Computer Architecture
(计算机体系结构)

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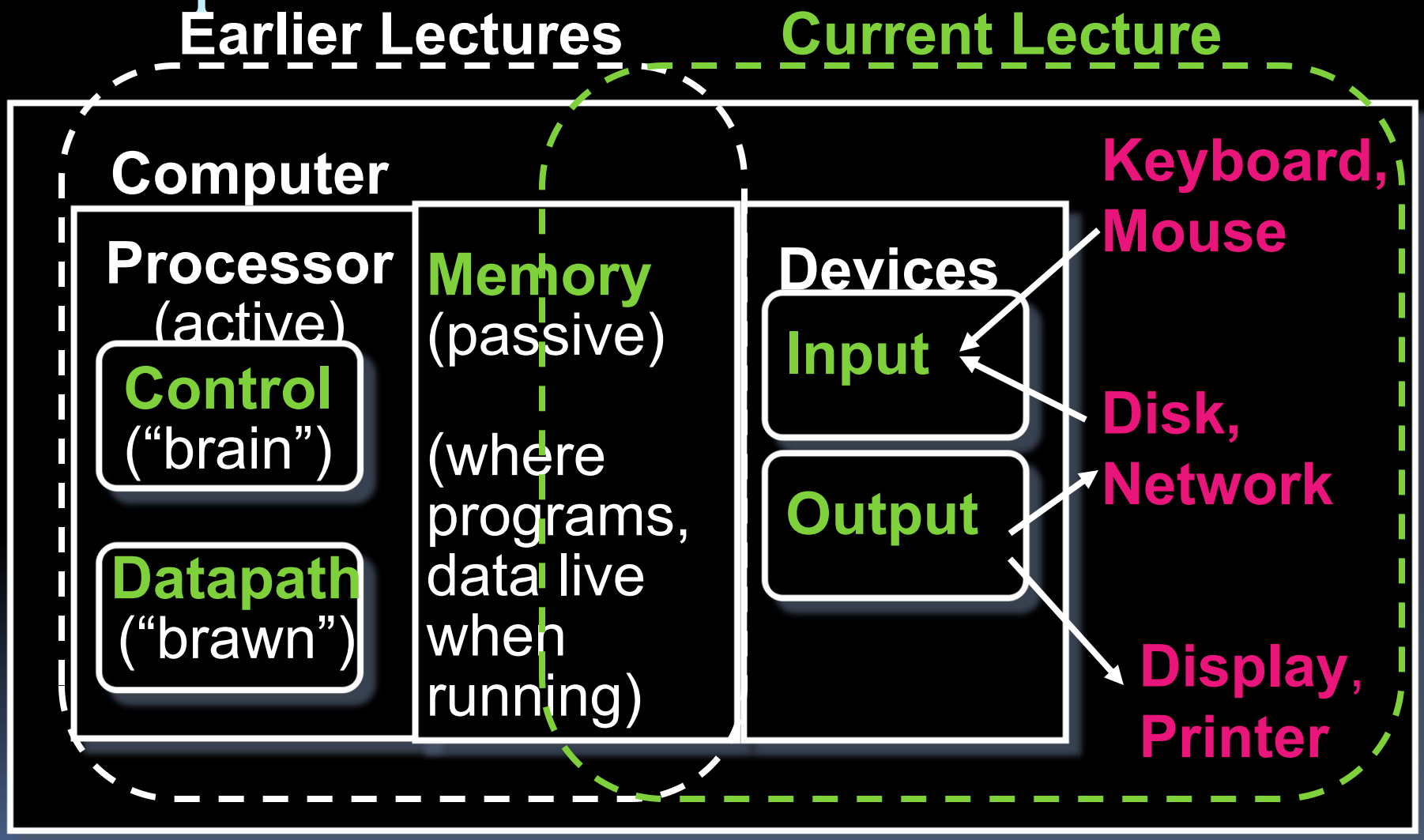
Lecture 32 – Input / Output
2020-11-06

We've merged 3 lectures into 1...

I/O BASICS

Recall : 5 components of any Computer



Motivation for Input/Output

- I/O is how humans interact with computers
- I/O gives computers long-term memory.
- I/O lets computers do amazing things:

Read pressure of synthetic hand and control synthetic arm and hand of fireman

Control propellers, fins, communicate in BOB (Breathable Observable Bubble)

- Computer without I/O like a car w/no wheels; great technology, but gets you nowhere

I/O Device Examples and Speeds

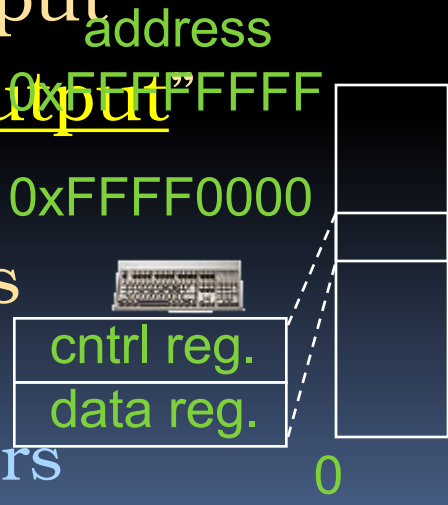
- I/O Speed: bytes transferred per second (from mouse to Gigabit LAN: 7 orders of mag!)

Device	Behavior	Partner	Data Rate (KB/s)
Keyboard	Input	Human	0.01
Mouse	Input	Human	0.02
Voice output	Output	Human	5.00
Floppy disk	Storage	Machine	50.00
Laser Printer	Output	Human	100.00
Magnetic Disk	Storage	Machine	10,000.00
Wireless Network	I or O	Machine	10,000.00
Graphics Display	Output	Human	30,000.00
Wired LAN Network	I or O	Machine	125,000.00

When discussing transfer rates, use 10^x

Instruction Set Architecture for I/O

- What must the processor do for I/O?
  - Input: reads a sequence of bytes
  - Output: writes a sequence of bytes
- Some processors have special input and output instructions
- Alternative model (used by MIPS):
  - Use loads for input, stores for output
  - Called "Memory Mapped Input/Output"
  - A portion of the address space dedicated to communication paths to I/O devices (no mem there)
    - Instead, they correspond to registers in I/O devices



Processor-I/O Speed Mismatch

- 1GHz microprocessor can execute 1 billion load or store instructions per second, or 4,000,000 KB/s data rate
  - I/O devices data rates range from 0.01 KB/s to 125,000 KB/s
- Input: device may not be ready to send data as fast as the processor loads it
  - Also, might be waiting for human to act
- Output: device not be ready to accept data as fast as processor stores it
- What to do?

Processor Checks Status before Acting

- Each I/O device generally has 2 registers:
  - Control Register, says it's OK to read/write (I/O ready) [think of a flagman on a road]
  - Data Register, contains data
- Processor reads from Control Register in loop, spins while waiting for device to set Ready bit in Control reg ($0 \Rightarrow 1$) to say its OK
- Processor then loads from (input) or writes to (output) data register
  - Load from or Store into Data Register resets Ready bit ($1 \Rightarrow 0$) of Control Register
- This is called "Polling"

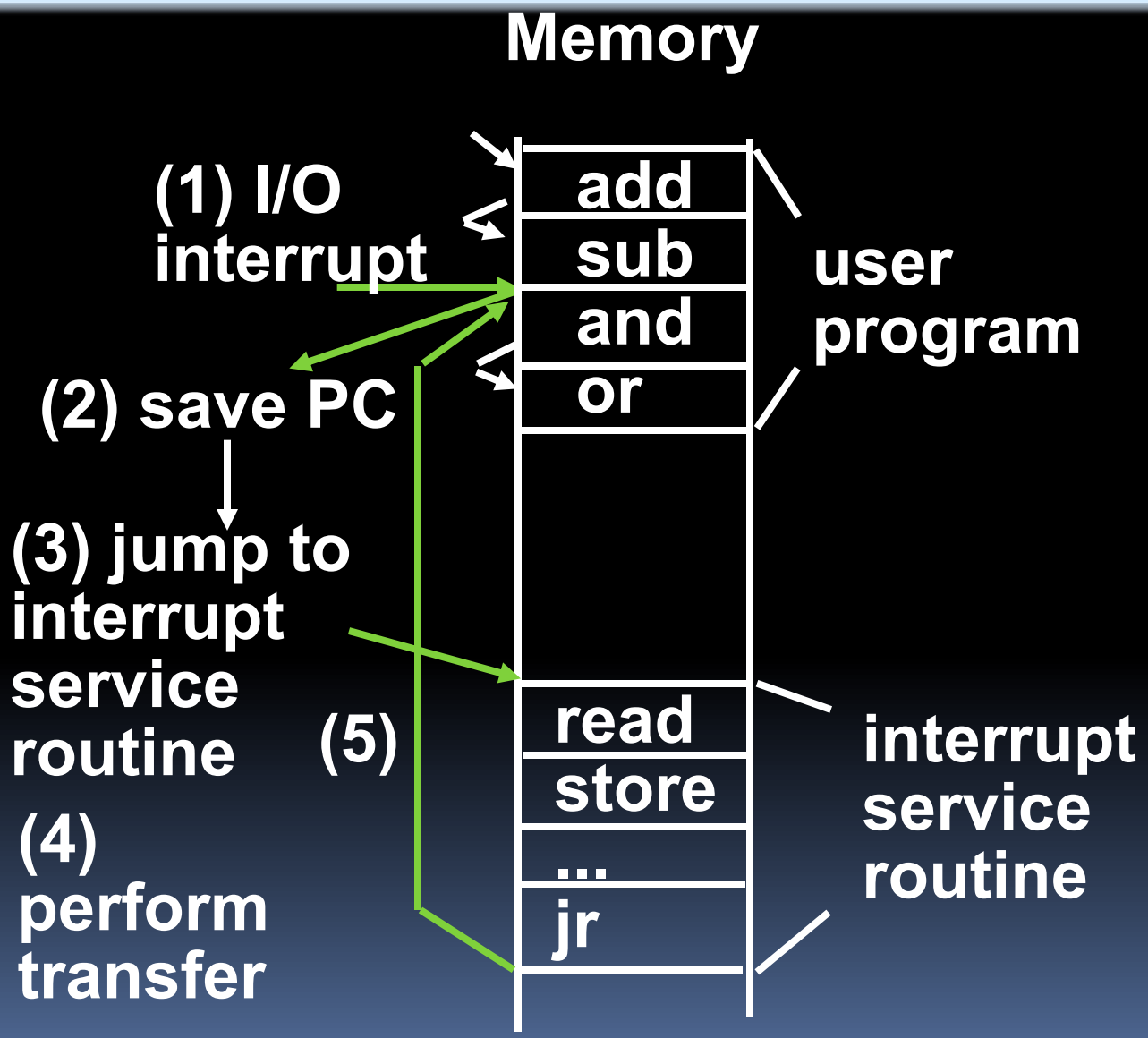
What is the alternative to polling?

- Wasteful to have processor spend most of its time “spin-waiting” for I/O to be ready
- Would like an unplanned procedure call that would be invoked only when I/O device is ready
- Solution: use exception mechanism to help I/O. Interrupt program when I/O ready, return when done with data transfer

I/O Interrupt

- An I/O interrupt is like overflow exceptions except:
  - An I/O interrupt is “asynchronous”
  - More information needs to be conveyed
- An I/O interrupt is asynchronous with respect to instruction execution:
  - I/O interrupt is not associated with any instruction, but it can happen in the middle of any given instruction
  - I/O interrupt does not prevent any instruction from completion

Interrupt-Driven Data Transfer



Administrivia

- Project 2 graded face-to-face, check web page for scheduling
- Project 3 (Cache simulator) out
  - You may work in pairs for this project
- Try the performance competition!
  - You may work in pairs for this too
  - Do it for fun!
  - Do it to shine!
  - Do it to test your metttle!
  - Do it for EPA!

Upcoming Calendar

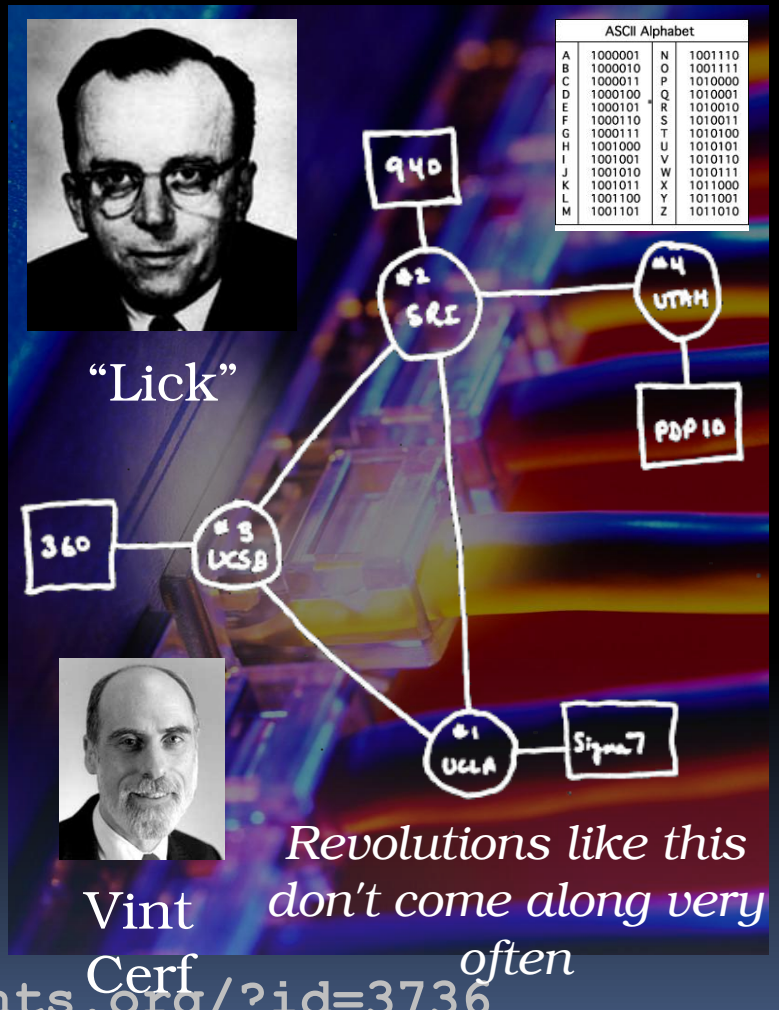
Week #	Mon	Wed	Thu Lab	Fri
#13 This week		I/O P3 out	VM	Performance
#14 Last week o' classes	Inter-machine Parallelism	Summary, Review, Evaluation	Parallel	Intra-machine Parallelism(Scott) P3 due
#15 RRR Week				Perf comp due 11:59pm
#16 Finals Week Review Sun May 9 3-6pm 10 Evans				Final Exam 8-11am in Hearst Gym

NETWORKS

www.computerhistory.org/internet_history

The Internet (1962)

- Founders
  - JCR Licklider, as head of ARPA, writes on "intergalactic network"
  - 1963 : ASCII becomes first universal computer standard
  - 1969 : Defense Advanced Research Projects Agency (DARPA) deploys 4 "nodes" @ UCLA, SRI, Utah, & UCSB
  - 1973 Robert Kahn & Vint Cerf invent TCP, now part of the Internet Protocol Suite www.greatachievements.org/?id=3736 en.wikipedia.org/wiki/Internet_Protocol_Suite
- Internet growth rates



Why Networks?

- Originally sharing I/O devices between computers
  - E.g., printers
- Then communicating between computers
  - E.g., file transfer protocol
- Then communicating between people
  - E.g., e-mail
- Then communicating between networks of computers
  - E.g., file sharing, www, …

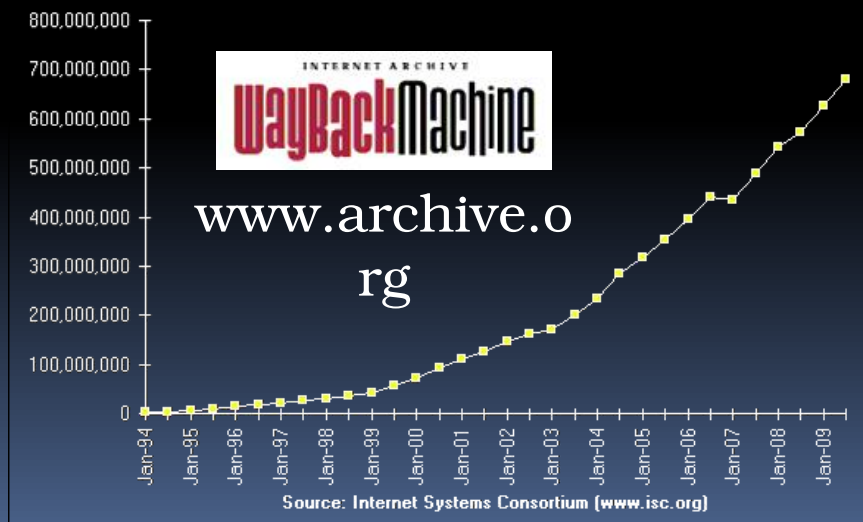
en.wikipedia.org/wiki/History_of_the_World_Wide_Web

The World Wide Web (1989)

- "System of interlinked hypertext documents on the Internet"
- History
  - 1945: Vannevar Bush describes hypertext system called "memex" in article
  - 1989: Tim Berners-Lee proposes, gets system up '90
  - ~2000 Dot-com entrepreneurs rushed in, 2001 bubble burst
- Wayback Machine
  - Snapshots of web over time

Tim Berners-Lee

World's First web server in 1990

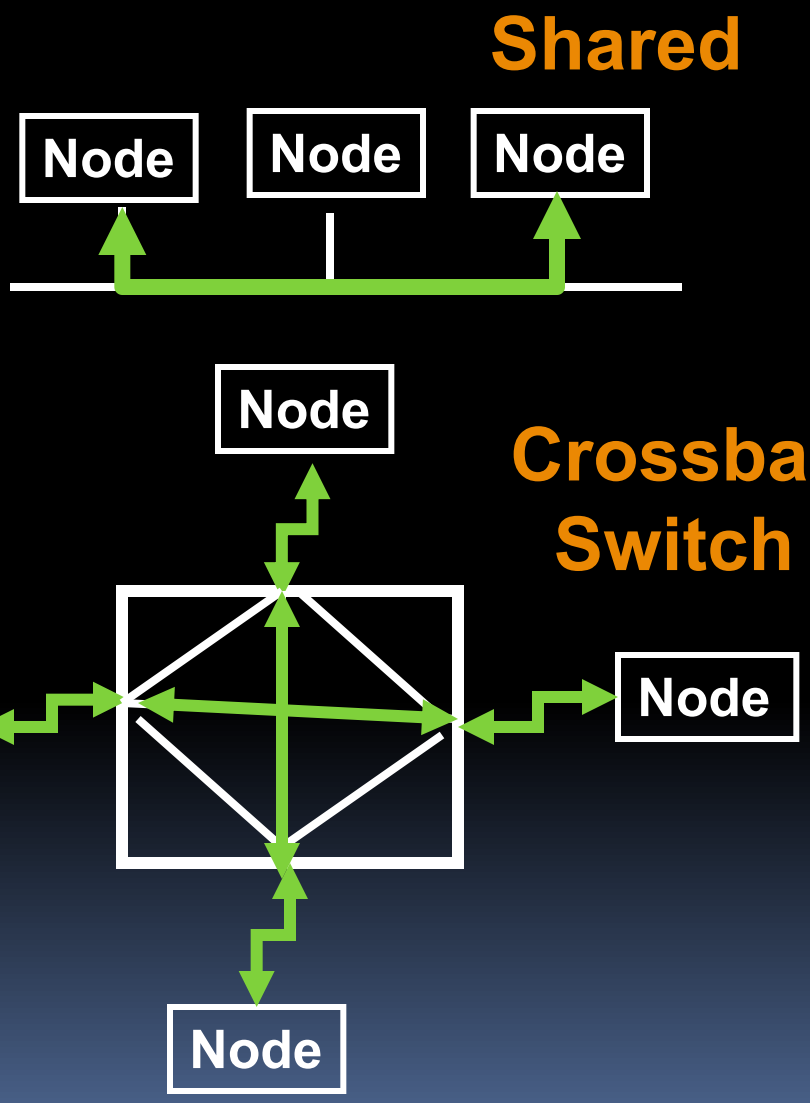


INTERNET ARCHIVE
WayBackMachine

www.archive.org

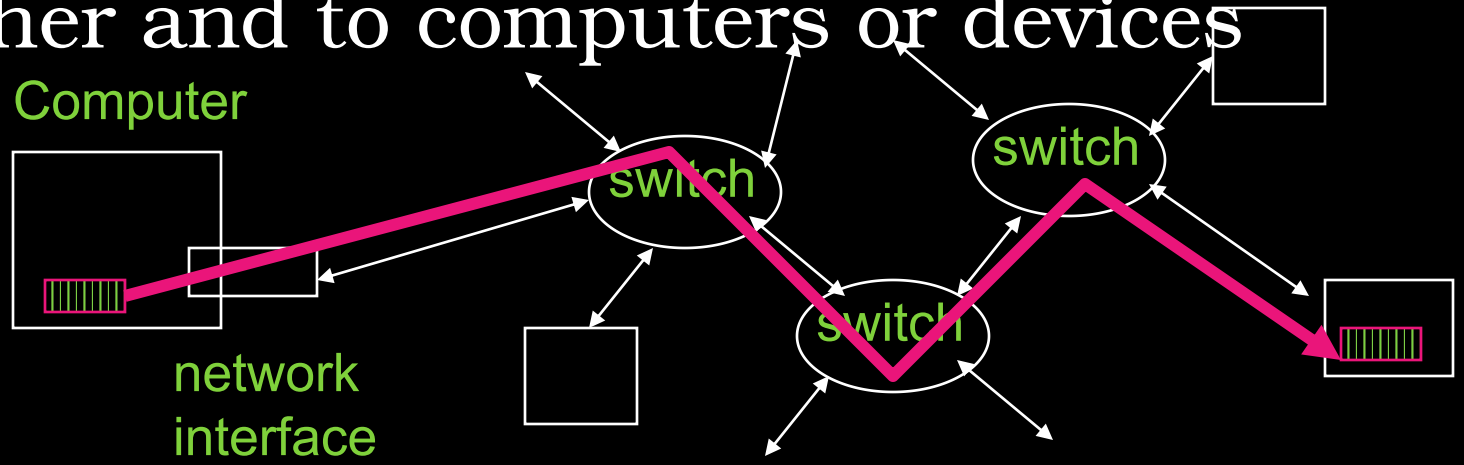
Shared vs. Switched Based Networks

- Shared vs. Switched:
  - Switched: pairs ("point-to-point" connections) communicate at same time
  - Shared: 1 at a time (CSMA/CD)
- Aggregate bandwidth (BW) in switched network is many times shared:
  - point-to-point faster since no arbitration, simpler



What makes networks work?

- links connecting switches to each other and to computers or devices



  - ability to name the components and to route packets of information - messages - from a source to a destination

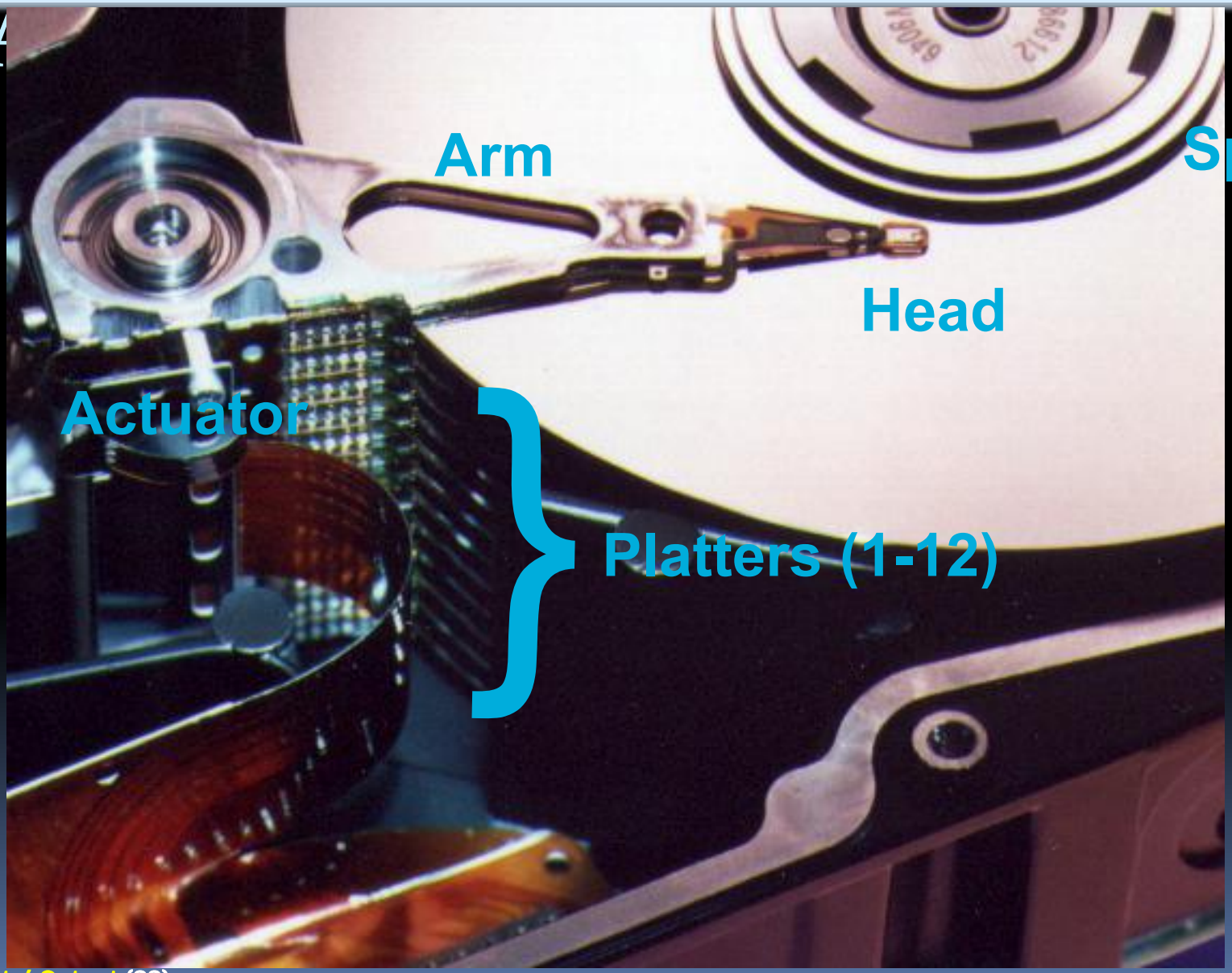
- Layering, redundancy, protocols, and encapsulation as means of abstraction (61C big idea)

DISKS

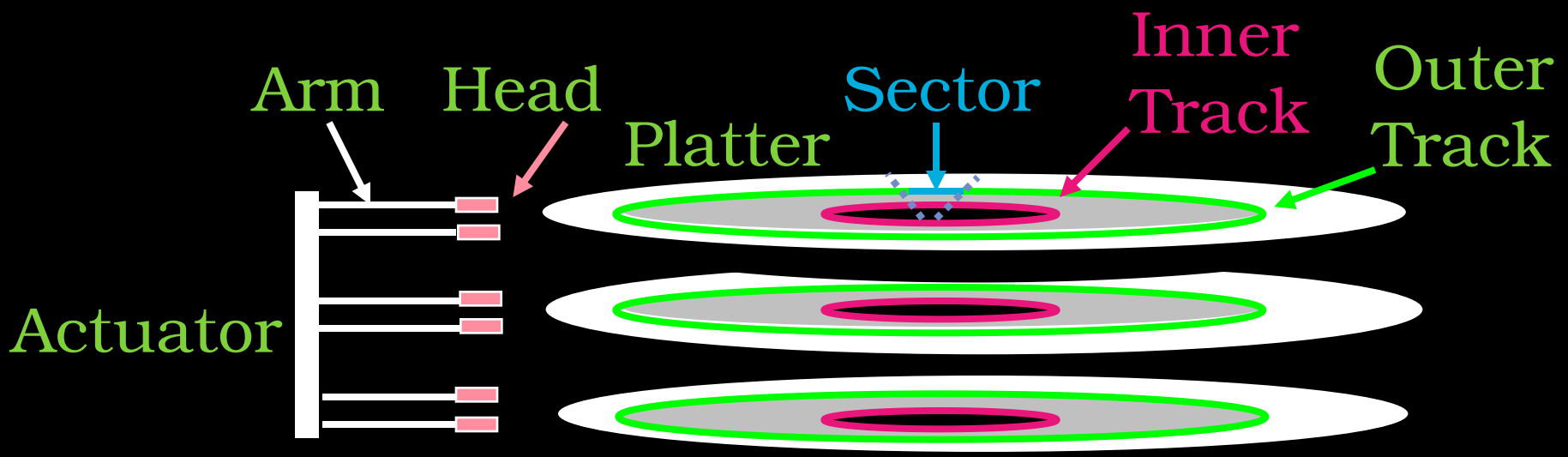
Magnetic Disk – common I/O device

- A kind of computer memory
  - Information stored by magnetizing ferrite material on surface of rotating disk
    - similar to tape recorder except digital rather than analog data
- Nonvolatile storage
  - retains its value without applying power to disk.
- Two Types
  - Floppy disks – slower, less dense, removable.
  - Hard Disk Drives (HDD) – faster, more dense, non-removable.
- Purpose in computer systems (Hard Drive):
  - Long-term, inexpensive storage for files
  - "Backup" for main-memory. Large, inexpensive, slow level in the memory hierarchy (virtual memory)

Photo of Disk Head, Arm, A

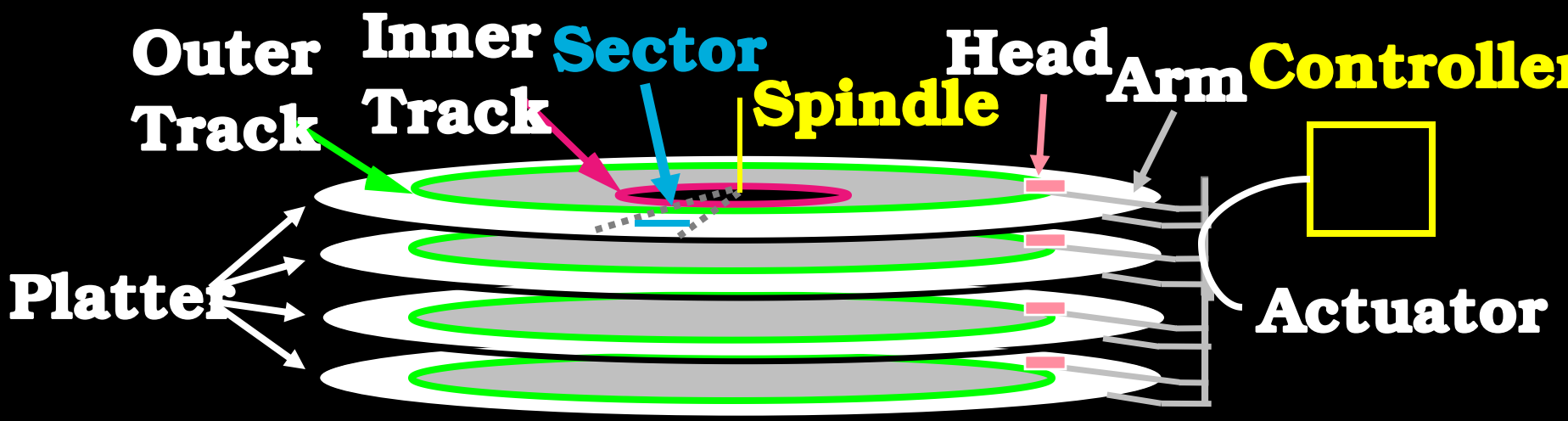


Disk Device Terminology



- Several platters, with information recorded magnetically on both surfaces (usually)
- **Bits recorded in tracks, which in turn divided into sectors (e.g., 512 Bytes)**
- **Actuator moves head (end of arm) over track ("seek"), wait for sector rotate under head, then read or write**

Disk Device Performance (1/2)



- **Disk Latency = Seek Time + Rotation Time + Transfer Time + Controller Overhead**
  - Seek Time? depends on no. tracks to move arm, speed of actuator
  - Rotation Time? depends on speed disk rotates, how far sector is from head
  - Transfer Time? depends on data rate (bandwidth) of disk (f(bit density,rpm)), size of request

Disk Device Performance (2/2)

- Average distance of sector from head?
- 1/2 time of a rotation
  - 7200 Revolutions Per Minute ⇒ 120 Rev/sec
  - 1 revolution = 1/120 sec ⇒ 8.33 milliseconds
  - 1/2 rotation (revolution) ⇒ 4.17 ms
- Average no. tracks to move arm?
  - Disk industry standard benchmark:
    - Sum all time for all possible seek distances from all possible tracks / # possible
    - Assumes average seek distance is random
- Size of Disk cache can strongly affect perf!
  - Cache built into disk system, OS knows nothing

Where does Flash memory come in?

- Microdrives and Flash memory (e.g., CompactFlash) are going head-to-head
  - Both non-volatile (no power, data ok)
  - Flash benefits: durable & lower power (no moving parts, need to spin µdrives up/down)
  - Flash limitations: finite number of write cycles (wear on the insulating oxide layer around the charge storage mechanism). Most ≥ 100K, some ≥ 1M W/erase cycles.

- How does Flash memory work?
  - NMOS transistor with an additional conductor between gate and source/drain which "traps" electrons. The presence/absence is a 1 or 0.

en.wikipedia.org/wiki/Flash_memory

en.wikipedia.org/wiki/Ipod
www.apple.com/ipod

What does Apple put in its iPods?

Toshiba flash 1, 2GB

Samsung flash 4, 8GB

Toshiba 1.8-inch HDD 80, 160GB

Toshiba flash 8, 16, 32GB

shuffle, nano, classic, touch

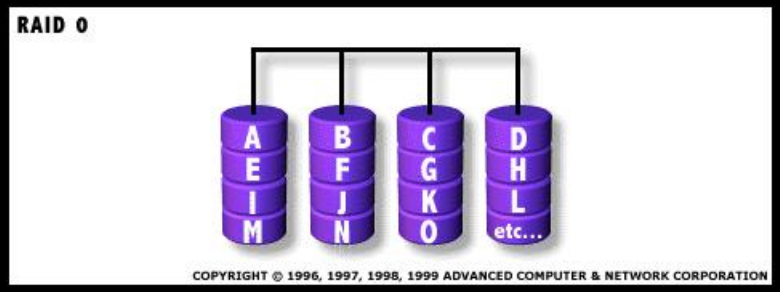
RAID : Redundant Array of Inexpensive Disks

- Invented @ Berkeley (1989)
- A multi-billion industry
  80% non-PC disks sold in RAID
- Idea:
  - Files are "striped" across multiple
  - Redundancy yields high data avail
    - Disks will still fail
  - Contents reconstructed from data redundantly stored in the array
    - Capacity penalty to store redundant info
    - Bandwidth penalty to update redundant info

Common RAID configurations

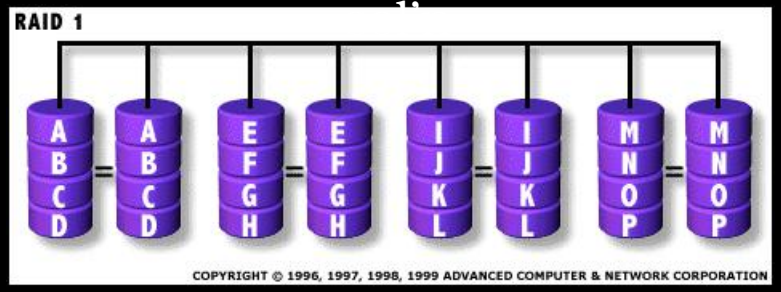
RAID 0

No redundancy, Fast access



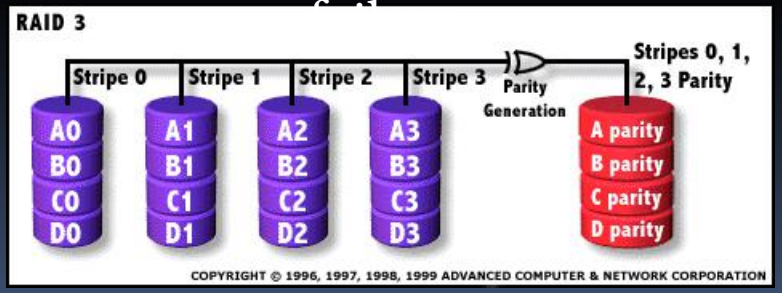
RAID 1

Mirror Data, most expensive



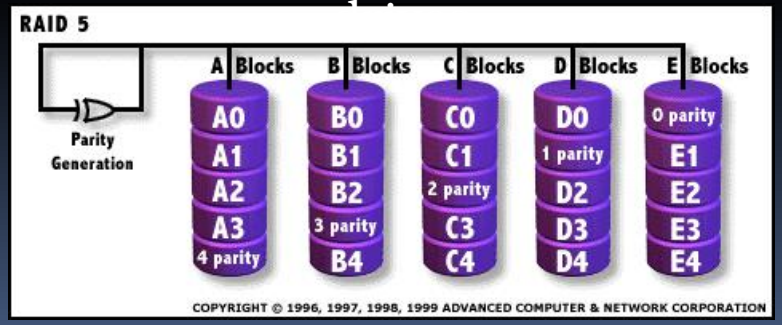
RAID 3

Parity drive protects against 1



RAID 5

Rotated parity across all



“And in conclusion…”

- I/O gives computers their 5 senses
- I/O speed range is 100-million to one
- Processor speed means must synchronize with I/O devices before use
- Polling works, but expensive
  - processor repeatedly queries devices
- Interrupts works, more complex
  - devices causes an exception, causing OS to run and deal with the device
- I/O control leads to Operating Systems