Operating Systems (INFR09047)

2019/2020 Semester 2

Introduction

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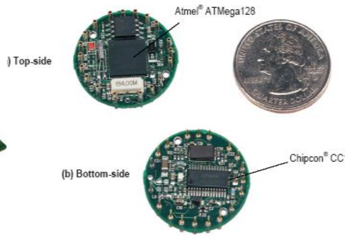
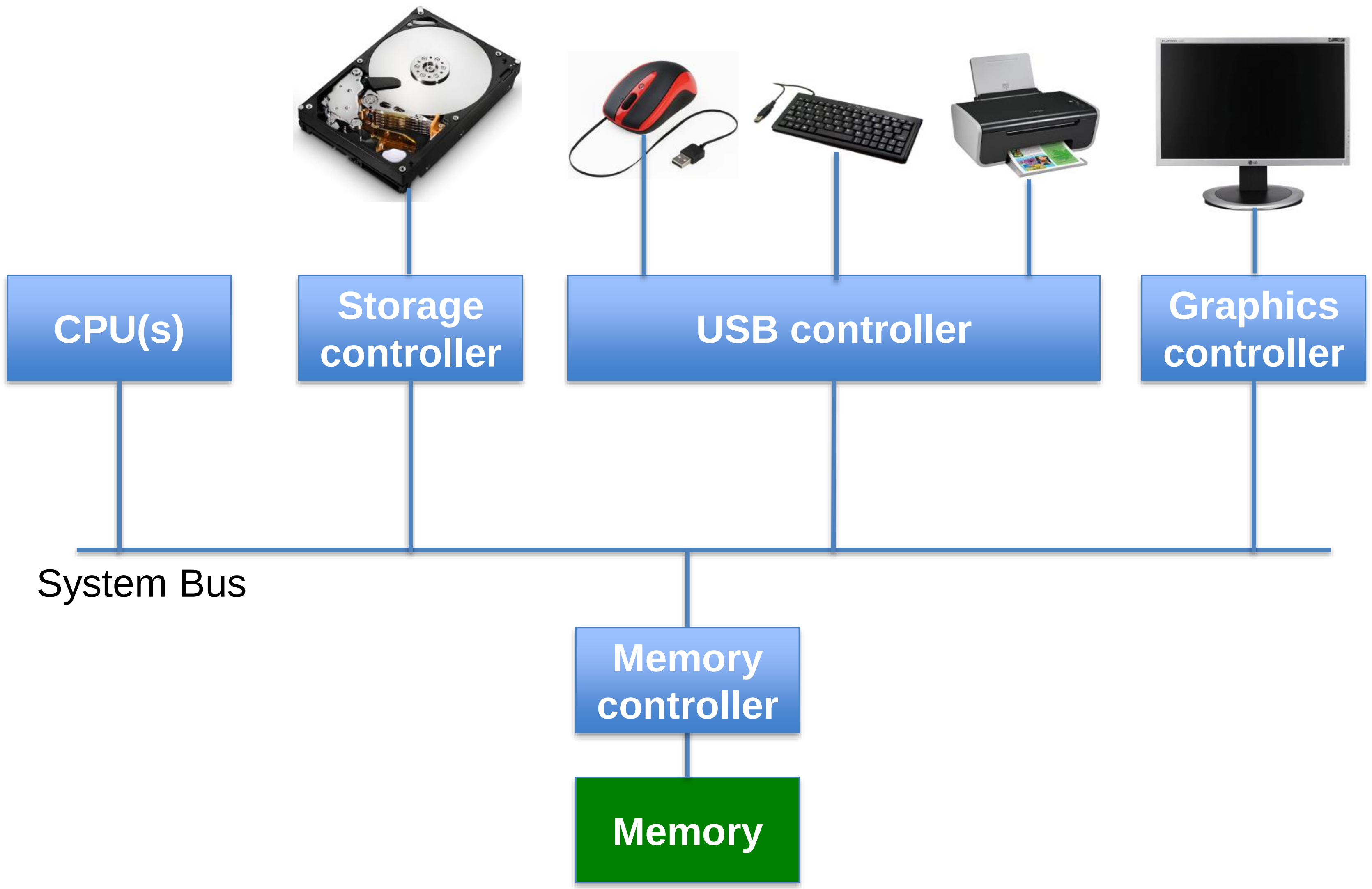
Chapter 1, Appendix A

Computing systems are everywhere



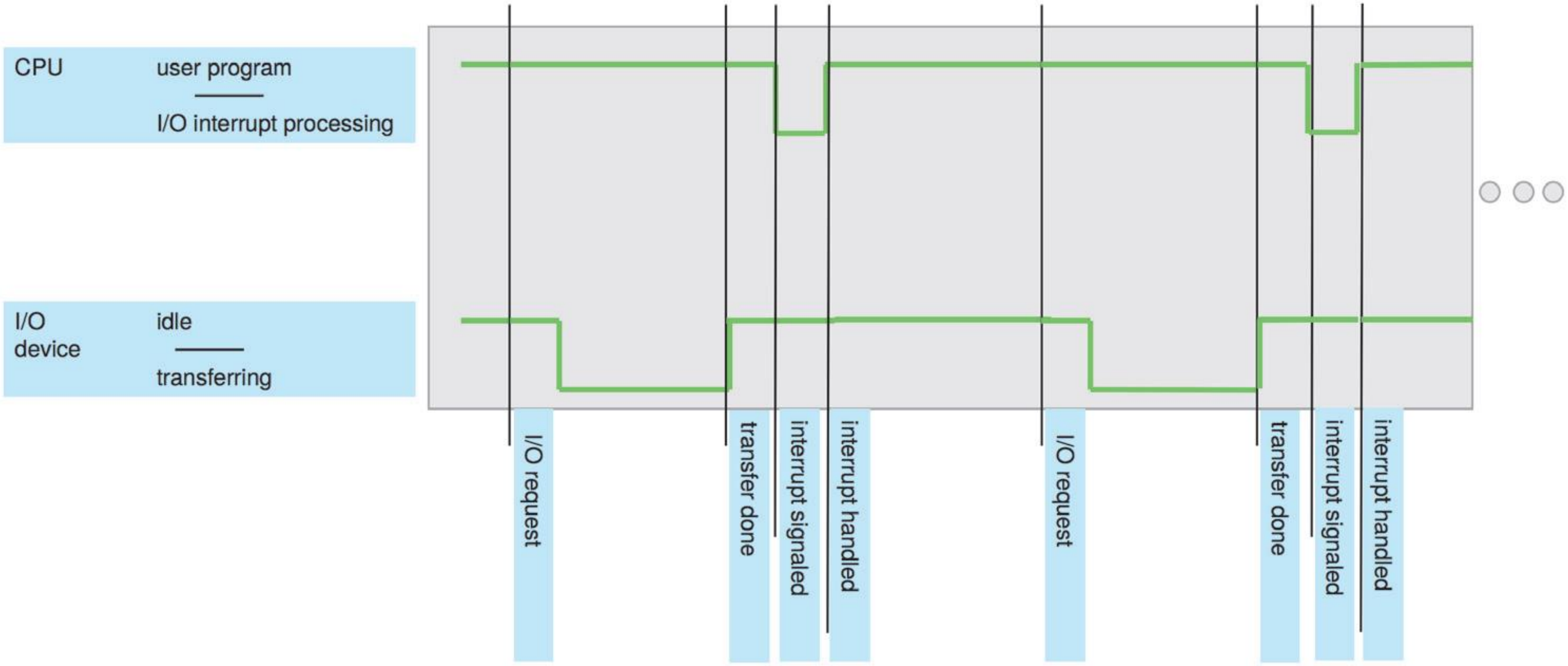
Modern computer system



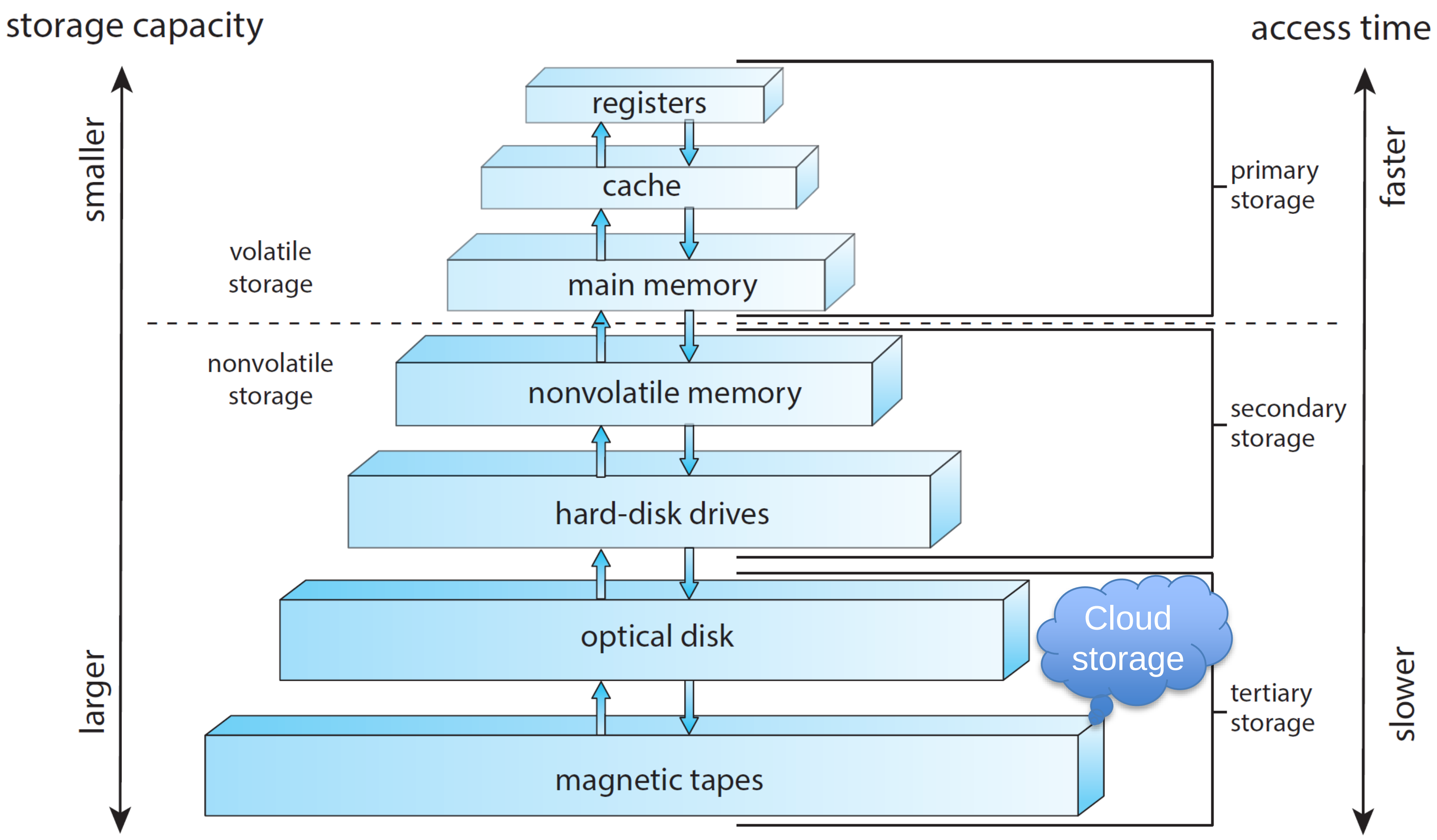
What is an Operating System?

- A program that manages a computer's hardware
- A program that acts as an intermediary between the user of a computer and computer hardware
- A big program
  - "The **Linux Kernel** Enters 2020 At **27.8 Million Lines** In Git But With Less Developers For 2019", 1 January 2020 at 09:14 AM EST
  - https://www.phoronix.com/scan.php?page=news_item&px=Linux-Git-Stats-EOY2019

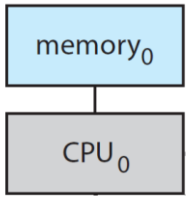
Hardware Recap: Interrupts



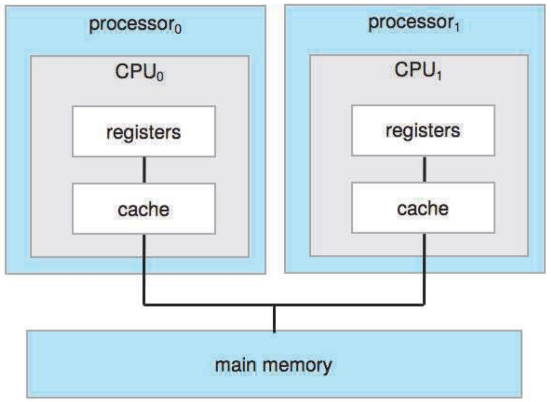
Hardware Recap: Storage Structure



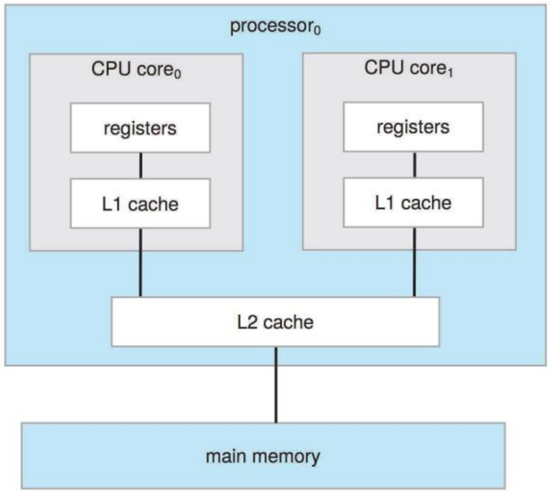
Hardware Recap: Memory and CPU

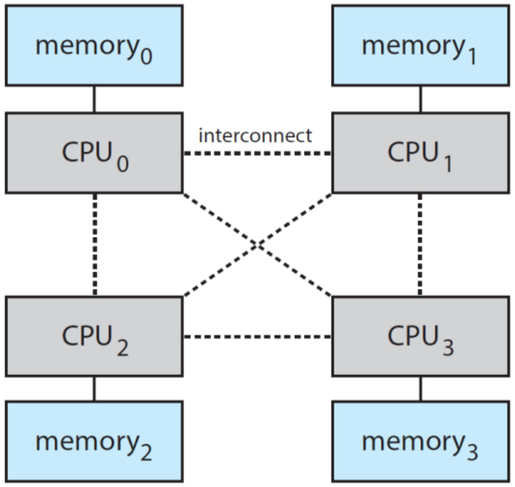


Single-core



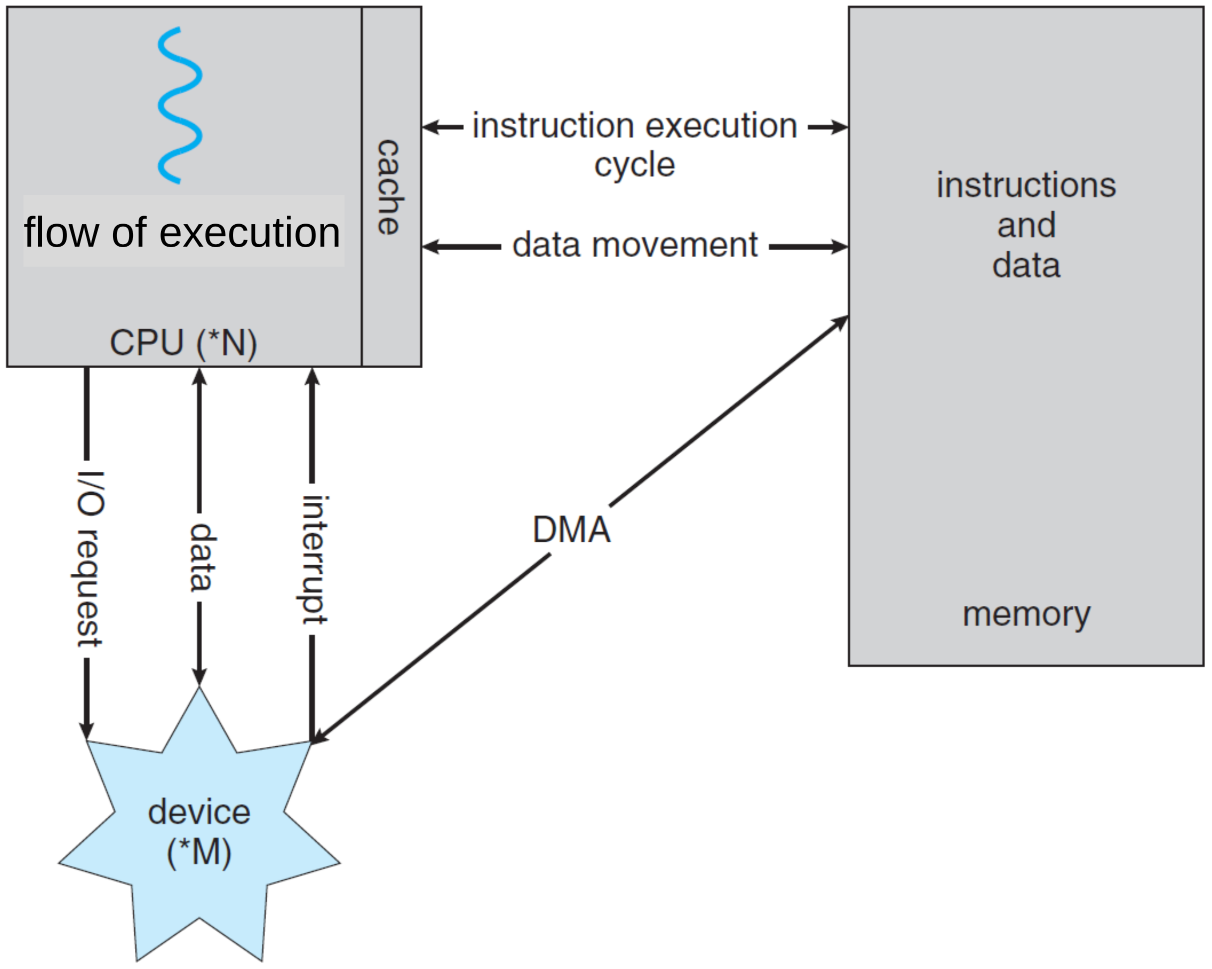
Multicore





NUMA

Hardware Recap: Big Picture



Operating Systems

MS-DOS

solaris™

iOS

Mac OS X

Windows

hp UX

Plan 9 from Bell Labs

MINIX 3

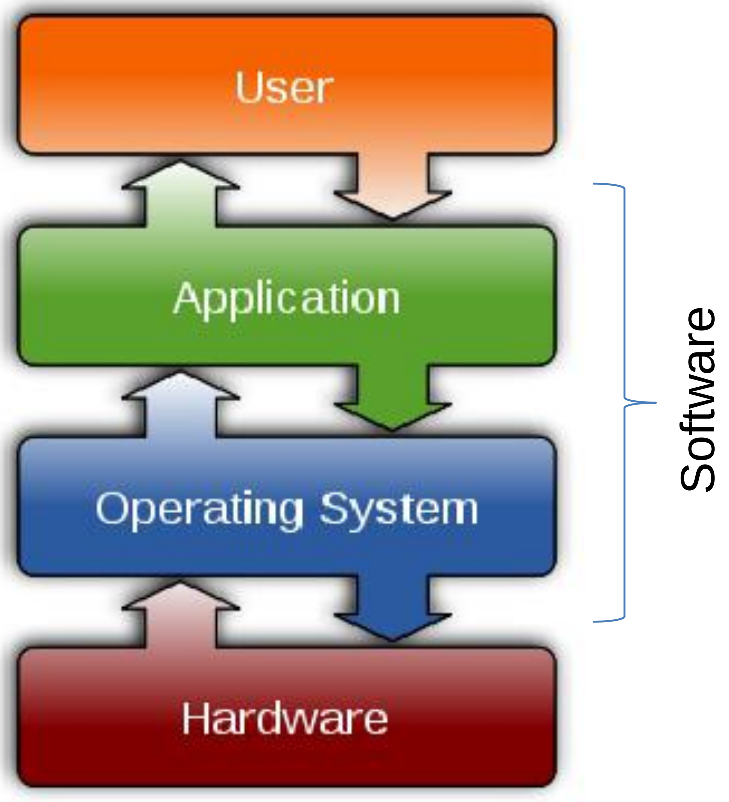
Linux™

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

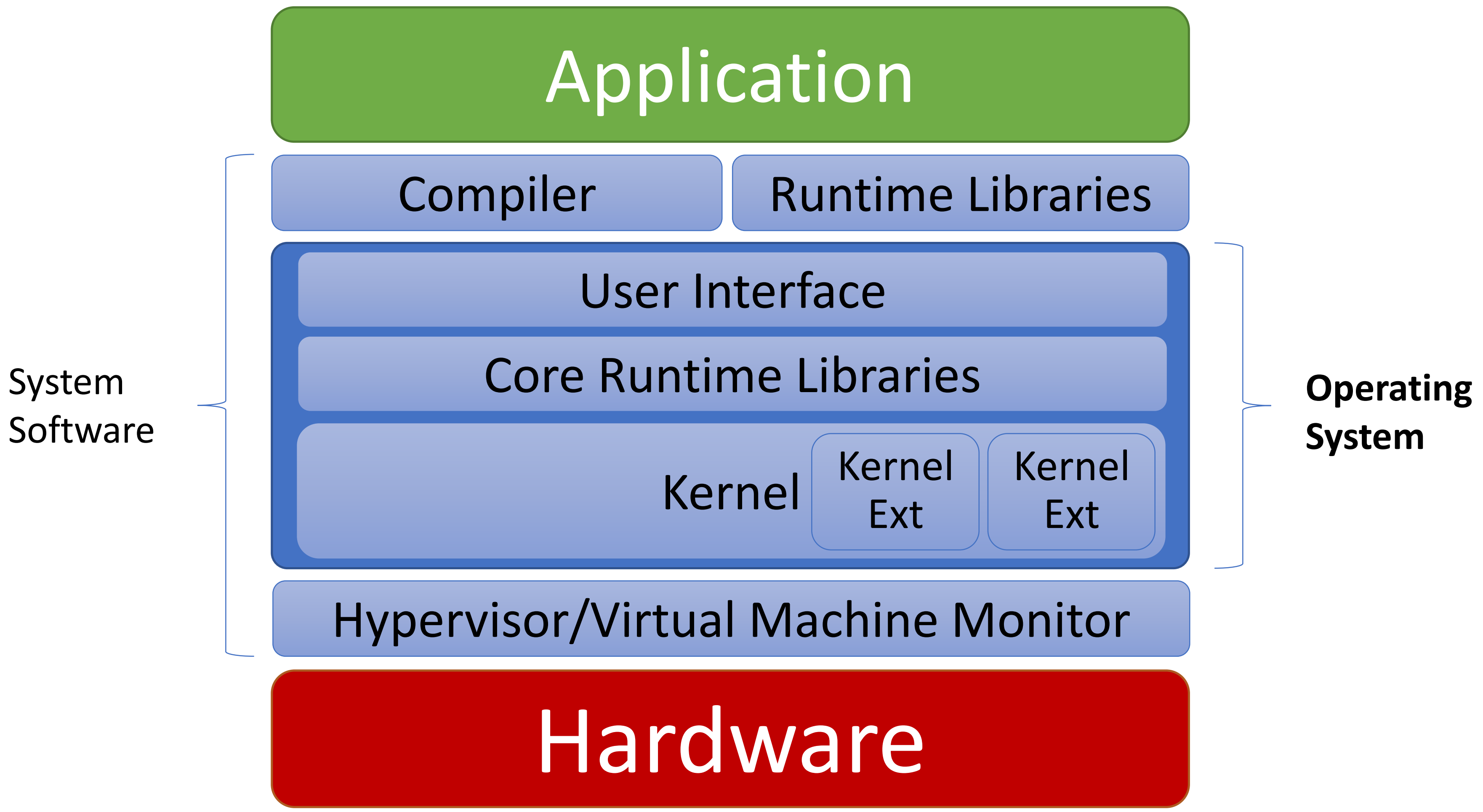
The traditional Picture

- “The OS is everything you don’t need to write in order to run your application”
- Think of the OS as a library
  - 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

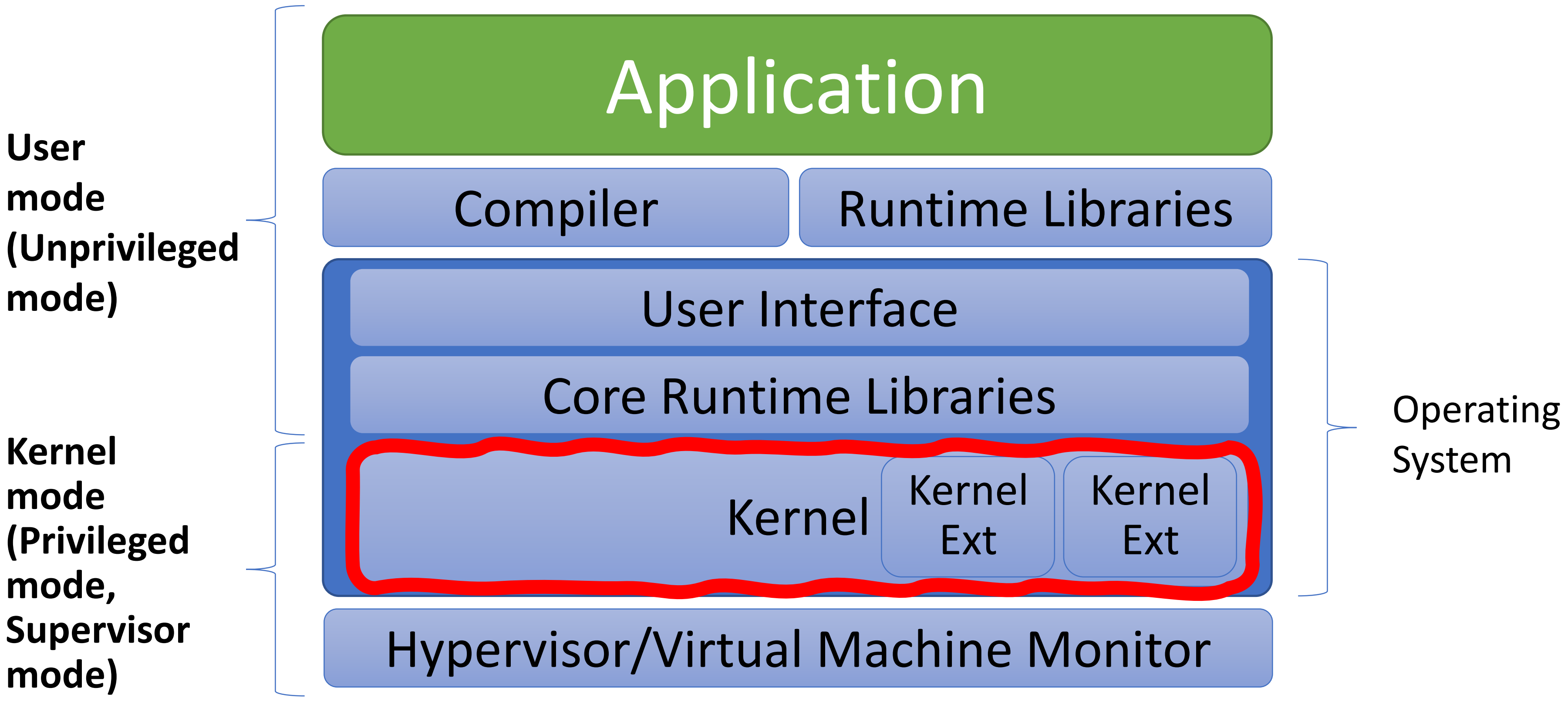


https://en.wikipedia.org/wiki/File:Operating_system_placement.svg

What is OS? #1


Application
Compiler
Runtime Libraries
User Interface
Core Runtime Libraries
Kernel
Kernel Ext
Kernel Ext
Hypervisor/Virtual Machine Monitor
Hardware
System Software
Operating System

What is OS? #2



NOTE there exist OSes that do not use modes, there is hardware that doesn’t support modes

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)
  - sockets (network)

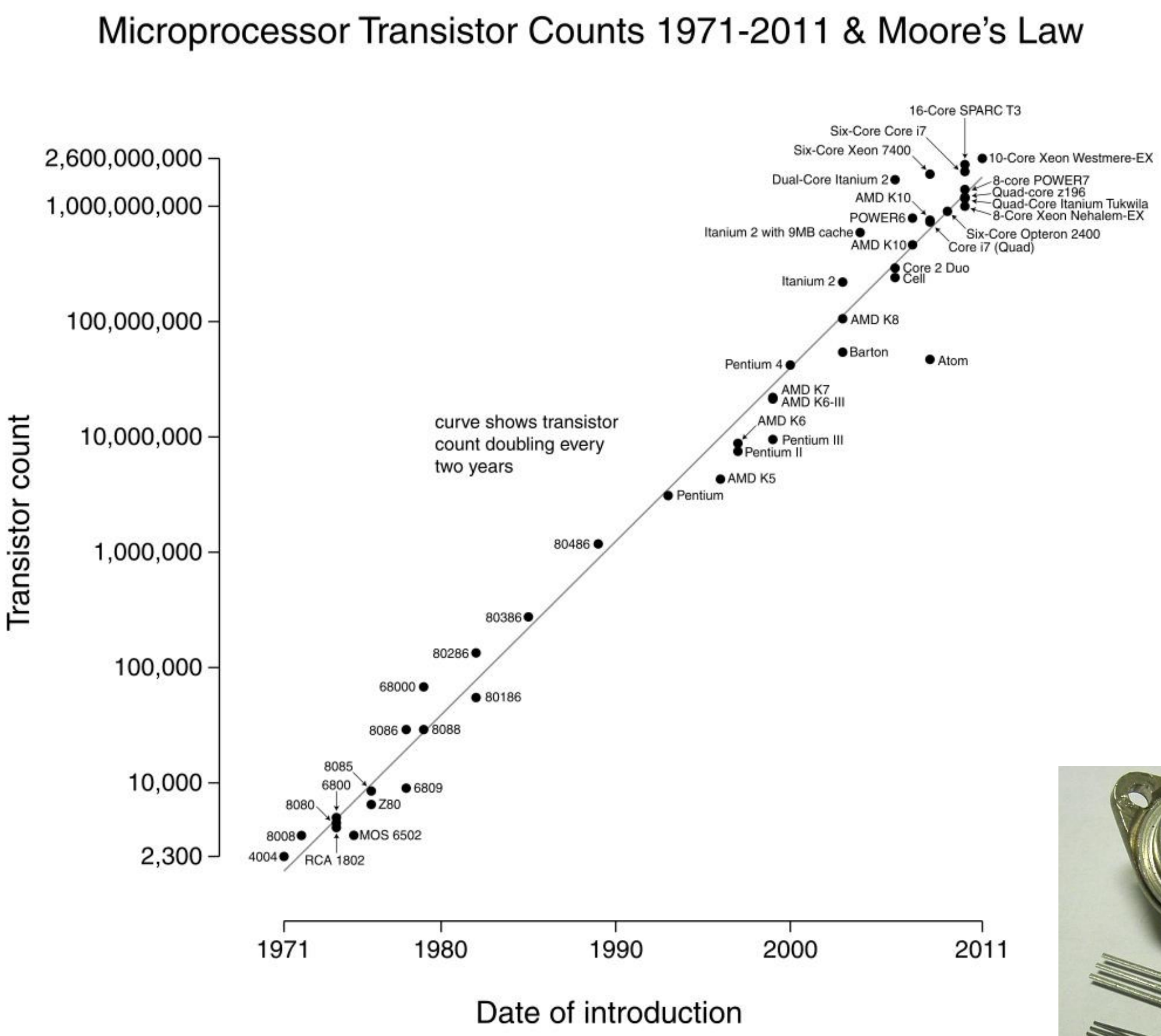
Why Bother with an OS?

- 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

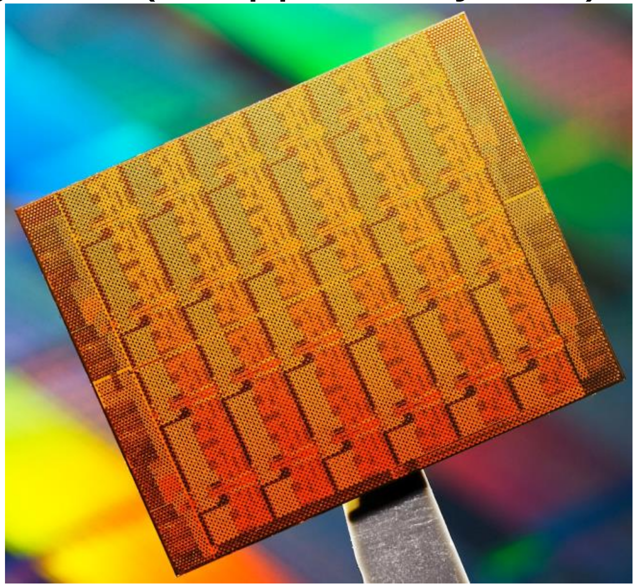
- What is an Operating System?
- What are the benefits of abstraction?
- What other benefits does an OS provide?

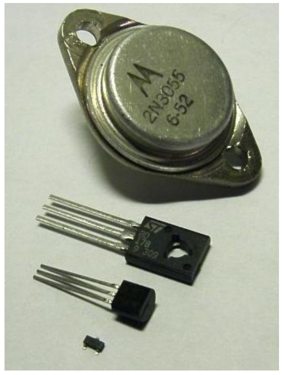
Hardware Complexity Increases



https://en.wikipedia.org/wiki/Transistor_count
https://en.wikipedia.org/wiki/Moore%27s_law

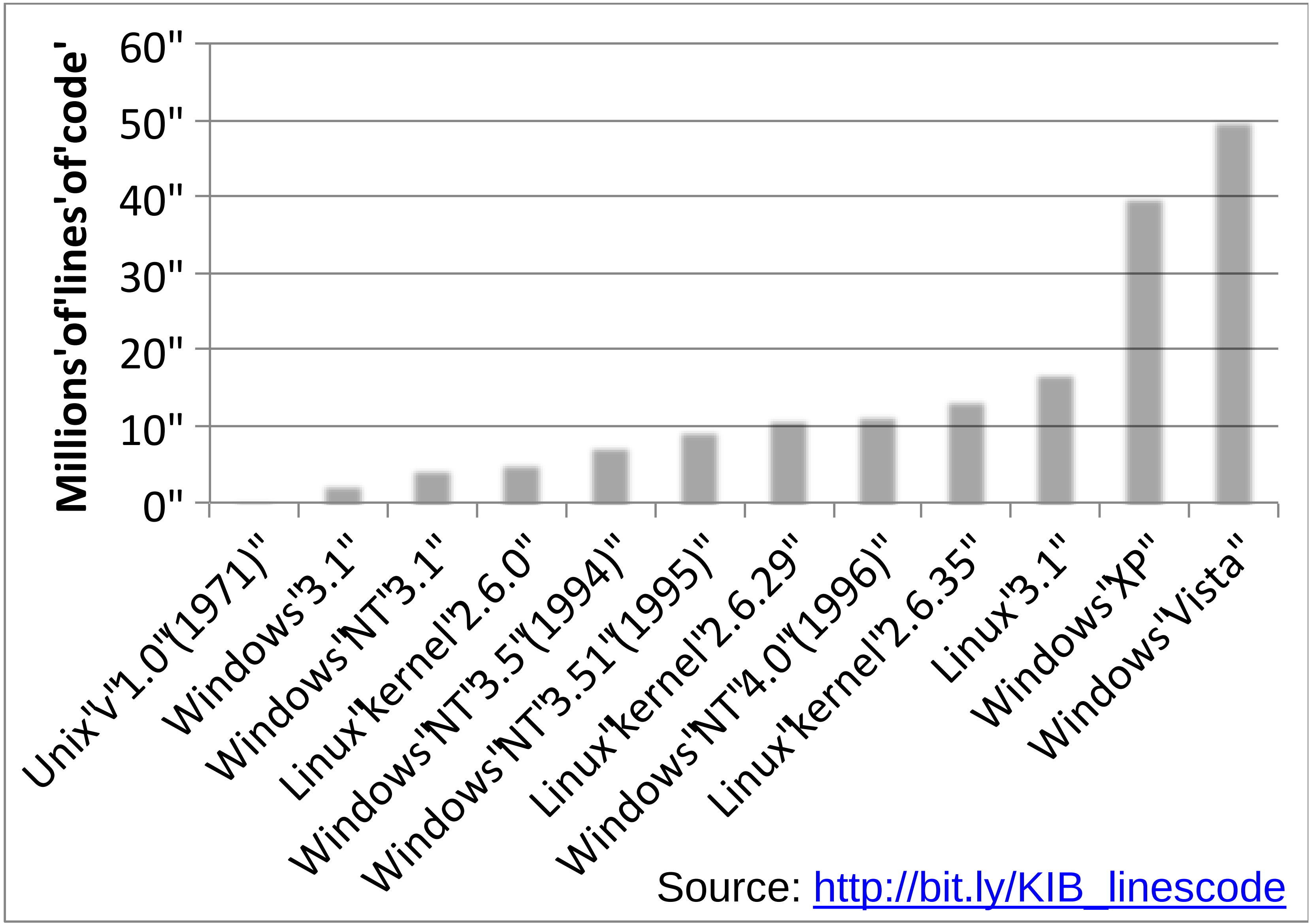
Moore's Law: 2X transistors/Chip Every 1.5 years (or approx. 2 years)





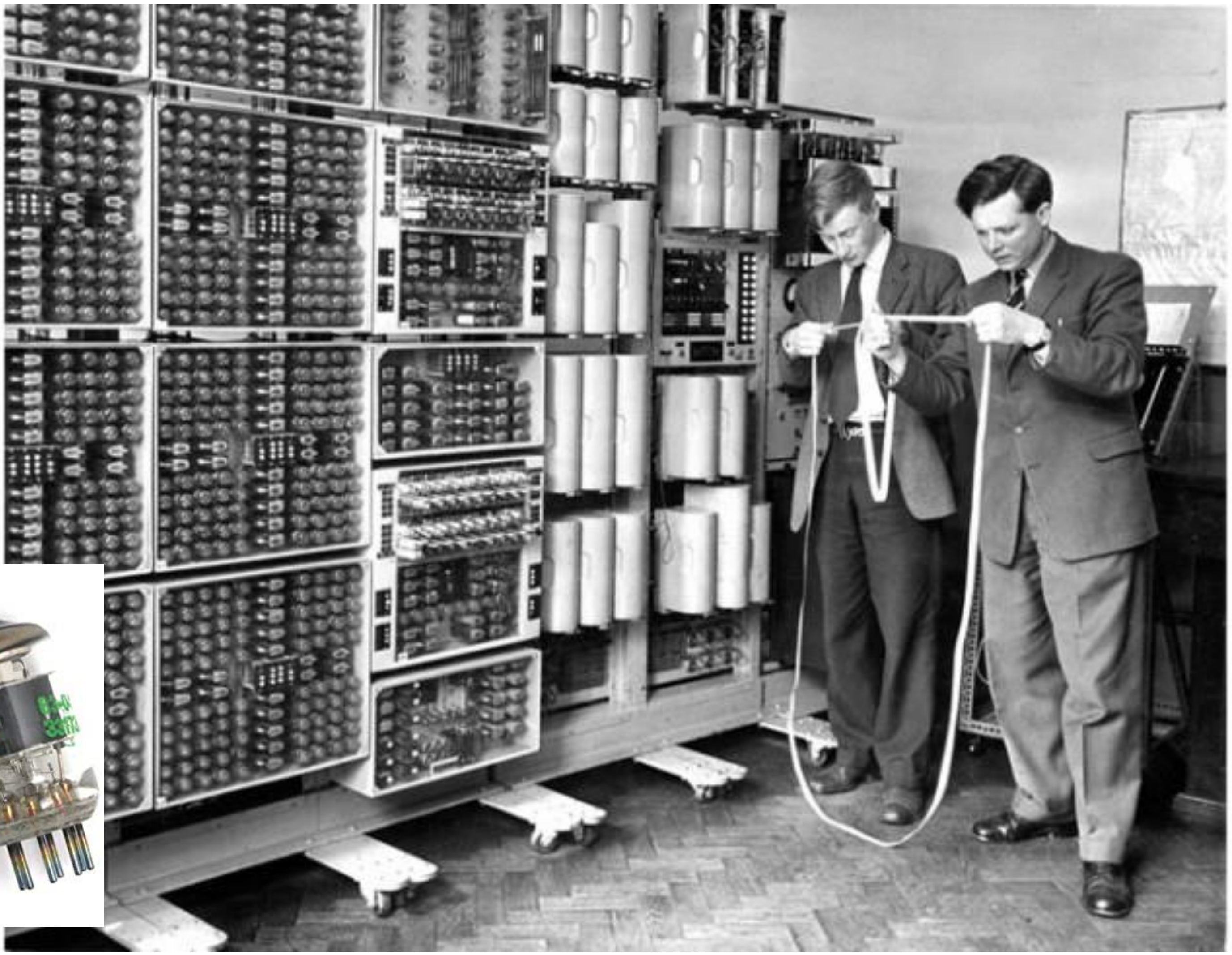
Transistor: the basic switching (0/1) component (discrete)

Software Complexity Increases



Source: http://bit.ly/KIB_linescode

Wolverhampton Instrument for Teaching Computing from Harwell (WITCH)



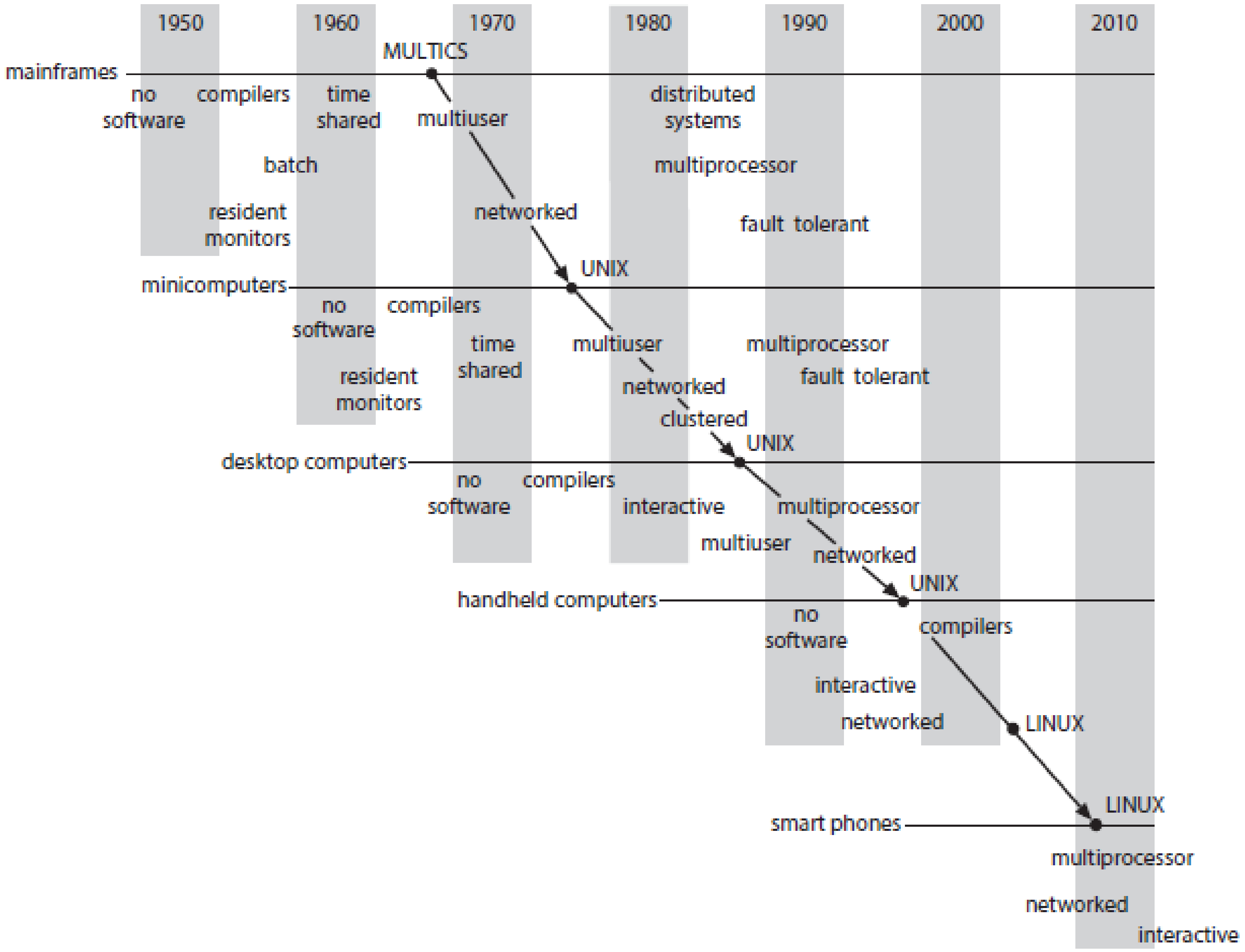
1951
No OS!

https://www.extremetech.com/extreme/140953-worlds-oldest-original-digital-computer-is-turned-back-on-after-61-years

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!!

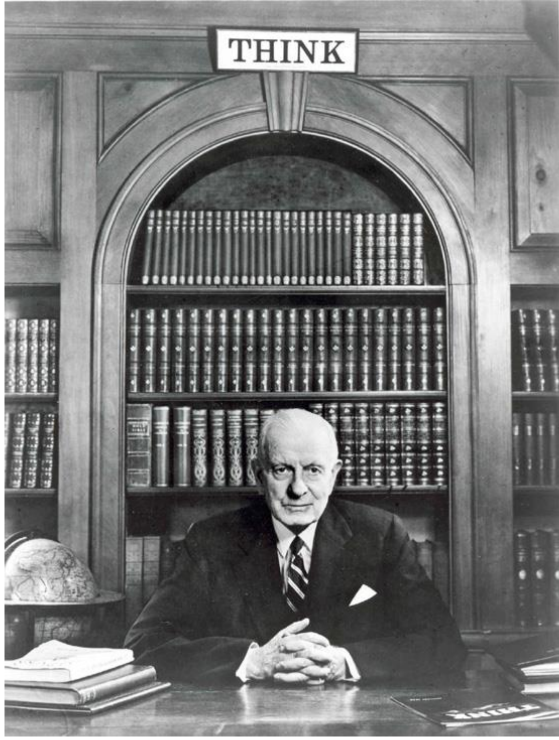
Progression of Concepts and Form Factors



An OS History Lesson

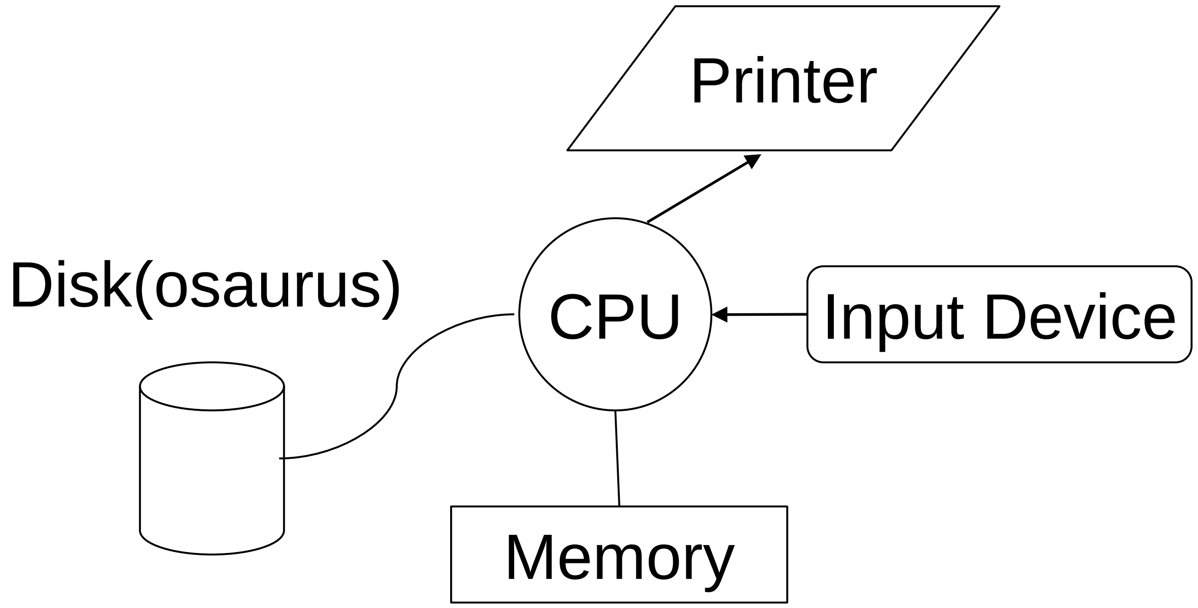
- Operating systems are the result of a 60 year long evolutionary process
  - They were born out of need
- We'll follow a bit of their evolution
- That should help make clear what some of their functions are, and why

In the Beginning...



- 1943
  - T.J. Watson (created IBM):
    " I think there is a world market for maybe <u>five computers</u>."
- Fast forward … 1950
  - There are maybe <u>20 computers in the world</u>
    - 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

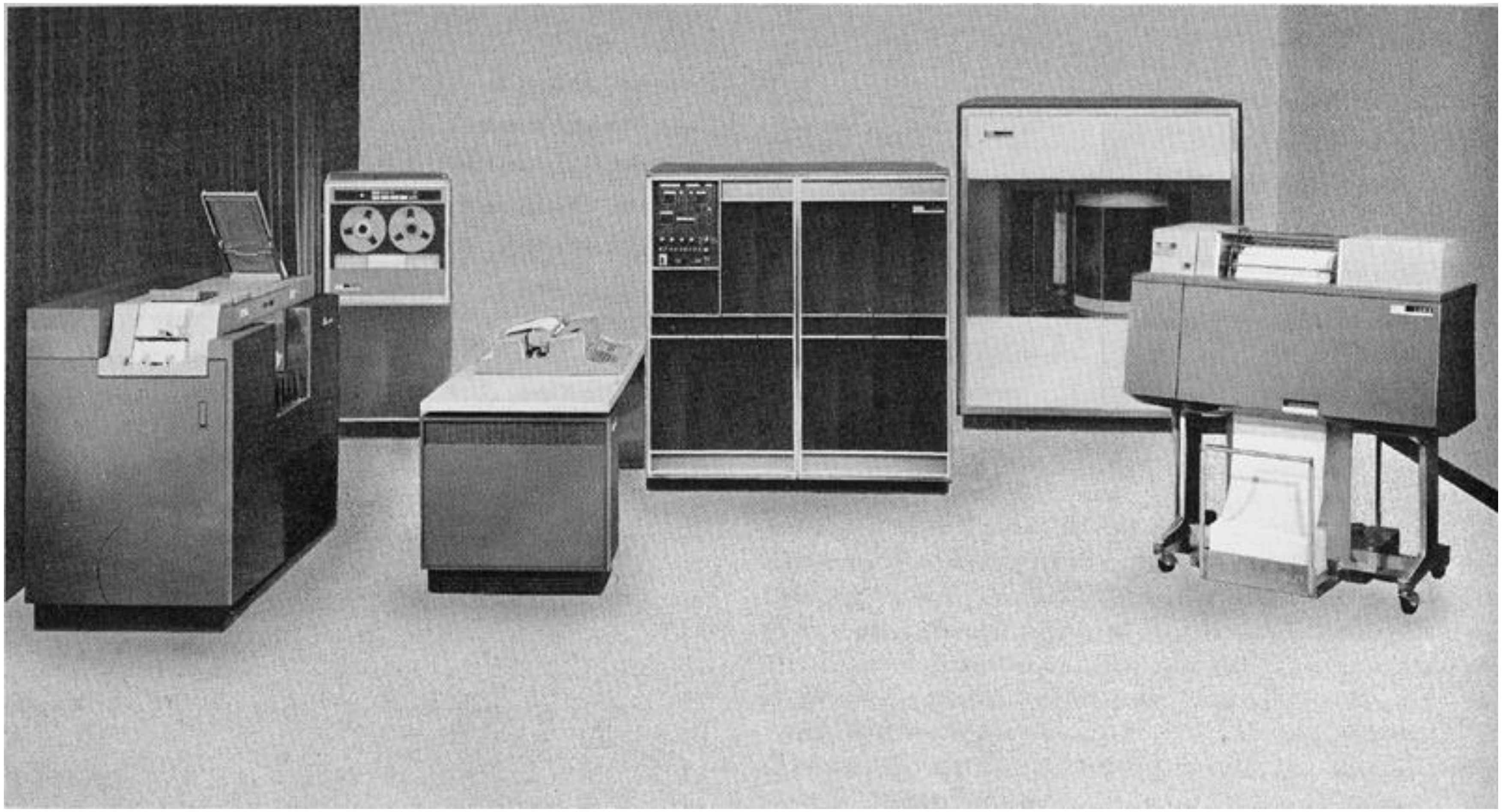


The OS as a linked library

- 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
      - Disk
      - Printer
      - …
  - 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 disk(osaurus) 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

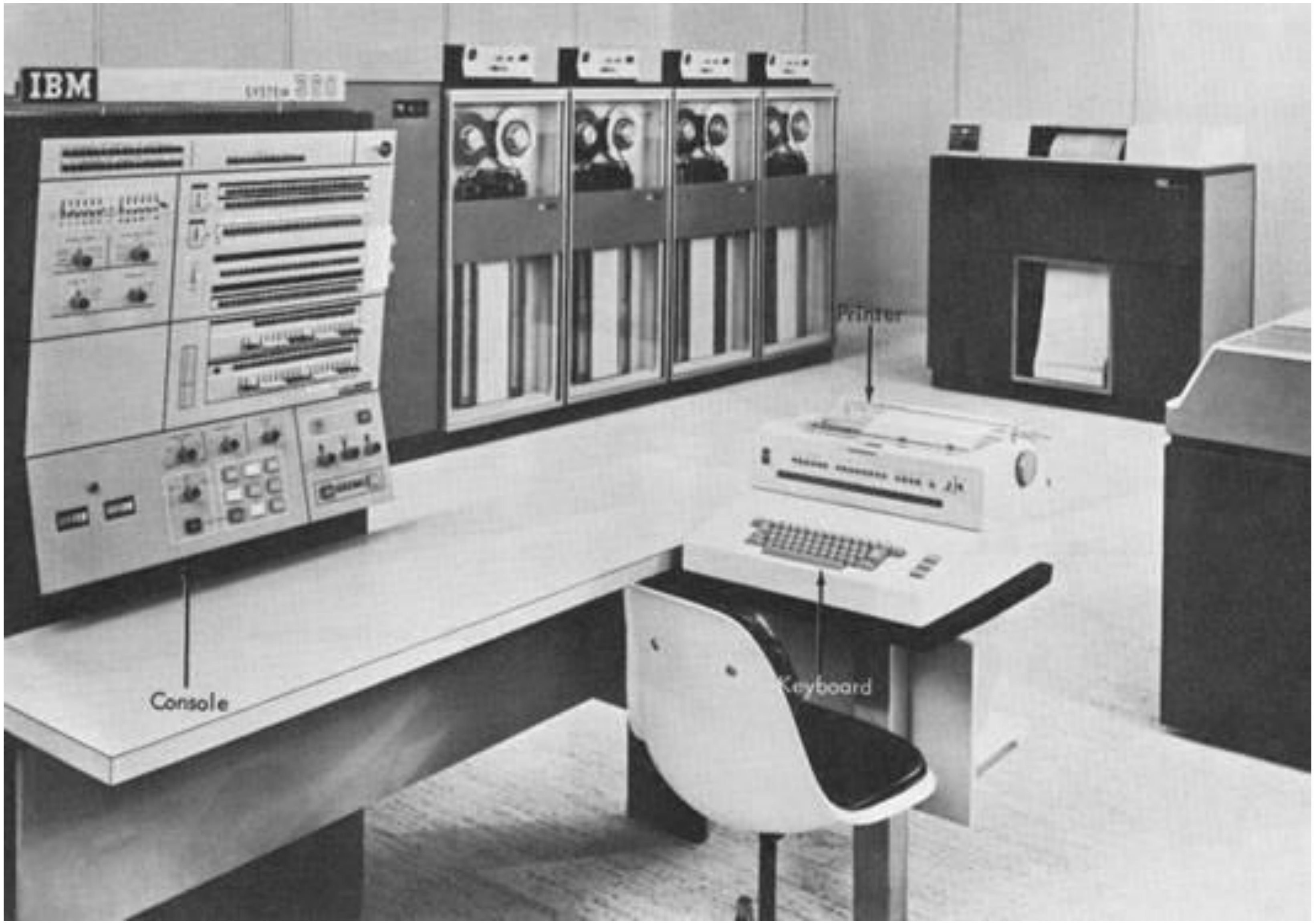


IBM 1401

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

From MIT …

- 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”

Multiple Terminals

- In early 1980s, a single timeshared VAX-11/780 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)

http://www.cs.man.ac.uk/CCS/res/res49.htm

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 applications running among multiple computers
  - interprocess communication
    - message passing, shared memory
  - networking stacks
- Sharing of distributed resources (hardware, software)
  - load balancing, authentication and access control, …

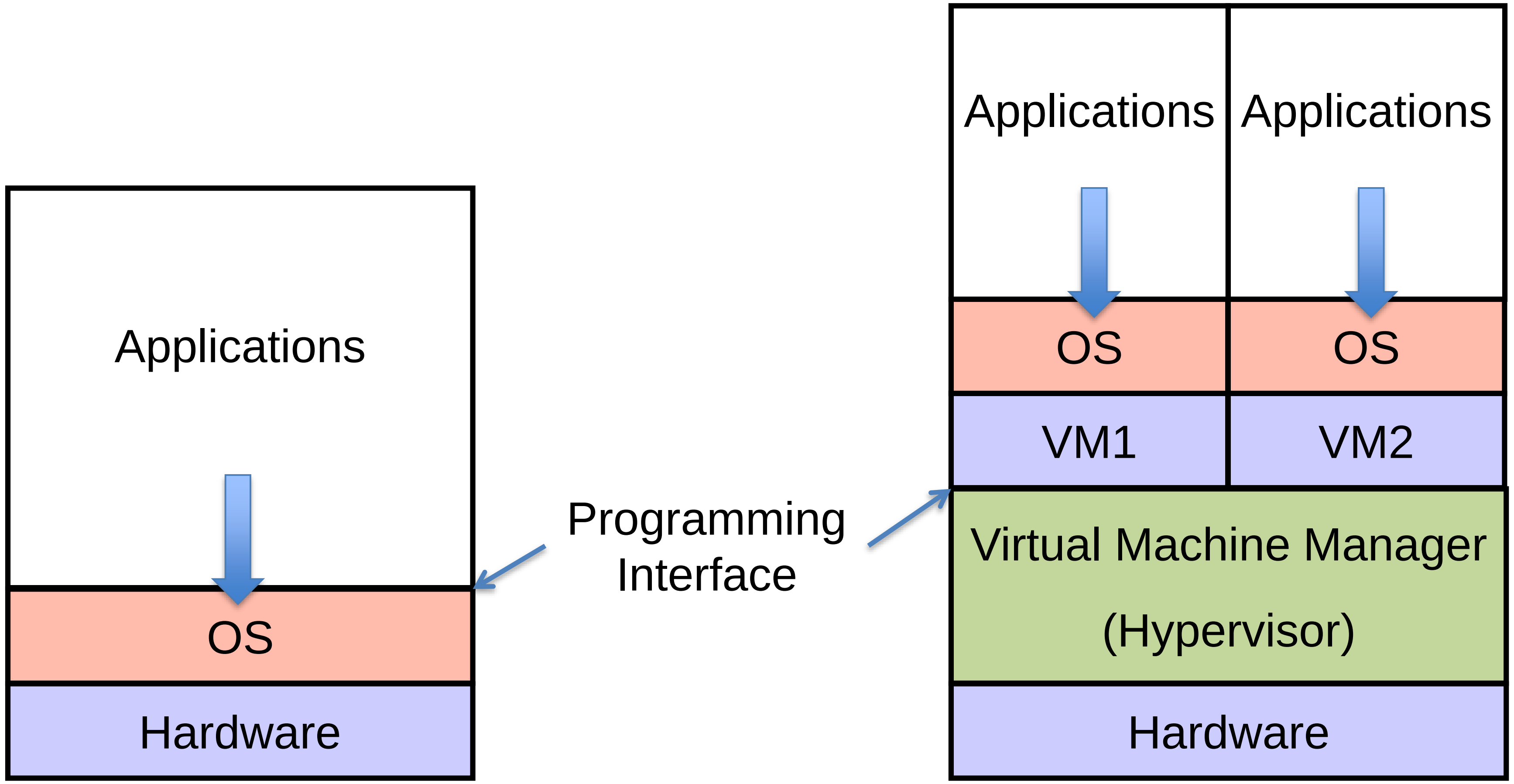
Client/Server Computing

- 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

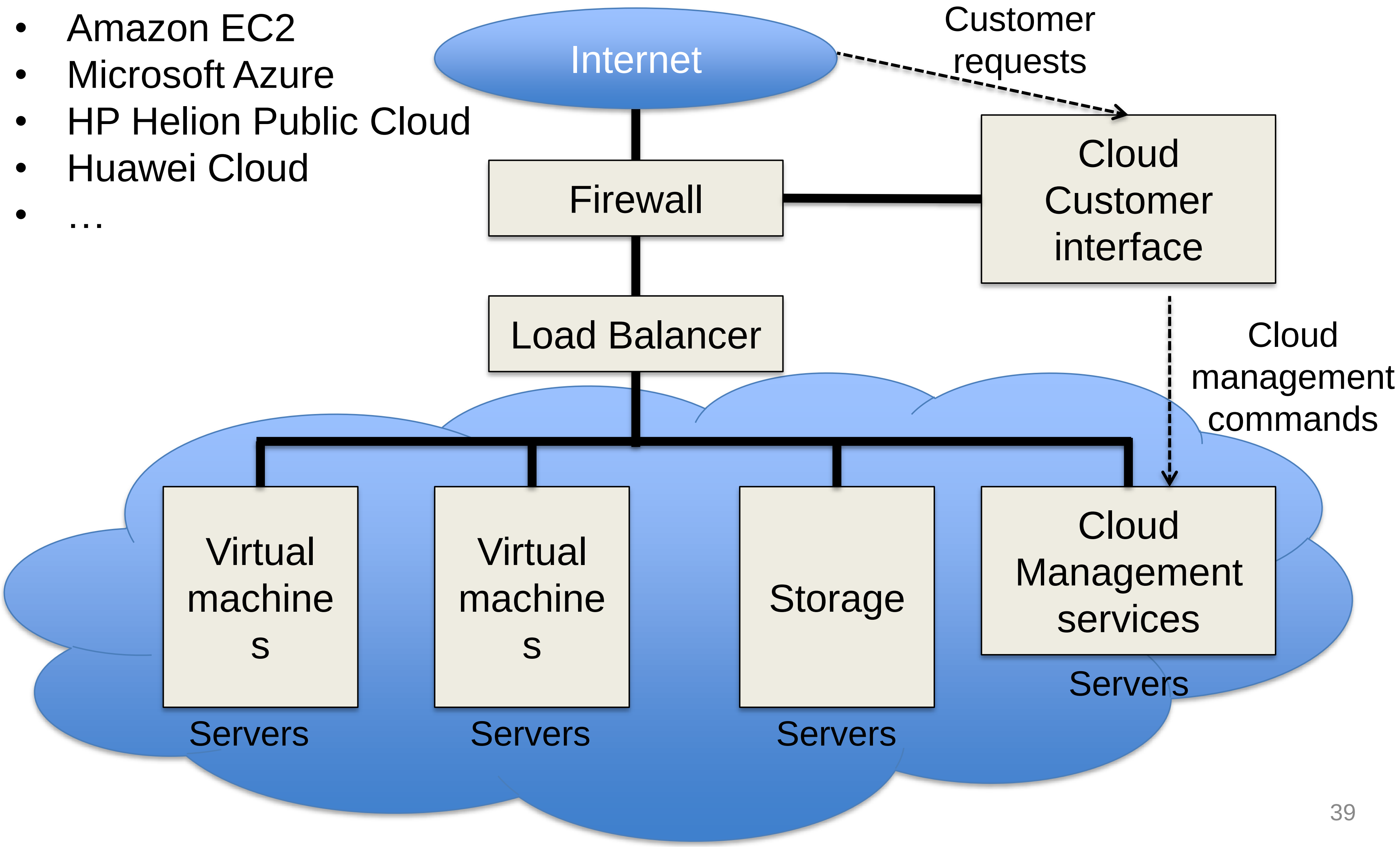
- Napster
- Gnutella
- BitTorrent
  - example technical challenge: self-organizing overlay network
  - technical advantage of BitTorrent?
  - er … legal advantage of BitTorrent?

Virtualization



Cloud Computing

- Amazon EC2
- Microsoft Azure
- HP Helion Public Cloud
- Huawei 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
- Almost all code runs on top an OS
  - Almost every computing device runs an OS
- But you need to understand the foundations
  - As a Computer Scientist or Computer Engineer
- Knowledge of how OSes work is crucial to proper, efficient, effective, and secure programming

It is a Great Time to Study Operating Systems!

- Many open-source OS projects
  - Check, study, and modify the code
  - Help find and fix bugs
- Emulators to run and debug OSes
  - Existent OSes
  - Historical/Future OSes (hardware not available)
- Renewed interest in OSes from major IT Companies
  - Rise of unikernels
  - Fully formally verified OSes
  - New OSes (e.g. Google Fucsia)