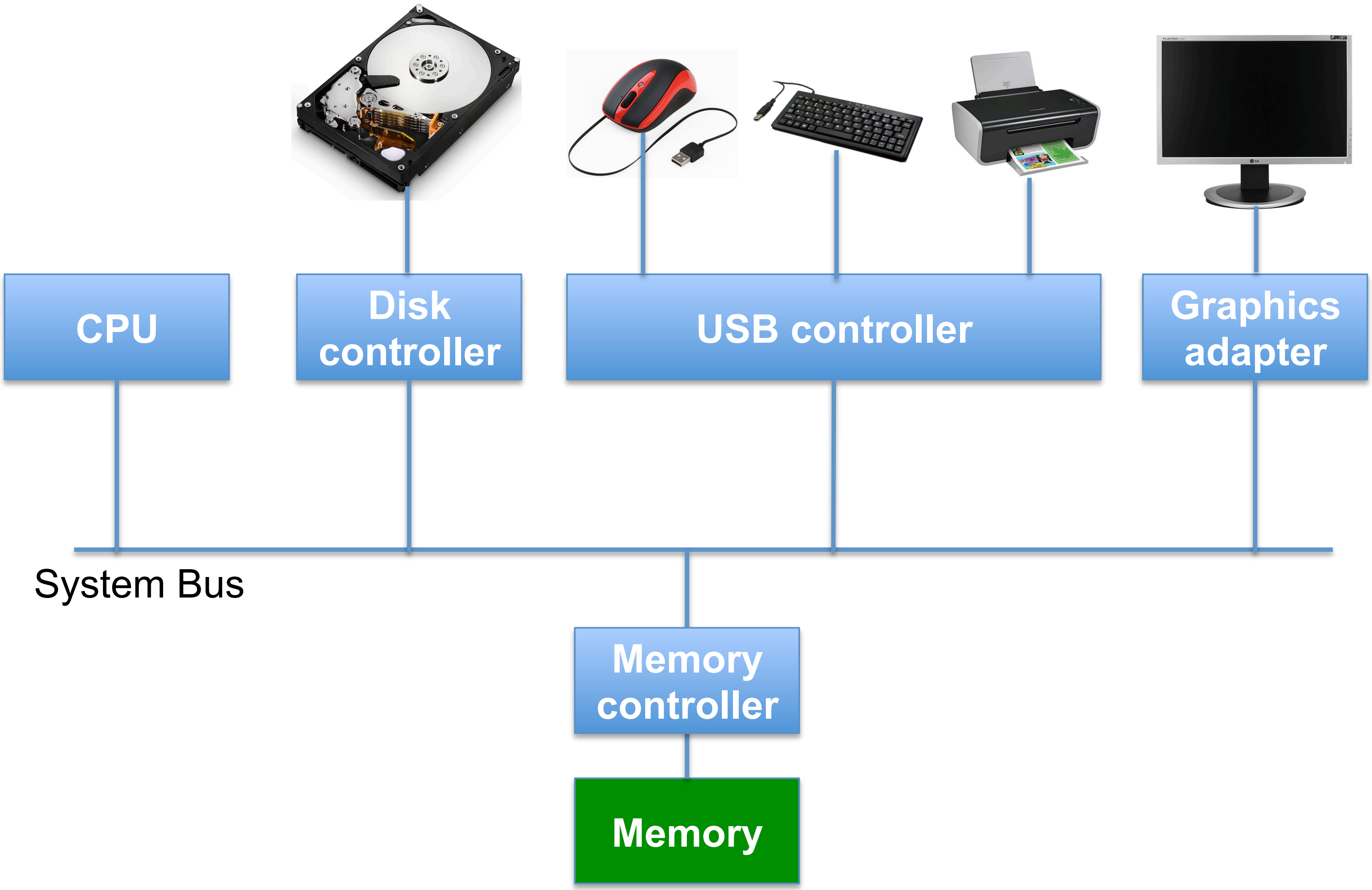


What is an Operating System?

- A big program
  - Linux 3.10 has 15M lines of code
- A program that manages a computer's hardware
- A program that acts an intermediary between the user of a computer and computer hardware

- Read Chapter 1.1 and 1.2 ☺

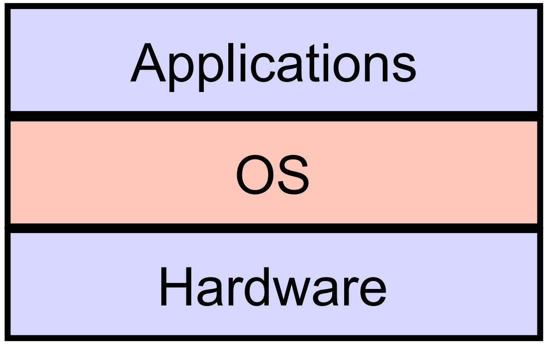
Modern computer system



Some goals of operating systems

- Simplify the execution of user programs and make solving user problems easier
- Use computer hardware efficiently
  - Allow sharing of hardware and software resources
- Make application software portable and versatile
- Provide isolation, security and protection among user programs
- Improve overall system reliability
  - error confinement, fault tolerance, reconfiguration

The traditional Picture



- "The OS is everything you don't need to write in order to run your application"
- This depiction invites you to think of the OS as a library; we'll see that
  - In some ways, it is:
    - all operations on I/O devices require OS calls (*syscalls)*
  - In other ways, it isn't:
    - you use the CPU/memory without OS calls
    - it intervenes without having been explicitly called

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)
  - files (disk)
  - programs (sequences of instructions)
  - sockets (network)

Why Bother with an OS?

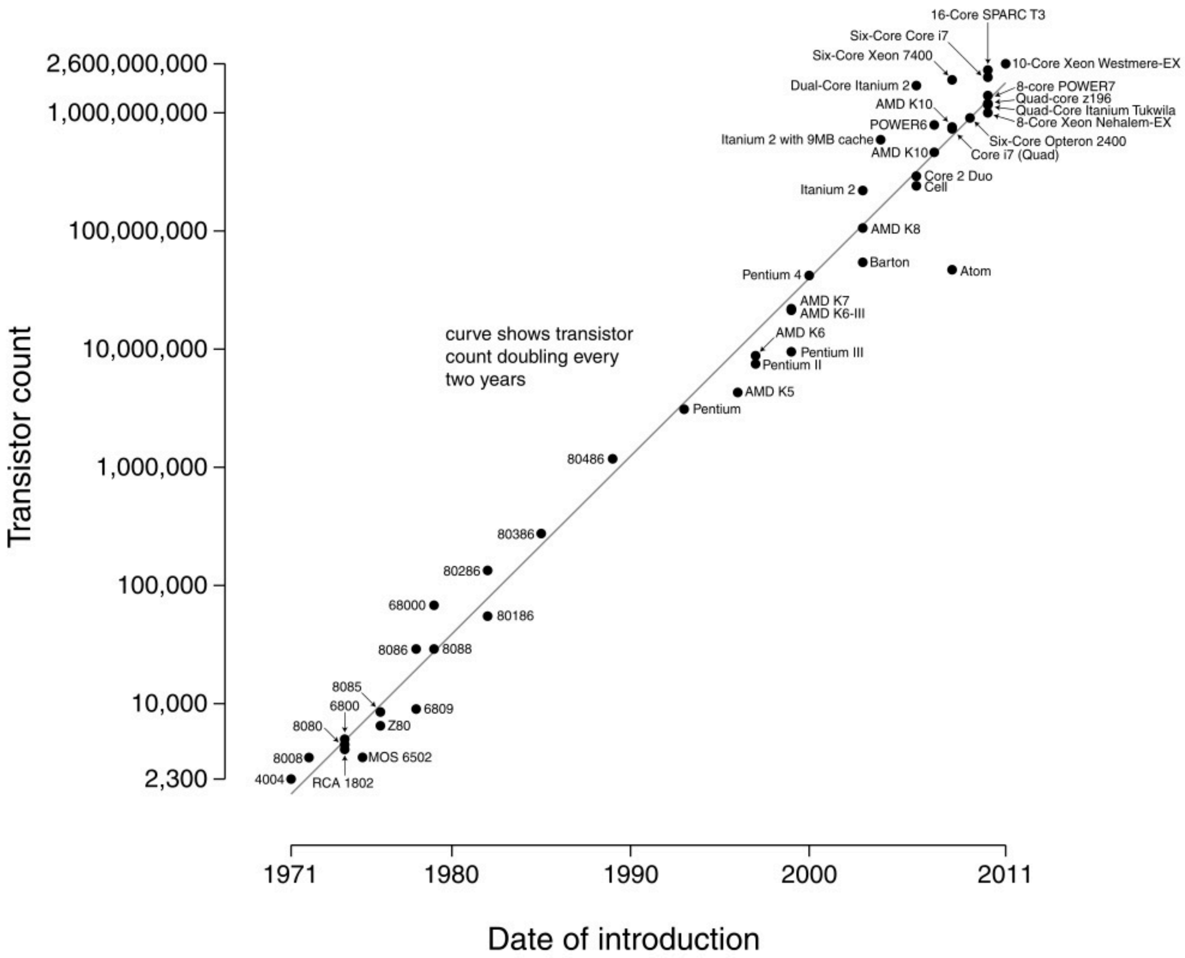
- Application benefits
  - programming simplicity
    - see high-level abstractions (files) instead of low-level hardware details (device registers)
    - abstractions are reusable across many programs
  - portability (across machine configurations or architectures)
    - device independence: 3com card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

Checkpoint

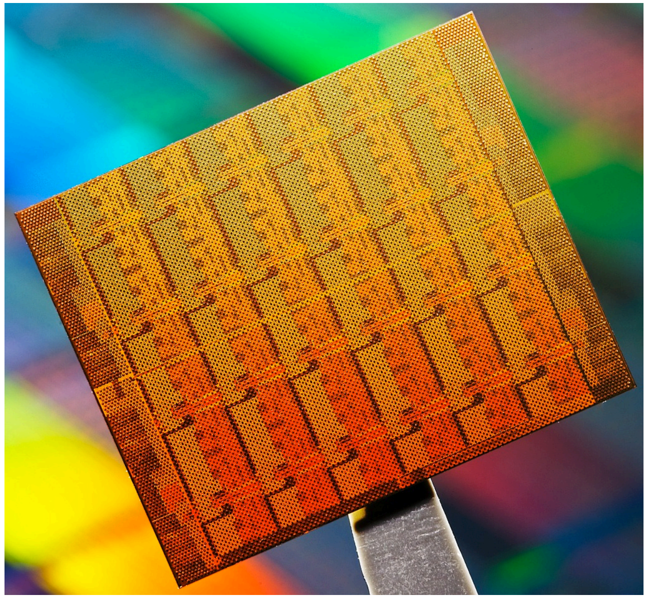
- What is an Operating System?
- What are the benefits of abstraction?
- What other benefits does an OS provide?

Hardware Complexity Increases

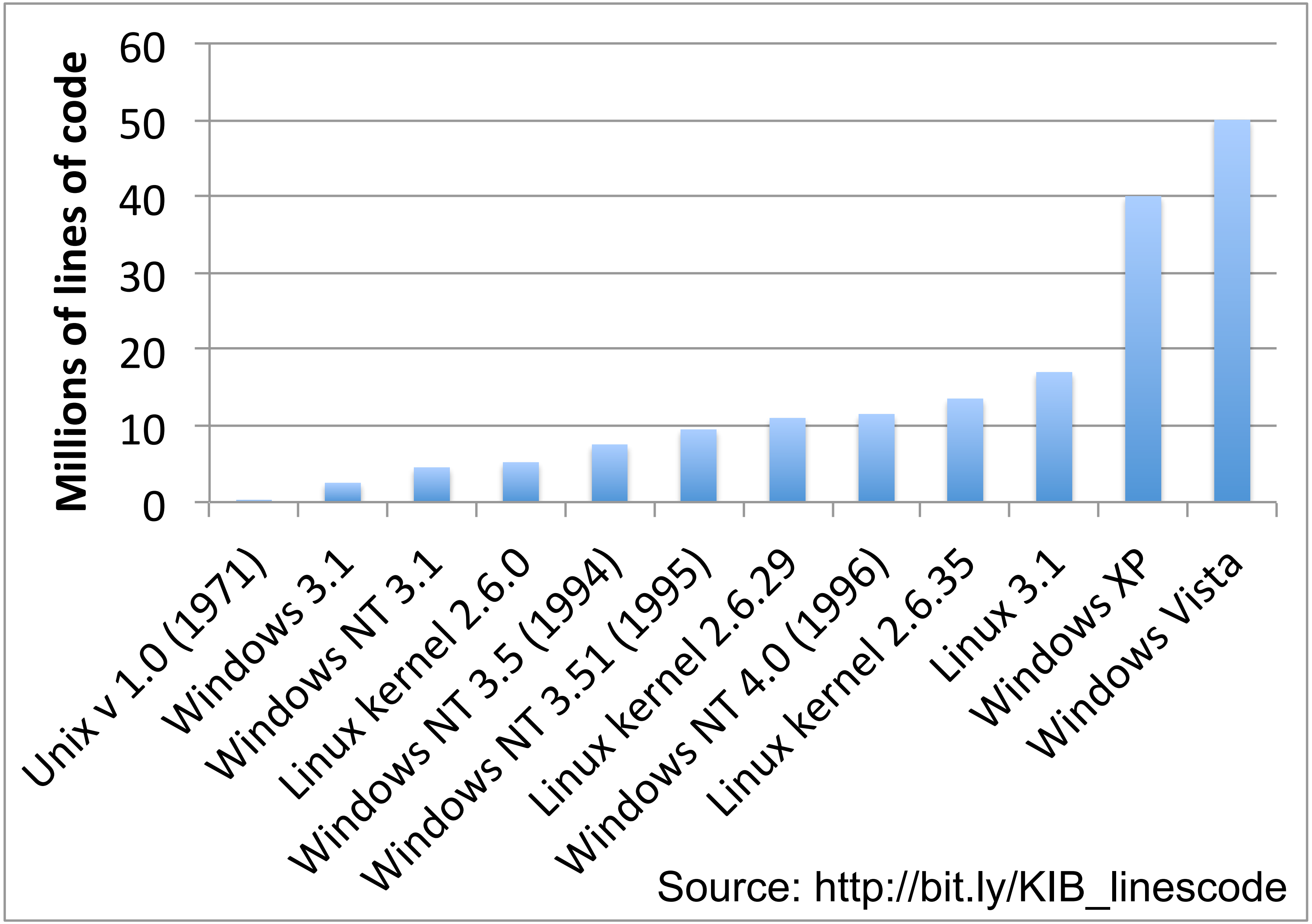
Microprocessor Transistor Counts 1971-2011 & Moore's Law



Moore's Law: 2X transistors/ Chip Every 1.5 years



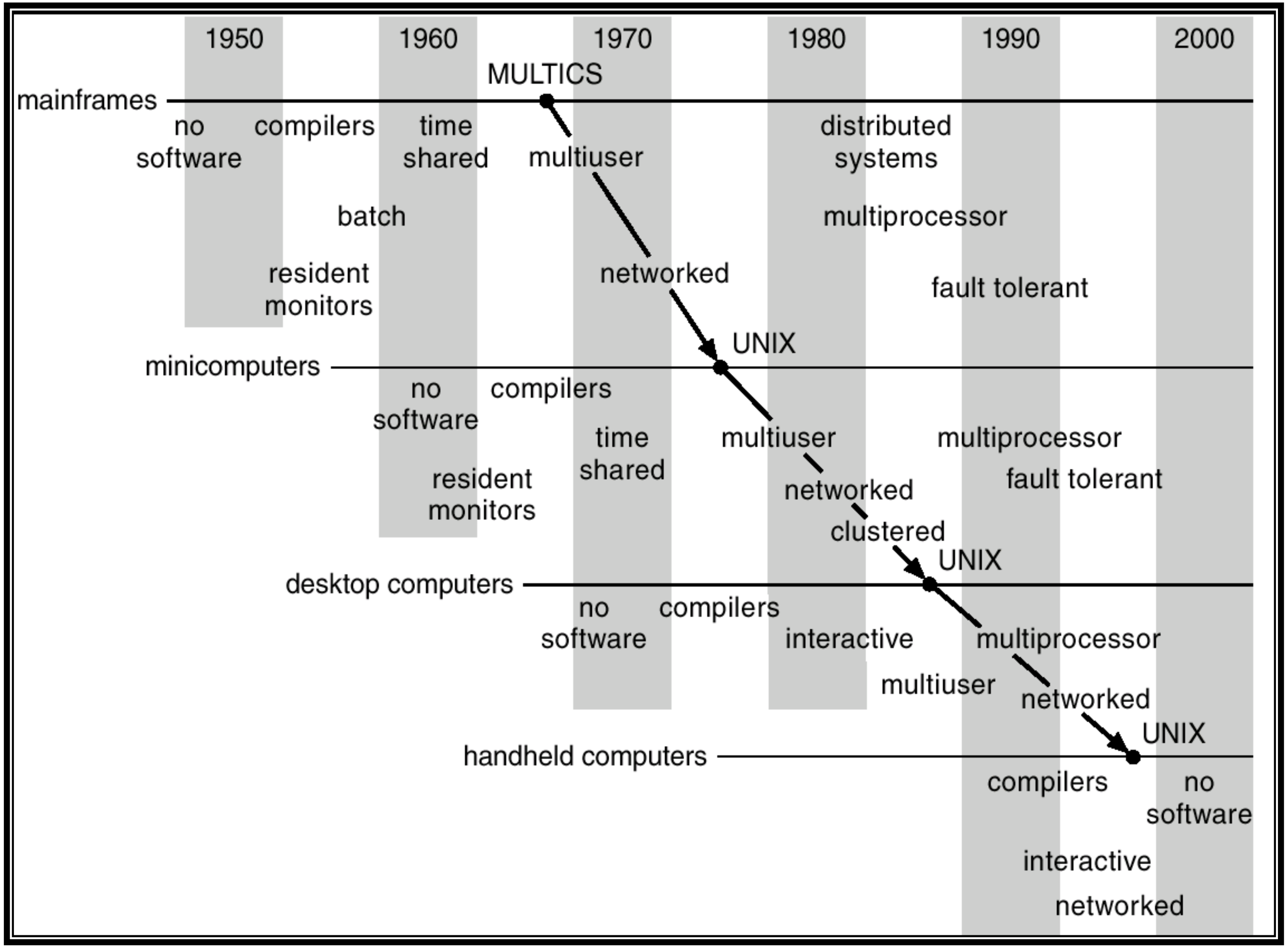
Software Complexity Increases



Hardware/Software Changes with 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 (iPod, iPhone, iPad, Android)
- 2010s: sensor networks, “data-intensive computing,” computers and the physical world
- 2020: it’s up to you!!

Progression of Concepts and Form Factors



An OS History Lesson

- Operating systems are the result of a 60 year long evolutionary process
  - They were born out of need

- We'll follow a bit of their evolution

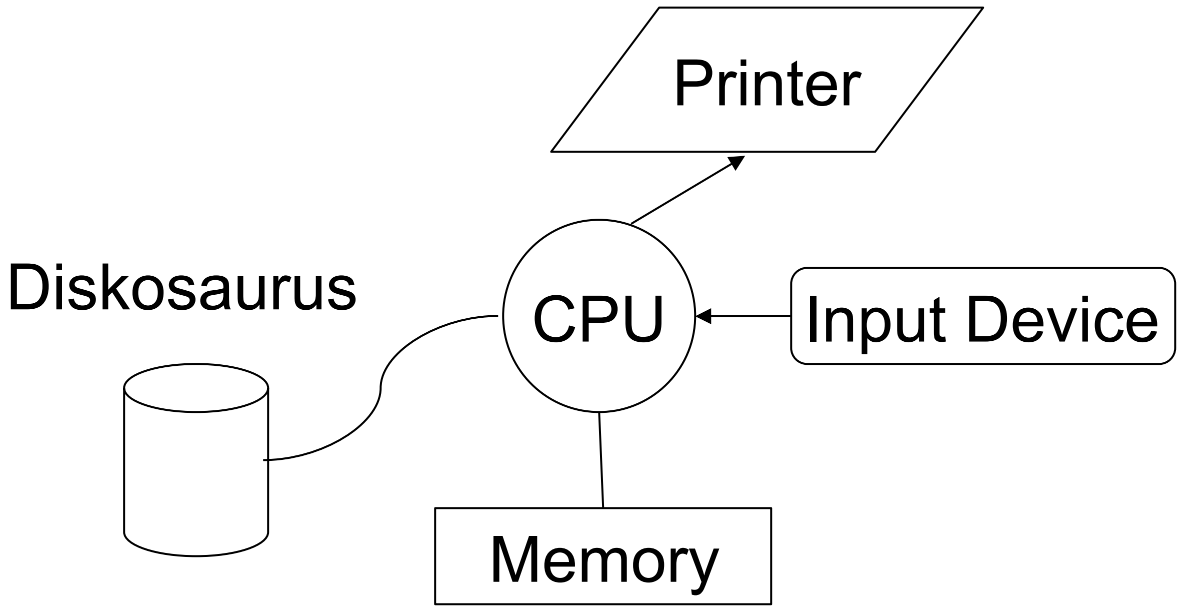
- That should help make clear what some of their functions are, and why

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
    - They carry with them the vestiges of these ancient forces

The Primordial Computer

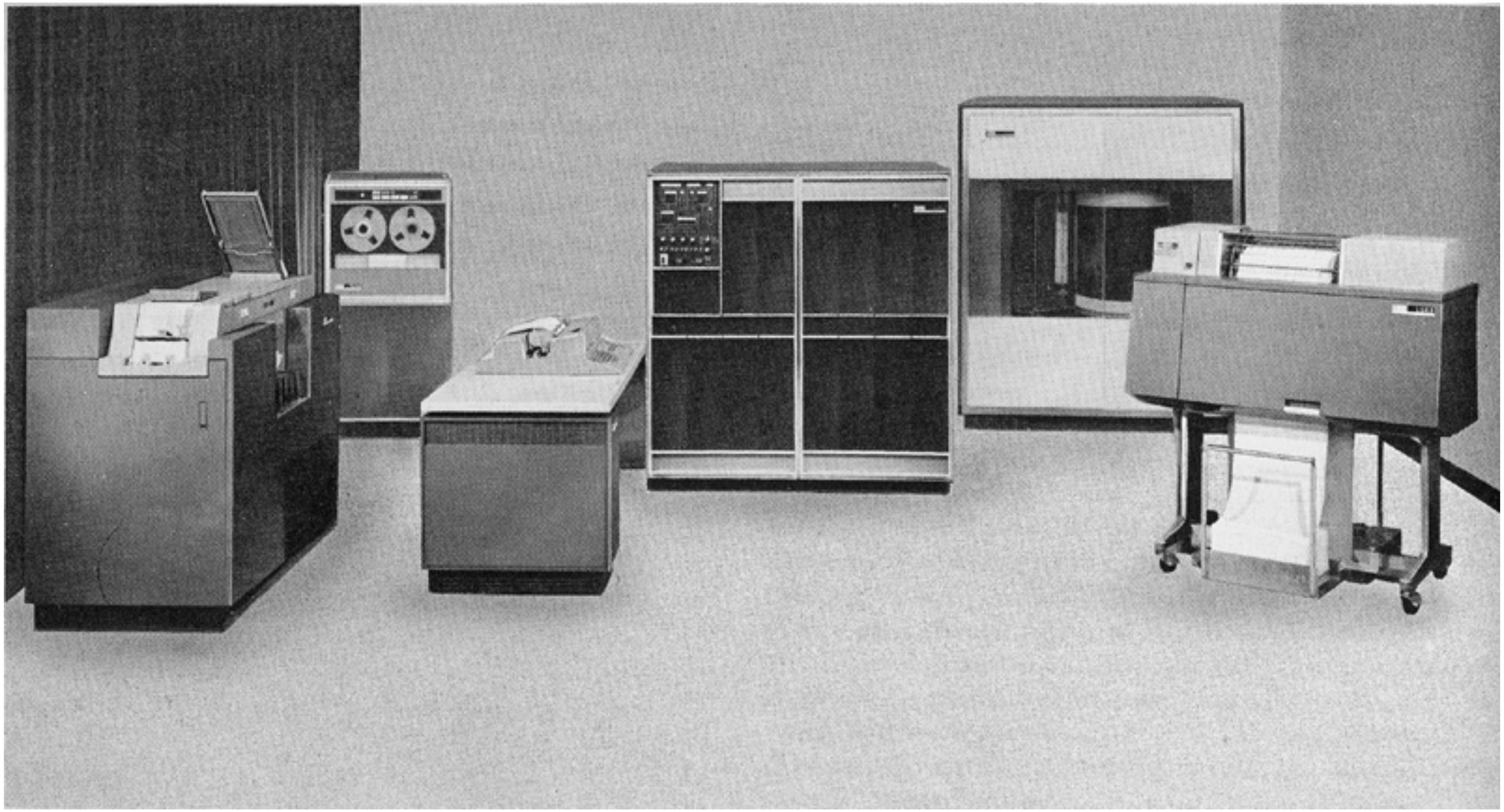


The OS as a linked library

- 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

Asynchronous I/O

- The diskosaurus was really slow
- 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
- Downsides
  - It's hard to get right
  - The benefits are job specific

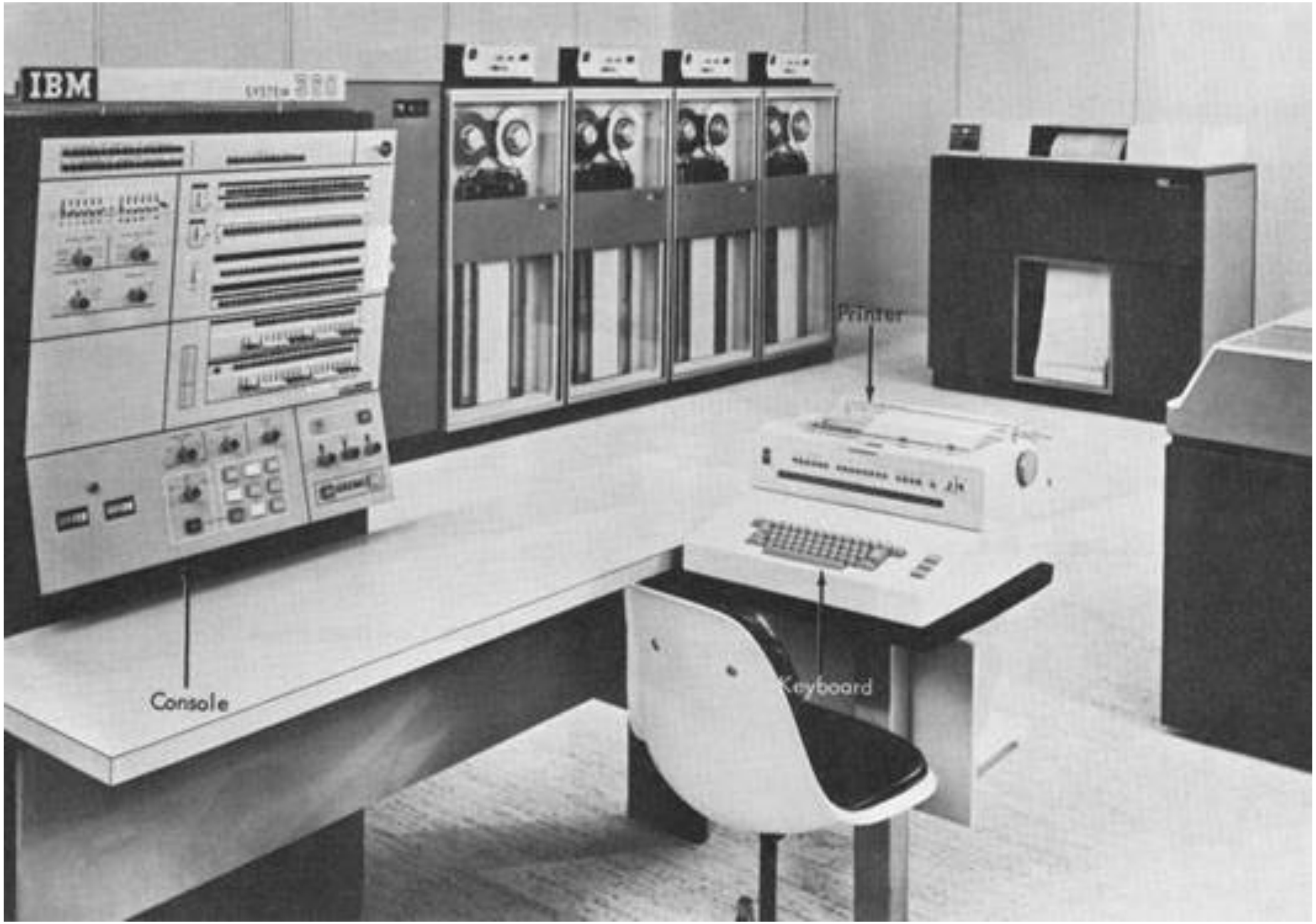


IBM 1401

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 computing of another
    - while one job waits for I/O completion, another job uses the CPU
  - Can get rid of asynchronous I/O within individual jobs
    - Life of application programmer becomes simpler; only the OS programmer needs to deal with asynchronous events
  - How do we tell when devices are done?
    - Interrupts
    - Polling

  - What new requirements does this impose?



IBM System 360

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”

- 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.

- An Apple iPhone 4 is 1GHz (x1000), has 512MB of RAM (x512), and 32GB of flash (x320).

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 between programs
  – 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

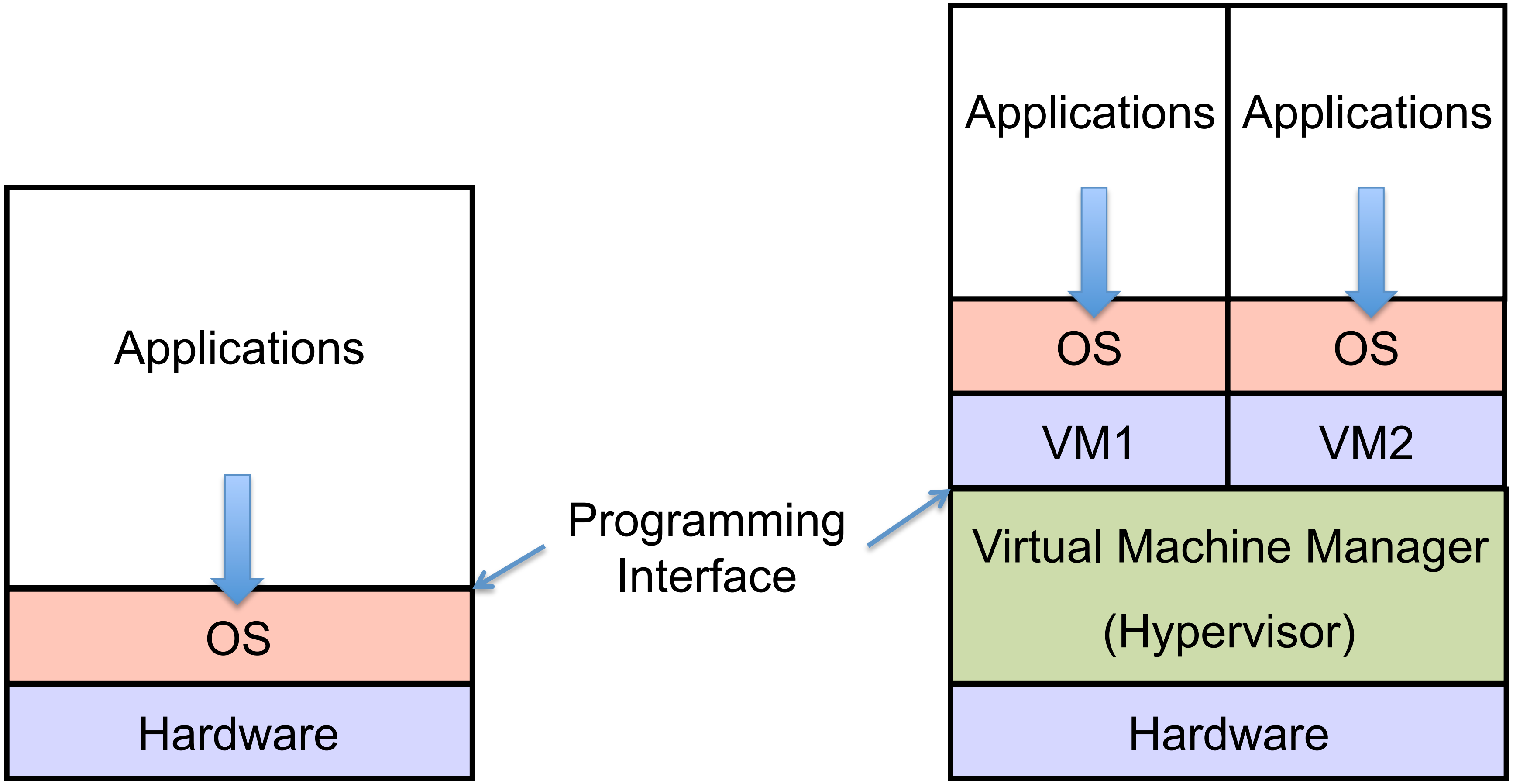
Client/Server Computing

- Mail server/service
- File server/service
- Print server/service
- Compute server/service
- Game server/service
- Music server/service
- Web server/service
- etc.

Peer-to-Peer (p2p) Systems

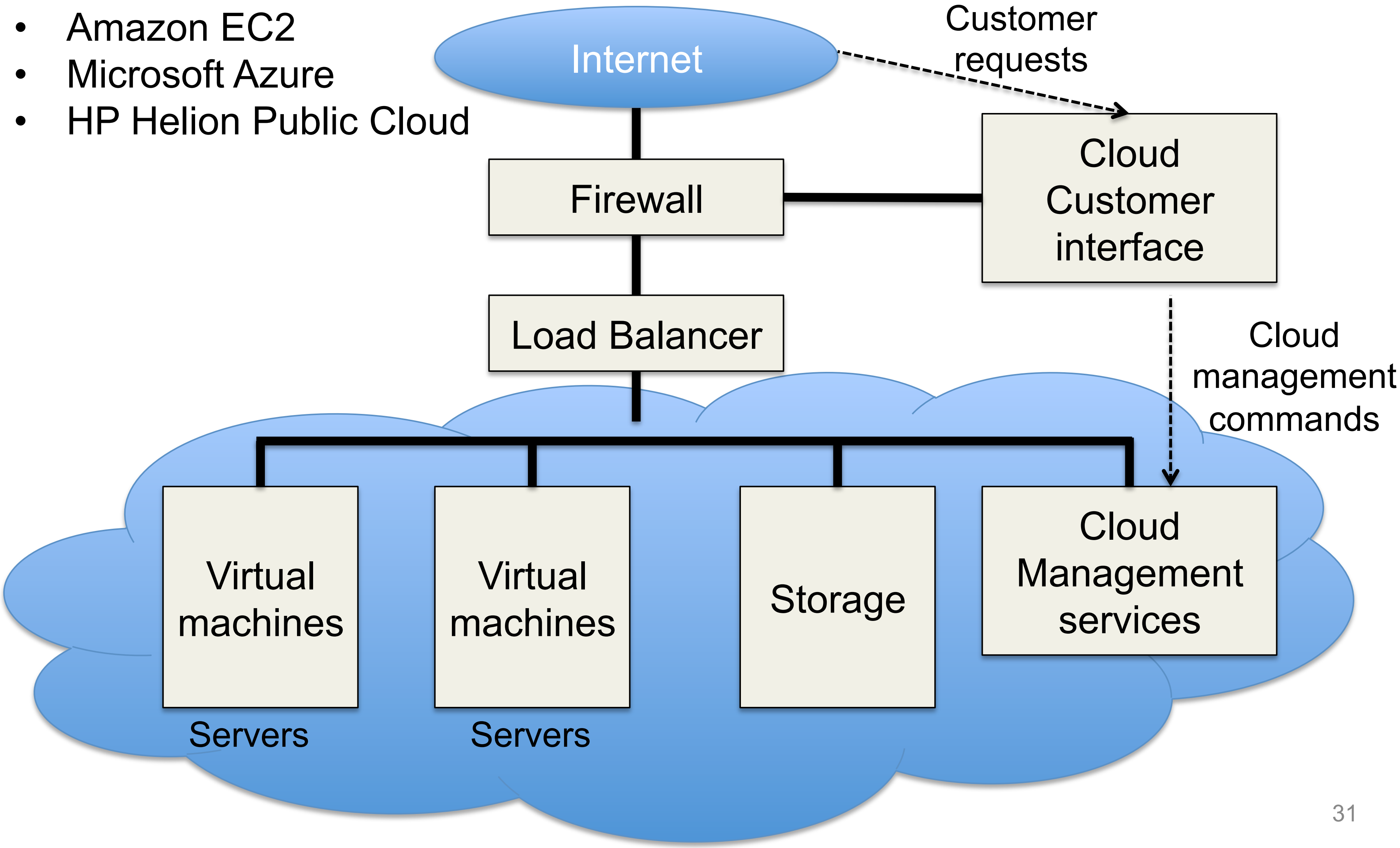
- Napster
- Gnutella
- BitTorrent
  - example technical challenge: self-organizing overlay network
  - technical advantage of BitTorrent?
  - er … legal advantage of BitTorrent?

Virtualization



Cloud Computing

- Amazon EC2
- Microsoft Azure
- HP Helion Public Cloud



The major OS issues

- **structure**: how is the OS organized?
- **sharing**: how are resources shared across users?
- **naming**: how are resources named (by users or programs)?
- **security**: how is the integrity of the OS and its resources ensured?
- **protection**: how is one user/program protected from another?
- **performance**: how do we make it all go fast?
- **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 parallel 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 multiple computers interact with each other?
- **accounting**: how do we keep track of resource usage, and perhaps charge for it?

There are tradeoffs, not right and wrong!

Why Should One Learn Operating Systems?

- You may not ever build an OS
- But as a computer scientist or computer engineer you need to understand the foundations
- Most importantly, operating systems exemplify the sorts of engineering design tradeoffs that you'll need to make throughout your careers – compromises among and within cost, performance, functionality, complexity, schedule …