inst.eecs.berkeley.edu/~cs61c/su05

CS61C : Machine Structures

Lecture #26: Disks & Networks

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Andy Carle

Outline

- **Buses**
- **Networks**
- **Disks**

Buses in a PC: connect a few devices (2002)

Bus - shared medium of communication that can connect to many devices. Hierarchy!!

CPU

Memory bus (FSB)

Memory

PCI Interface

PCI: Internal (Backplane) I/O bus

Ethernet Interface

SCSI Interface

SCSI: External I/O bus

(1 to 15 disks)

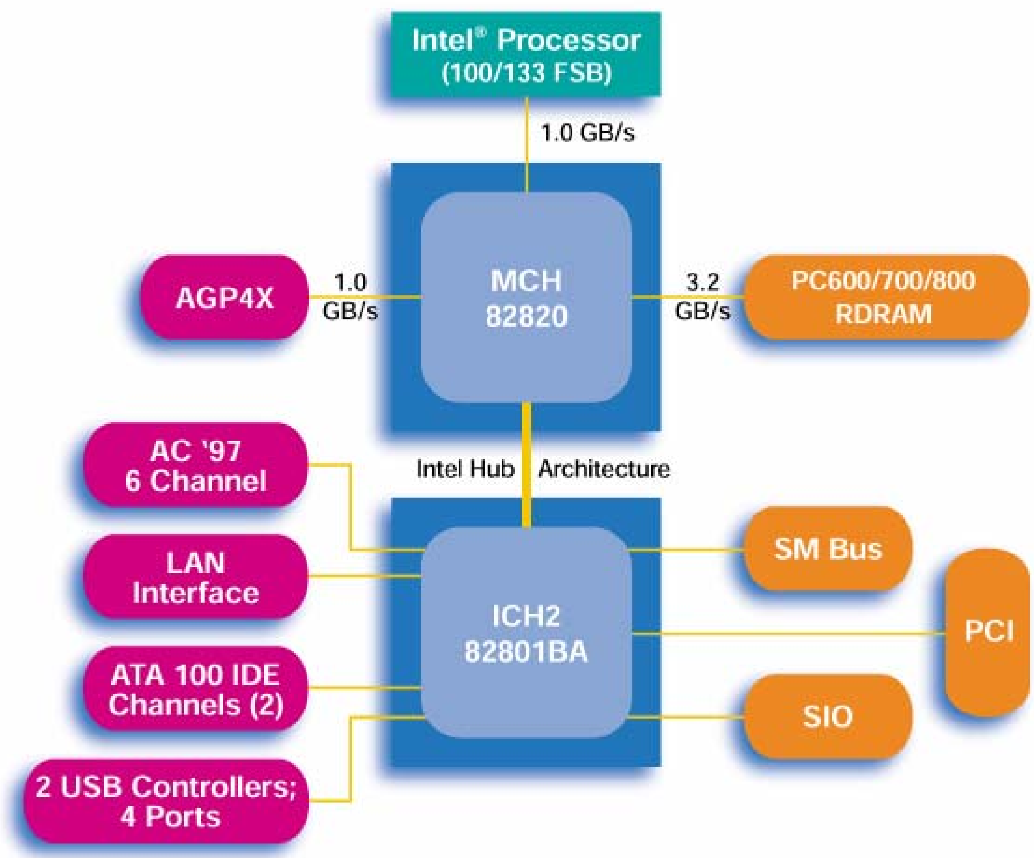
Ethernet Local Area Network

- Data rates (P4)
  - Memory: 400 MHz, 8 bytes $\Rightarrow$ 3.2 GB/s (peak)
  - PCI: 100 MHz, 8 bytes wide $\Rightarrow$ 0.8 GB/s (peak)
  - SCSI: “Ultra4” (160 MHz), “Wide” (2 bytes) $\Rightarrow$ 0.3 GB/s (peak)

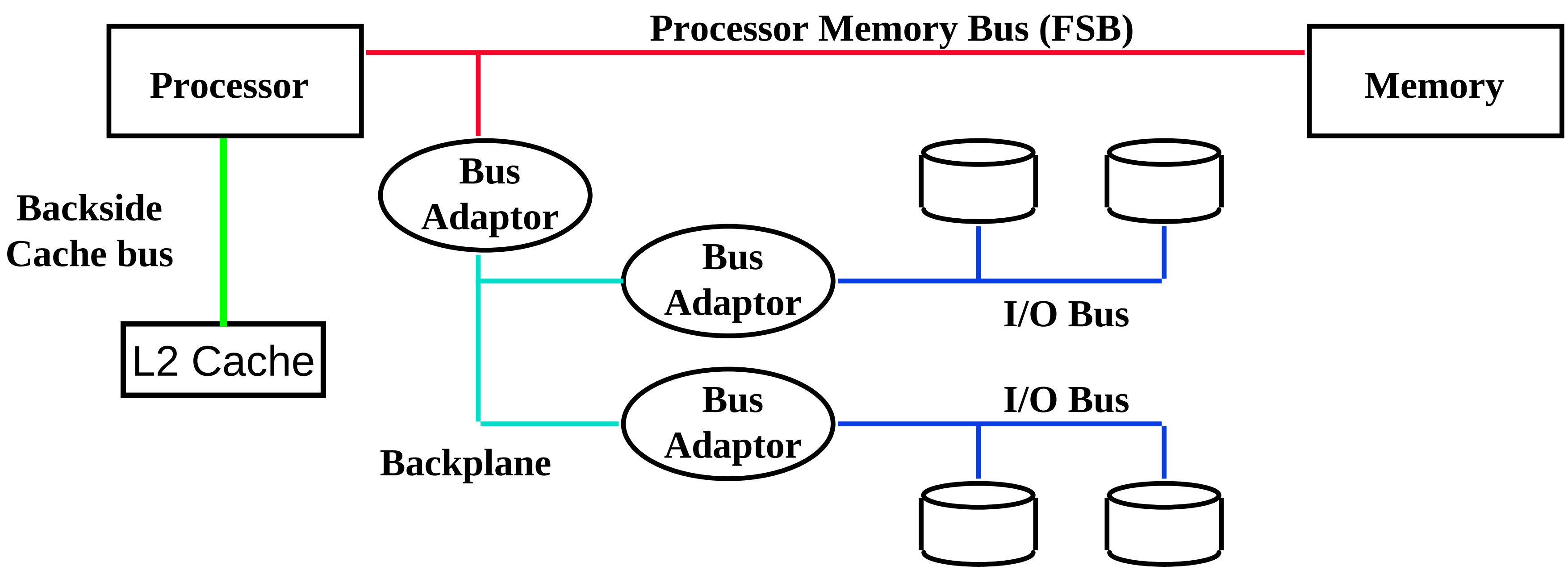
Gigabit Ethernet: $\Rightarrow$ 0.125 GB/s (peak)

Main components of Intel Chipset: Pentium II/III

- **Northbridge:**
  - **Handles memory**
  - **Graphics**
- **Southbridge: I/O**
  - **PCI bus**
  - **Disk controllers**
  - **USB controlers**
  - **Audio**
  - **Serial I/O**
  - **Interrupt controller**
  - **Timers**



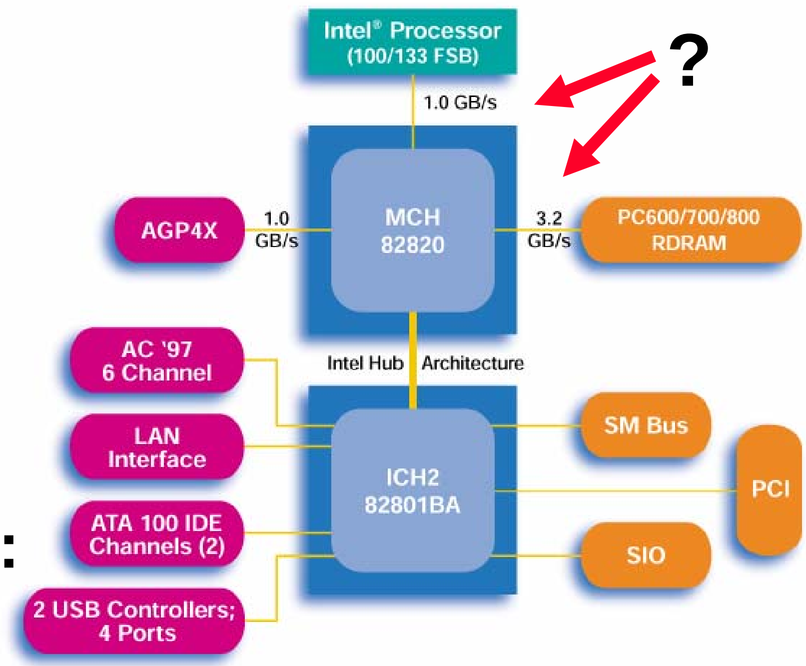
A Three-Bus System (+ backside cache)



- A small number of backplane buses tap into the processor-memory bus
    - FSB bus is only used for processor-memory traffic
    - I/O buses are connected to the backplane bus (PCI)
    - Advantage: load on the FSB is greatly reduced

What is DMA (Direct Memory Access)?

- **Typical I/O devices must transfer large amounts of data to memory of processor:**
  - **Disk must transfer complete block**
  - **Large packets from network**
  - **Regions of frame buffer**



- **DMA gives external device ability to access memory directly:**
  - **much lower overhead than having processor request one word at a time.**

- **Issue: Cache coherence:**
  - **What if I/O devices write data that is currently in processor Cache?**
    - **The processor may never see new data!**
  - **Solutions:**
    - **Flush cache on every I/O operation (expensive)**
    - **Have hardware invalidate cache lines ("Coherence" cache misses?)**

Outline

- Buses
- Networks
- Disks

Why Networks?

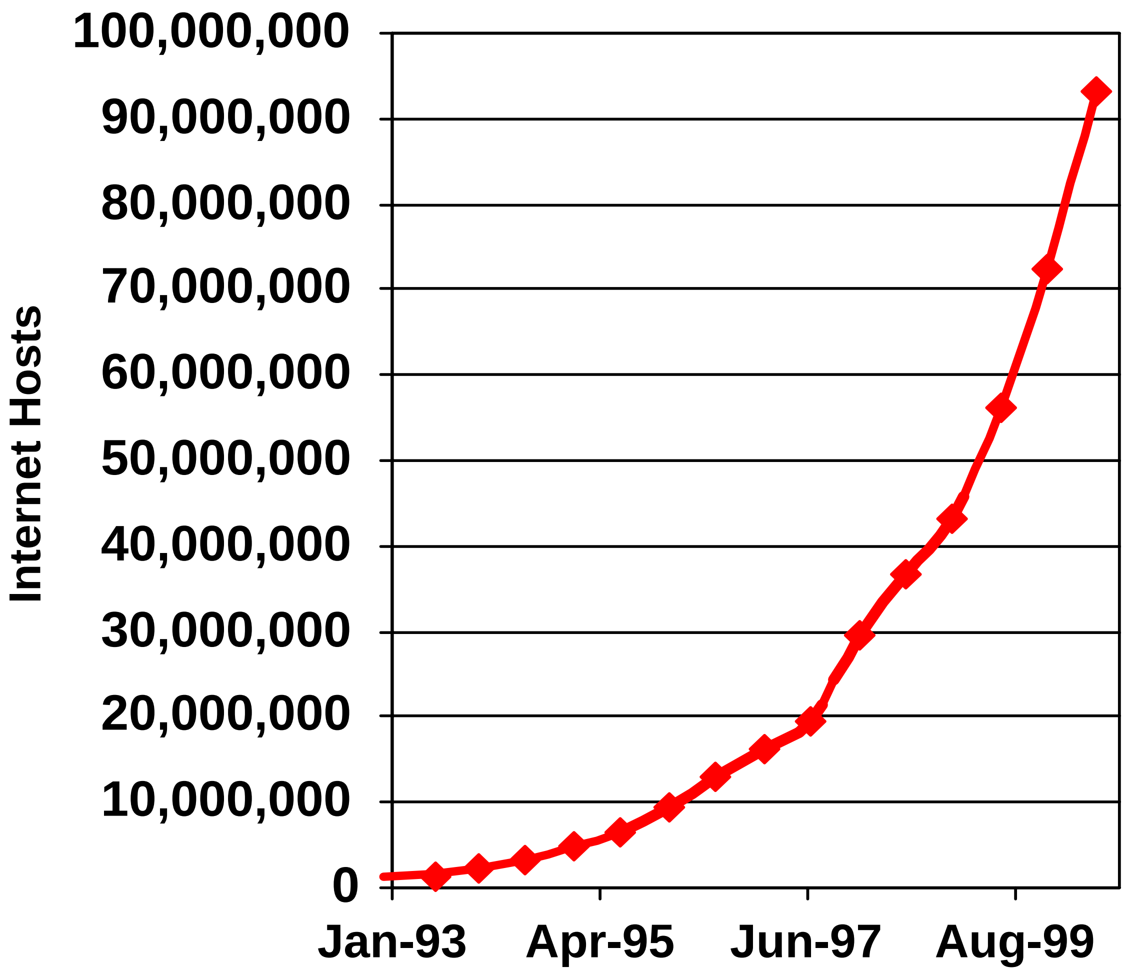
- Originally sharing I/O devices between computers
  (e.g., printers)
- Then Communicating between computers
  (e.g, file transfer protocol)
- Then Communicating between people
  (e.g., email)
- Then Communicating between networks of computers
  ⇒ p2p File sharing, WWW, …

How Big is the Network (1999)?

~30	Computers in 271 Soda
~400	in inst.cs.berkeley.edu
~4,000	in eecs&cs .berkeley.edu
~50,000	in berkeley.edu
~5,000,000	in .edu
~46,000,000	in US (.com .net .edu .mil .us .org)
~56,000,000	in the world

Source: Internet Software Consortium

Growth Rates



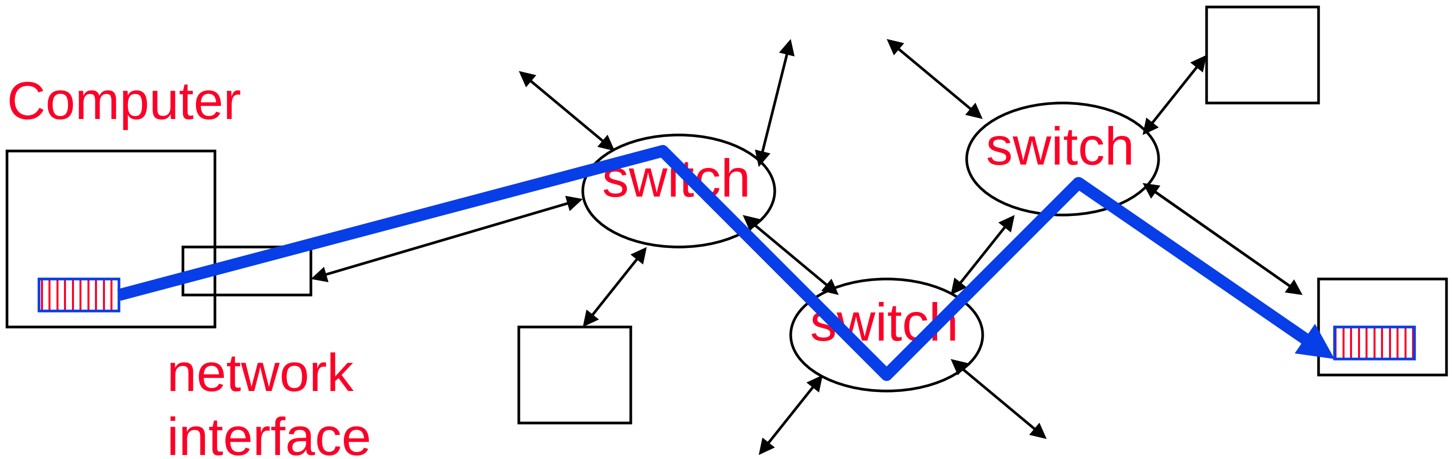
Ethernet Bandwidth

1983	3 mb/s
1990	10 mb/s
1997	100 mb/s
1999	1000 mb/s
2004	10 Gig E

"Source: Internet Software Consortium (http://www.isc.org/)".

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

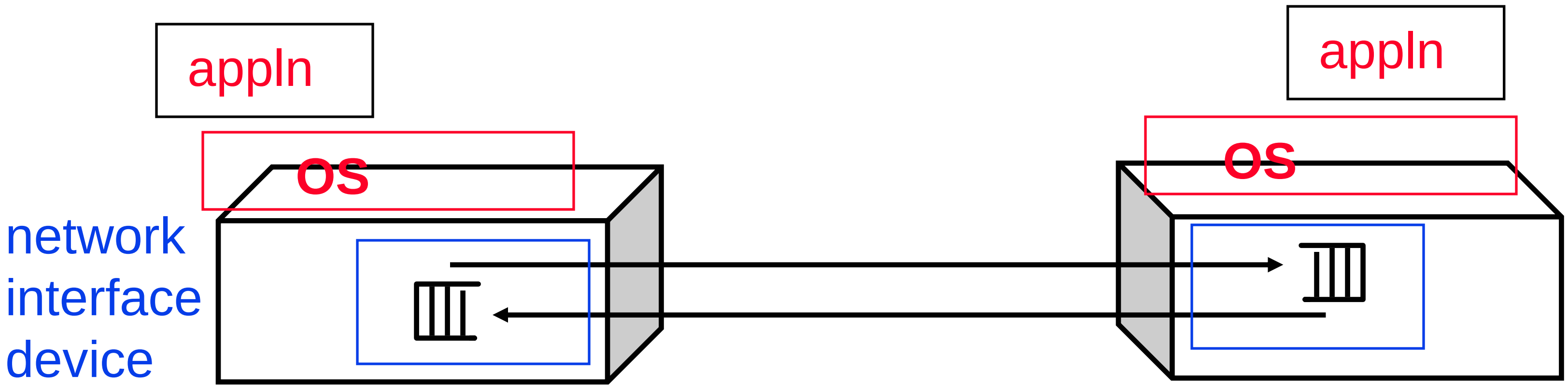
- Layering, protocols, and encapsulation as means of abstraction (61C big idea)

Typical Types of Networks

- **Local Area Network (Ethernet)**
  - Inside a building: Up to 1 km
  - (peak) Data Rate: 10 Mbits/sec, 100 Mbits /sec,10Gbits/sec (1.25, 12.5, 1250 MBytes/s)
  - Run, installed by network administrators
- **Wide Area Network**
  - Across a continent (10km to 10000 km)
  - (peak) Data Rate: 1.5 Mb/s to >10000 Mb/s
  - Run, installed by telecommunications companies (Sprint, UUNet[MCI], AT&T)
- **Wireless Networks**

ABCs of Networks: 2 Computers

- **Starting Point: Send bits between 2 computers**



- **Queue (First In First Out) on each end**
- **Can send both ways ("Full Duplex")**
- **Information sent called a "message"**
  - **Note: Messages also called packets**

A Simple Example: 2 Computers

- **What is Message Format?**
  - **Similar idea to Instruction Format**
  - **Fixed size? Number bits?**

Length	**Data**
8 bit	**32 x Length bits**

- **Header(Trailer): information to deliver message**
- **Payload: data in message**
- **What can be in the data?**
  - **anything that you can represent as bits**
  - **values, chars, commands, addresses...**

Questions About Simple Example

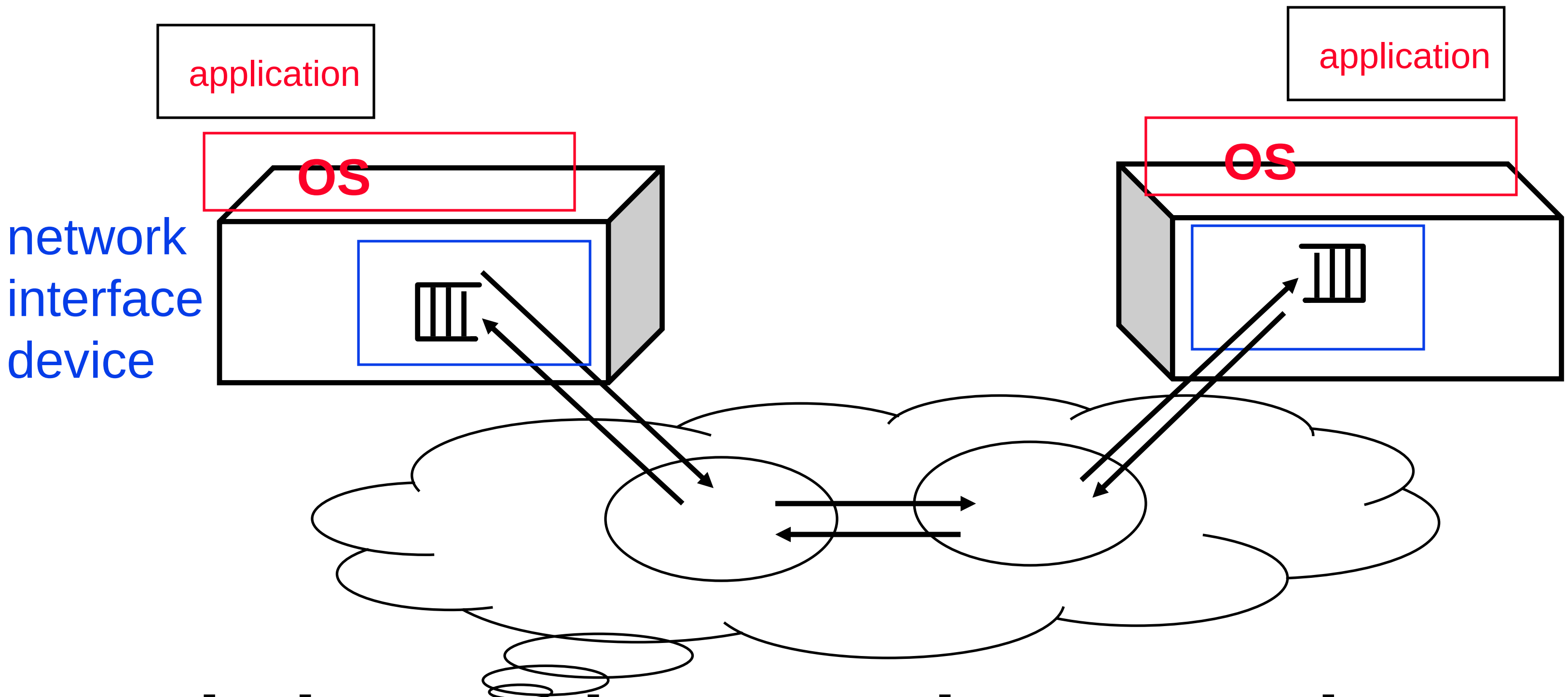
- **What if more than 2 computers want to communicate?**
  - **Need computer "address field" in packet to know which computer should receive it (destination), and to which computer it came from for reply (source) [just like envelopes!]**

Dest.	Source	Len	
Net ID	Net ID		CMD/ Address /Data
8 bits	8 bits	8 bits	32xn bits

Header

Payload

ABCs: many computers



- switches and routers interpret the header in order to deliver the packet
- source encodes and destination decodes content of the payload

Questions About Simple Example

- What if message is garbled in transit?
- Add redundant information that is checked when message arrives to be sure it is OK
- 8-bit sum of other bytes: called "Check sum"; upon arrival compare check sum to sum of rest of information in message

Math 55 talks about what a Check sum is…

Questions About Simple Example

- What if message never arrives?
- Receiver tells sender when it arrives (ack) [ala registered mail], sender retries if waits too long
- Don’t discard message until get “ACK” (for ACKnowledgment);
Also, if check sum fails, don’t send ACK

Observations About Simple Example

- **Simple questions such as those above lead to more complex procedures to send/receive message and more complex message formats**
- **Protocol: algorithm for properly sending and receiving messages (packets)**

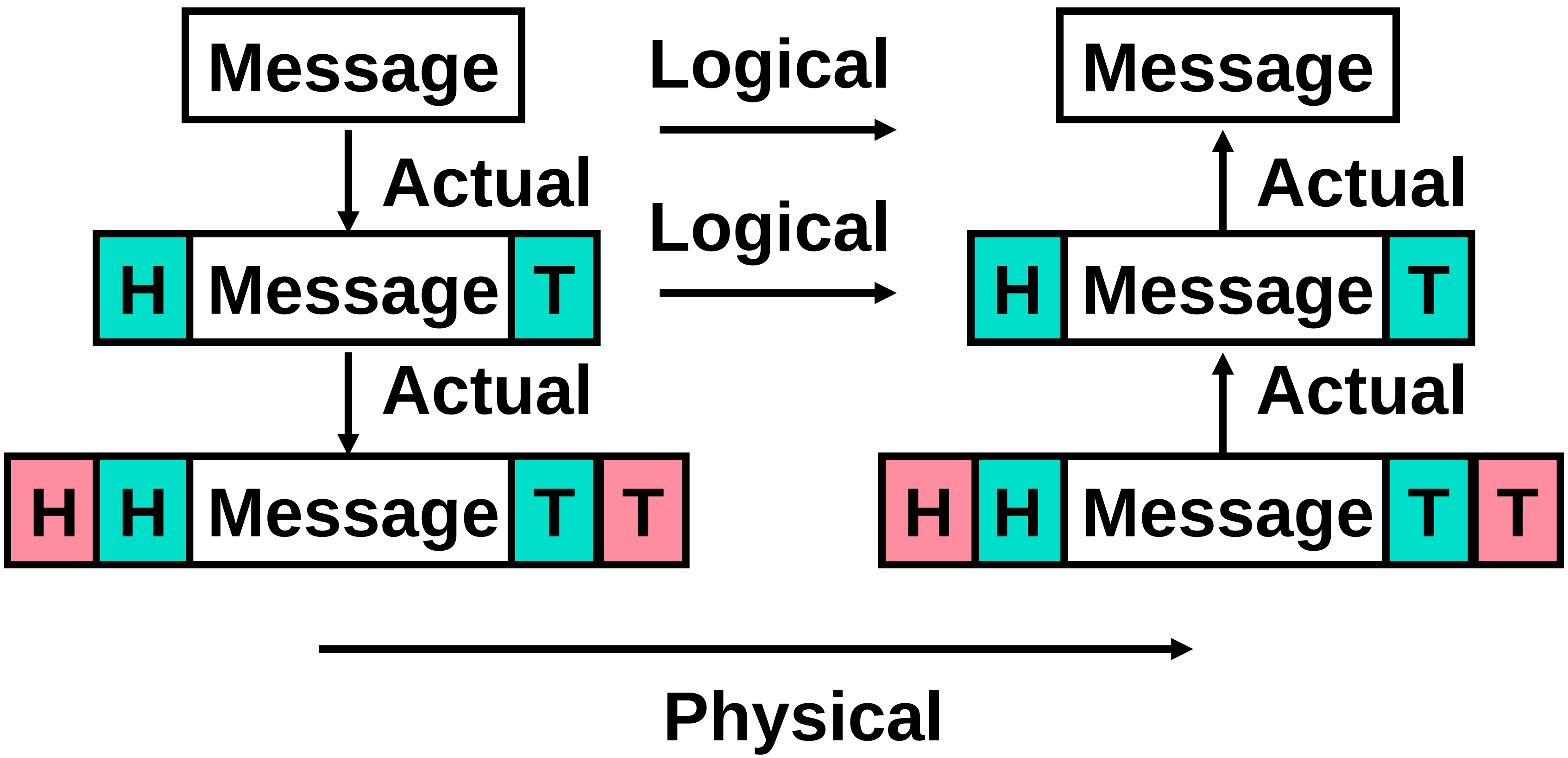
Software Protocol to Send and Receive

- **SW Send steps**
  - 1: Application copies data to OS buffer
  - 2: OS calculates checksum, starts timer
  - 3: OS sends data to network interface HW and says start
- **SW Receive steps**
  - 3: OS copies data from network interface HW to OS buffer
  - 2: OS calculates checksum, if OK, send ACK; if not, <u>delete message</u> (sender resends when timer expires)
  - 1: If OK, OS copies data to user address space, & signals application to continue

Protocol for Networks of Networks?

- Internetworking: allows computers on independent and incompatible networks to communicate reliably and efficiently;
  - Enabling technologies: SW standards that allow reliable communications without reliable networks
  - Hierarchy of SW layers, giving each layer responsibility for portion of overall communications task, called protocol families or protocol suites
- Abstraction to cope with complexity of communication vs. Abstraction for complexity of computation

Protocol Family Concept



Protocol Family Concept

- Key to **protocol families** is that communication occurs **logically** at the same level of the protocol, called **peer-to-peer**…

  …but is **implemented via services at the next lower level**

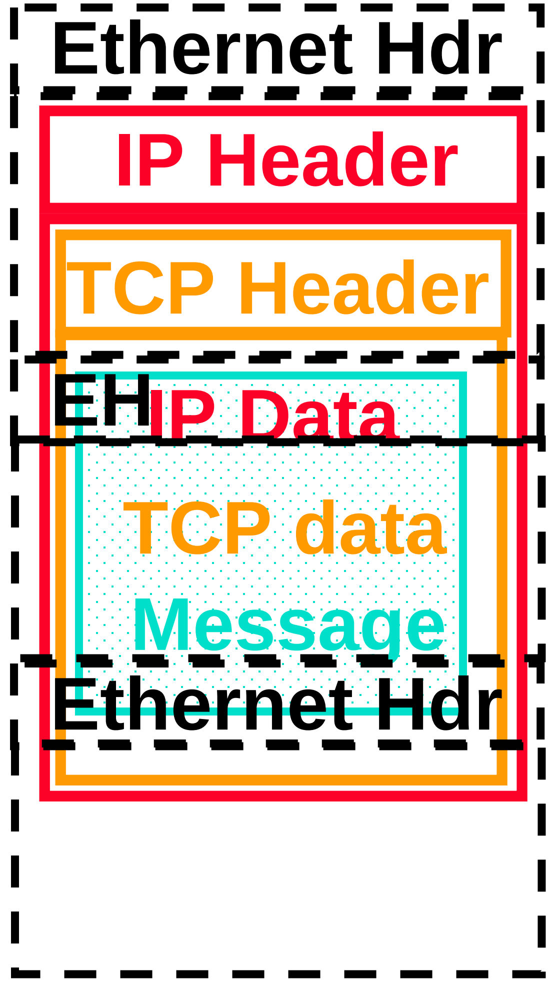
- **Encapsulation:** carry higher level information within lower level "envelope"
- **Fragmentation:** break packet into multiple smaller packets and reassemble

Protocol for Network of Networks

- **Transmission Control Protocol/Internet Protocol (TCP/IP)**
  - **This protocol family is the basis of the Internet, a WAN protocol**
  - **IP makes best effort to deliver**
  - **TCP guarantees delivery**
  - **TCP/IP so popular it is used even when communicating locally: even across homogeneous LAN**

TCP/IP packet, Ethernet packet, protocols

- Application sends message
- TCP breaks into 64KB segments, adds 20B header
- IP adds 20B header, sends to network
- If Ethernet, broken into 1500B packets with headers, trailers (24B)
- All Headers, trailers have length field, destination, ...

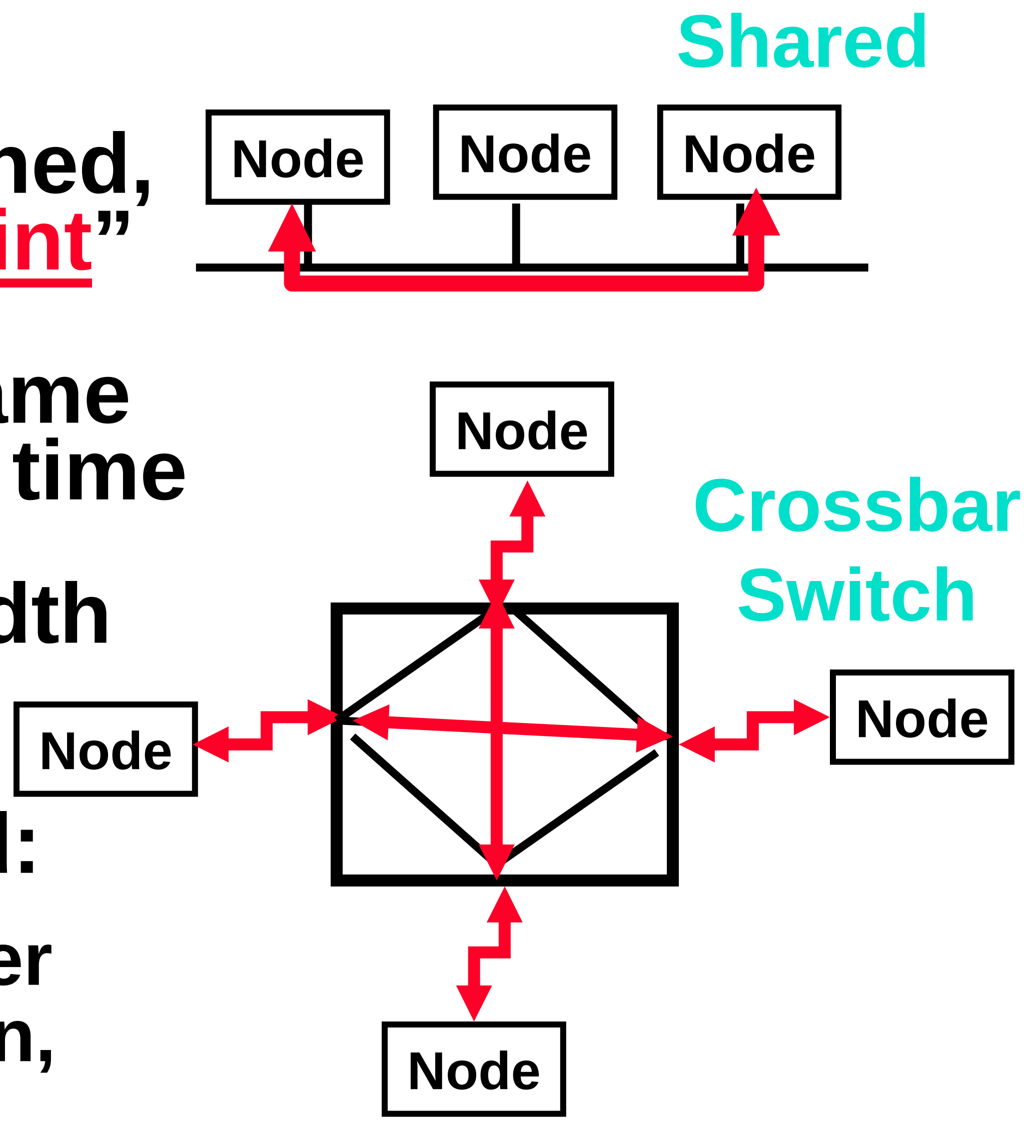


Overhead vs. Bandwidth

- **Networks are typically advertised using peak bandwidth of network link: e.g., 100 Mbits/sec Ethernet ("100 base T")**
- **Software overhead to put message into network or get message out of network often limits useful bandwidth**
- **Assume overhead to send and receive = 320 microseconds (μs), want to send 1000 Bytes over "100 Mbit/s" Ethernet**
  - **Network transmission time: 1000Bx8b/B /100Mb/s = 8000b / (100b/μs) = 80 μs**
  - **Effective bandwidth: 8000b/(320+80)μs = 20 Mb/s**

Shared vs. Switched Based Networks

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



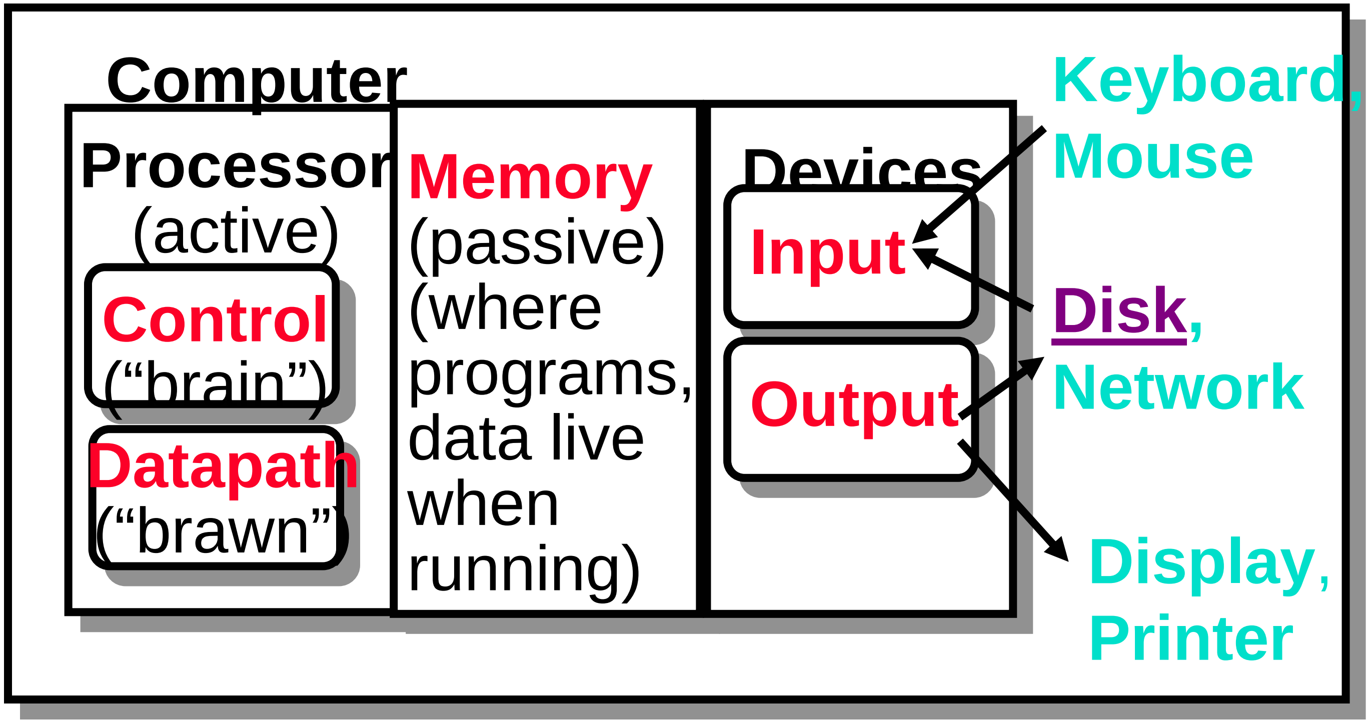
Network Summary

- Protocol suites allow heterogeneous networking
  - Another form of principle of abstraction
  - Protocols $\Rightarrow$ operation in presence of failures
  - Standardization key for LAN, WAN
- Integrated circuit ("Moore's Law") revolutionizing network switches as well as processors
  - Switch just a specialized computer
- Trend from shared to switched networks to get faster links and scalable bandwidth

Outline

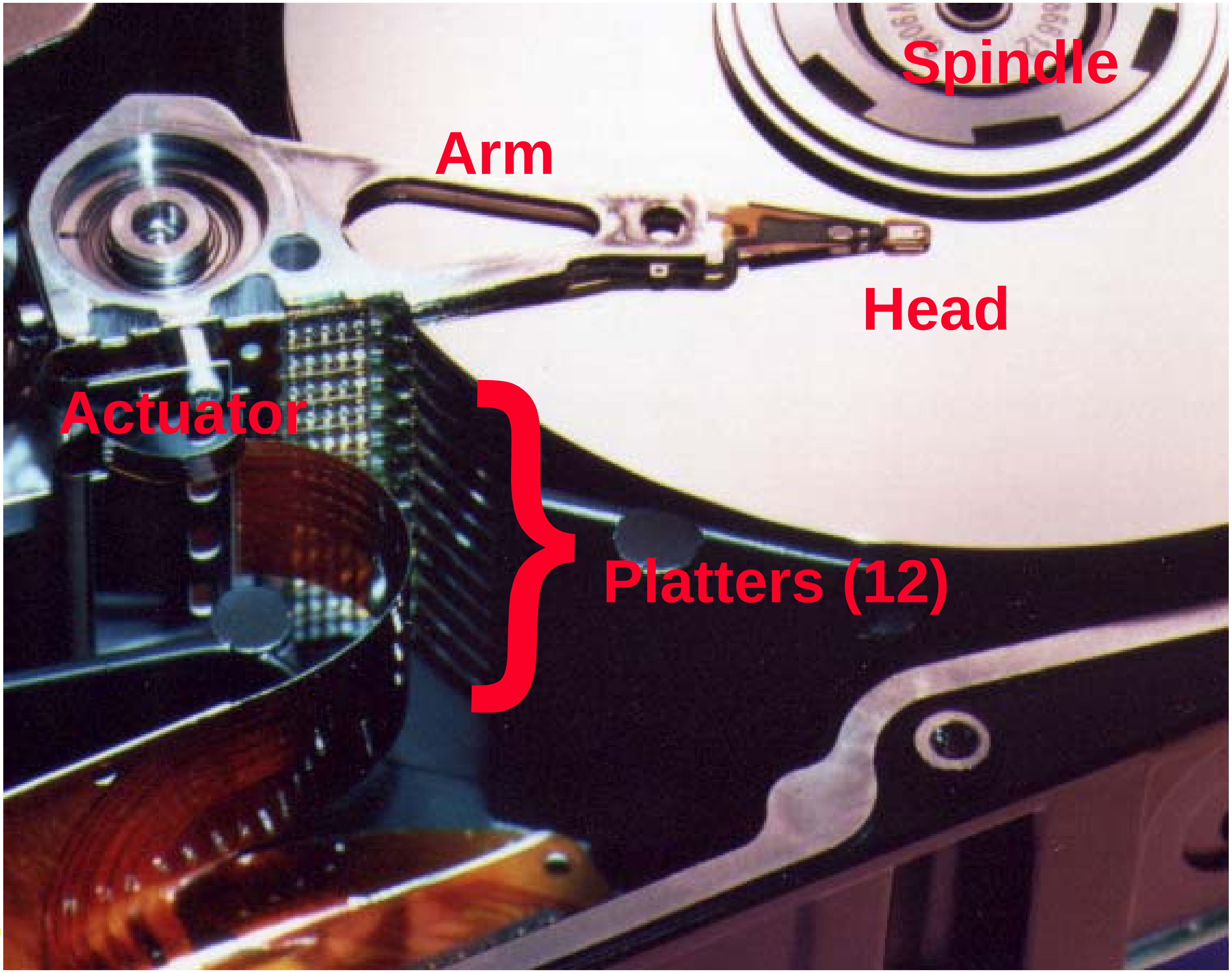
- Buses
- Networks
- Disks

Magnetic Disks

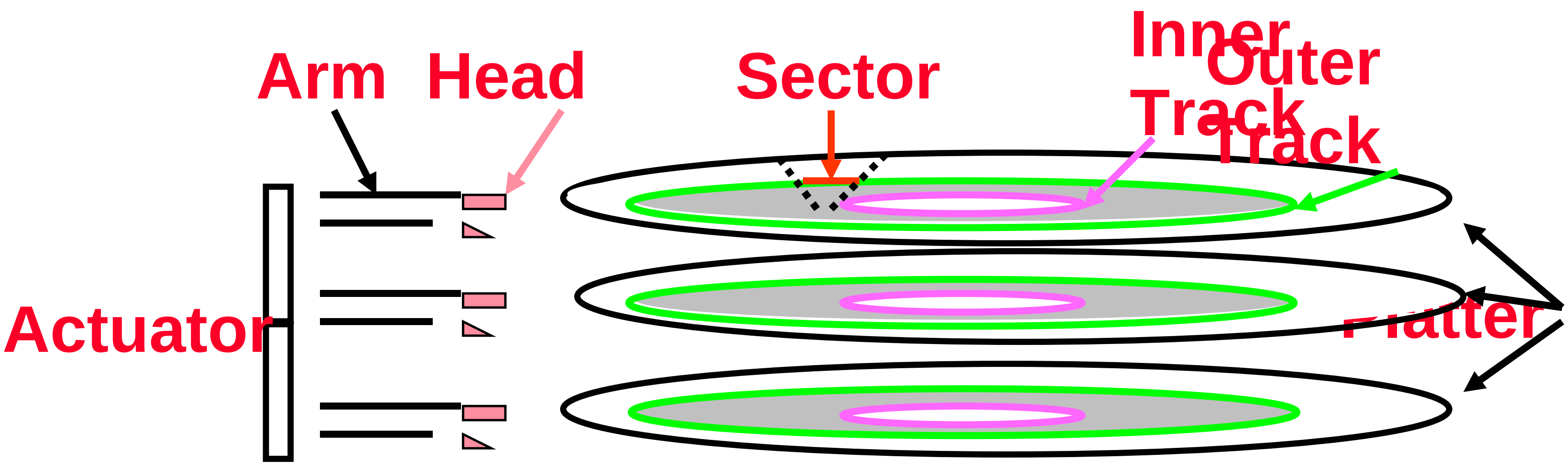


- **Purpose:**
  - **Long-term, nonvolatile, inexpensive storage for files**
  - **Large, inexpensive, slow level in the memory hierarchy (discuss later)**

Photo of Disk Head, Arm, Actuator

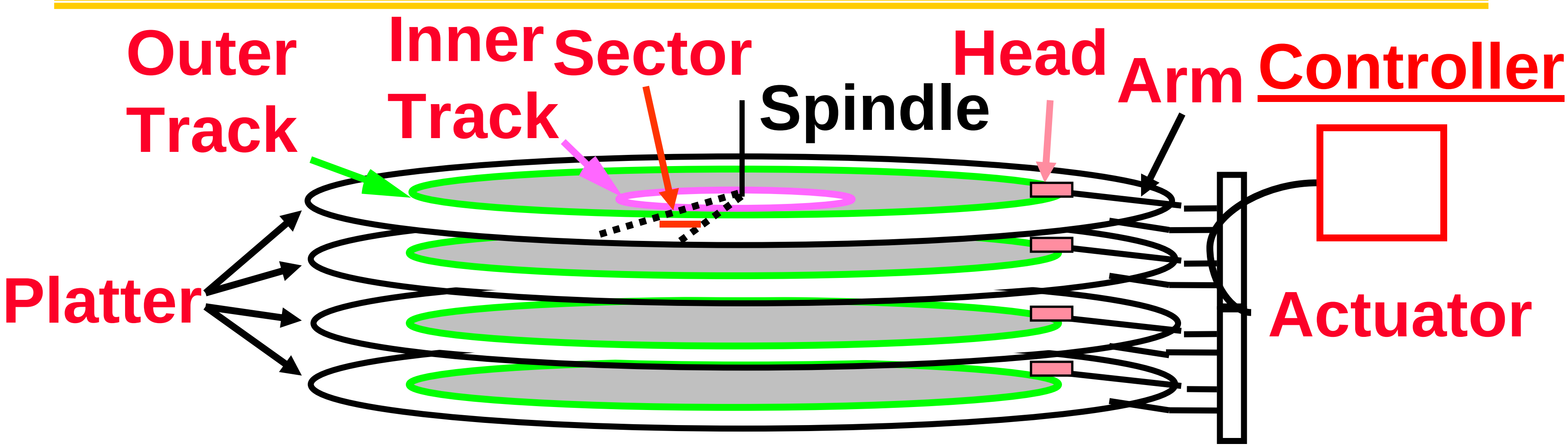


Disk Device Terminology



- 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



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

Data Rate: Inner vs. Outer Tracks

- To keep things simple, originally same # of sectors/track
  - Since outer track longer, lower bits per inch
- Competition decided to keep bits/inch (BPI) high for all tracks ("constant bit density")
  - More capacity per disk
  - More sectors per track towards edge
  - Since disk spins at constant speed, outer tracks have faster data rate
- Bandwidth outer track 1.7X inner track!

Disk Performance Model /Trends

- **Capacity : + 100% / year (2X / 1.0 yrs)**

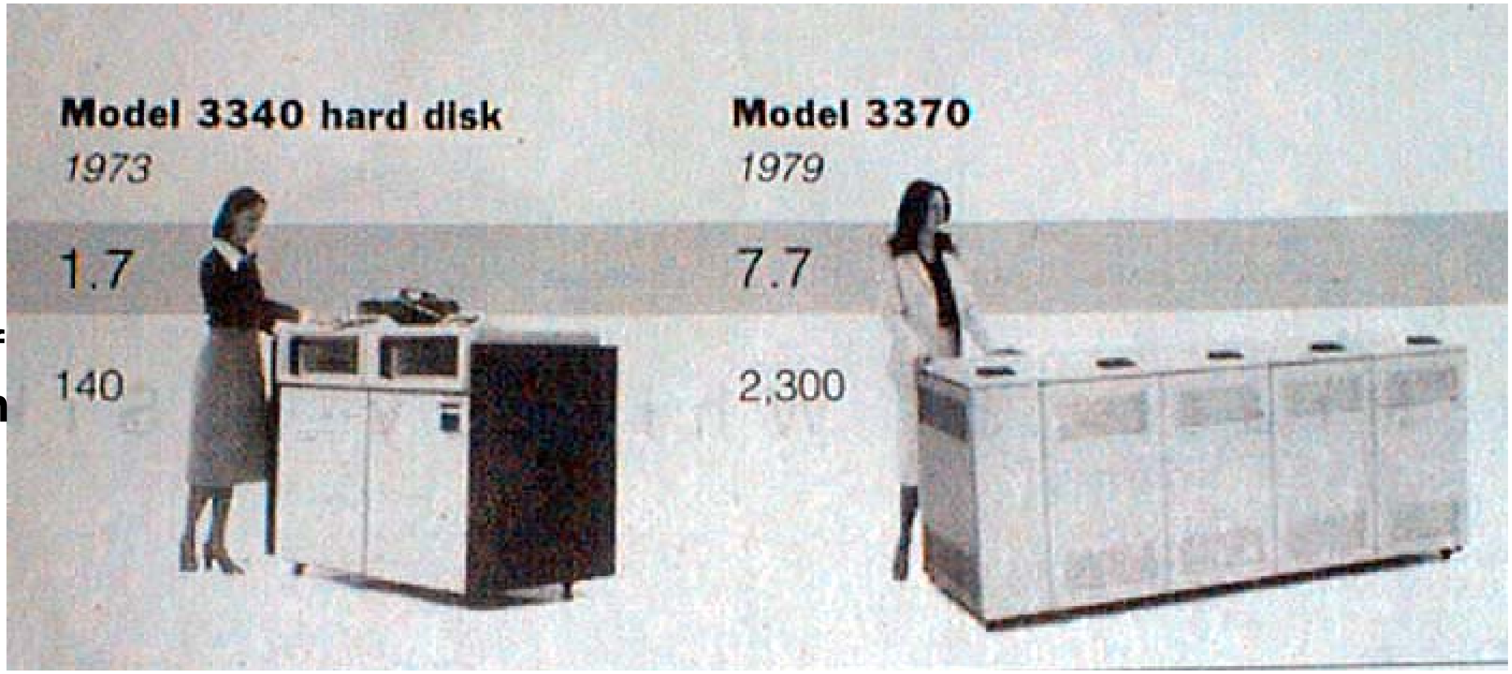
  Over time, grown so fast that # of platters has reduced (some even use only 1 now!)

- **Transfer rate (BW) : + 40%/yr (2X / 2 yrs)**
- **Rotation+Seek time : – 8%/yr (1/2 in 10 yrs)**
- **Areal Density**
  - **Bits recorded along a track: Bits/Inch (BPI)**
  - **# of tracks per surface: Tracks/Inch (TPI)**
  - **We care about bit density per unit area Bits/Inch^2**
  - **Called Areal Density = BPI x TPI**
- **MB/$: > 100%/year (2X / 1.0 yrs)**
  - **Fewer chips + areal density**

Disk History (IBM)

Data density Mbit/sq. in.

Capacity of Unit Shown Megabytes



1973:
1. 7 Mbit/sq. in
0.14 GBytes

1979:
7. 7 Mbit/sq. in
2.3 GBytes

source: New York Times, 2/23/98, page C3,
“Makers of disk drives crowd even more data into even smaller spaces”

Disk History

1989:
63 Mbit/sq. in
60 GBytes

1997:
1450 Mbit/sq. in
2.3 GBytes

1997:
3090 Mbit/sq. in
8.1 GBytes

source: New York Times, 2/23/98, page C3,
"Makers of disk drives crowd even more data into even smaller spaces"

Modern Disks: Barracuda 7200.7 (2004)

- 200 GB, 3.5-inch disk
- 7200 RPM; Serial ATA
- 2 platters, 4 surfaces
- 8 watts (idle)
- 8.5 ms avg. seek
- 32 to 58 MB/s Xfer rate
- $125 = $0.625 / GB

source: www.seagate.com;

Modern Disks: Mini Disks

- **2004 Toshiba Minidrive:**
  - **2.1” x 3.1” x 0.3”**
  - **40 GB, 4200 RPM, 31 MB/s, 12 ms seek**
  - **20GB/inch^3 !!**
  - **Mp3 Players**

Modern Disks: 1 inch disk drive!

- **2004 Hitachi Microdrive:**
  - **1.7” x 1.4” x 0.2”**
  - **4 GB, 3600 RPM, 4-7 MB/s, 12 ms seek**
  - **8.4 GB/inch^3**
  - **Digital cameras, PalmPC**
- **2006 MicroDrive?**
  - **16 GB, 10 MB/s!**
  - **Assuming past trends continue**

Modern Disks: << 1 inch disk drive!

- **Not magnetic but …**

- **1gig Secure digital**
  - **Solid State NAND Flash**
  - **1.2" x 0.9" x 0.08" (!!)**
  - **11.6 GB/inch^3**

Magnetic Disk Summary

- Magnetic Disks continue rapid advance: 60%/yr capacity, 40%/yr bandwidth, slow on seek, rotation improvements, MB/$ improving 100%/yr?
  - Designs to fit high volume form factor
- RAID
  - Higher performance with more disk arms per $
  - Adds option for small # of extra disks
  - Today RAID is > $27 billion dollar industry, 80% nonPC disks sold in RAIDs; started at Cal