CS61C : Machine Structures

Lecture 40
I/O : Disks

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I talk to robots... ⇒

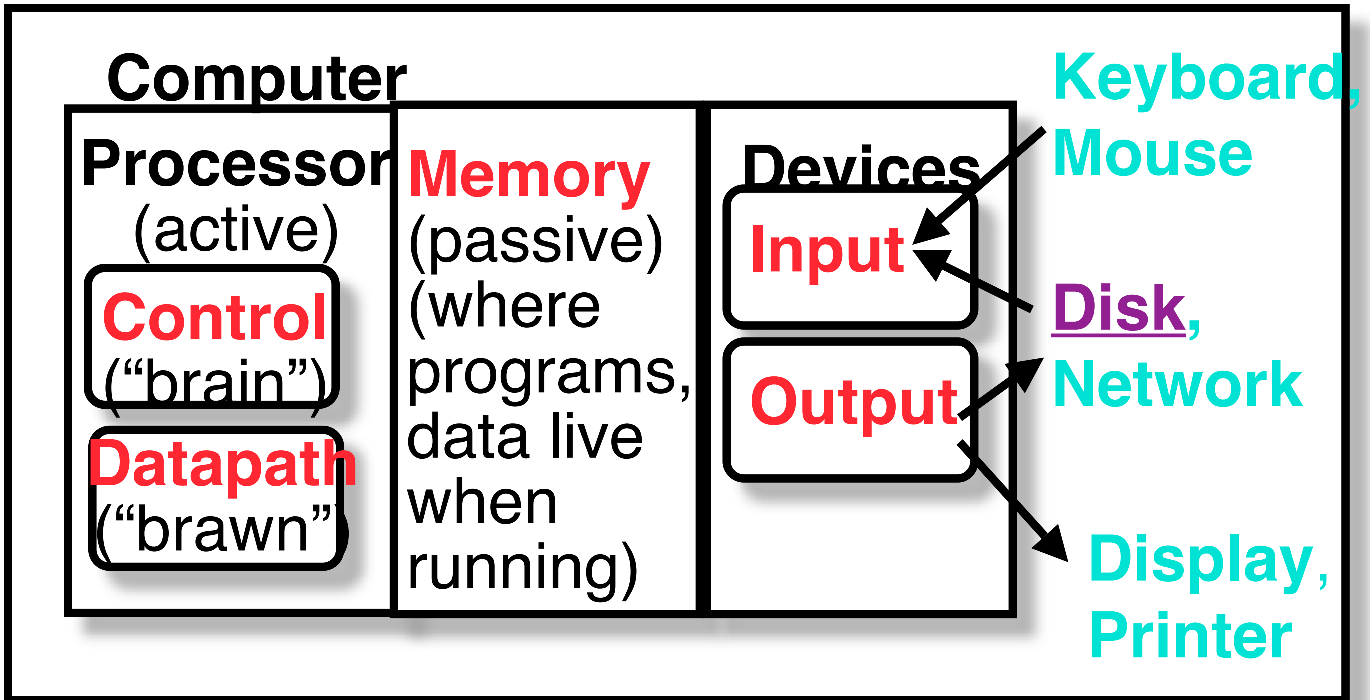
"Japan's growing elderly population will be able to buy companionship in the form of a robot, programmed to provide just enough small talk to keep them from going senile. Snuggling Ifbot, dressed in an astronaut suit with a glowing face, has the conversation ability of a five-year-old, the language level needed to stimulate the brains of sr citizens"

www.thematuremarket.com/SeniorStrategic/dossier.php?numtxt=3567&idrb=5

Review

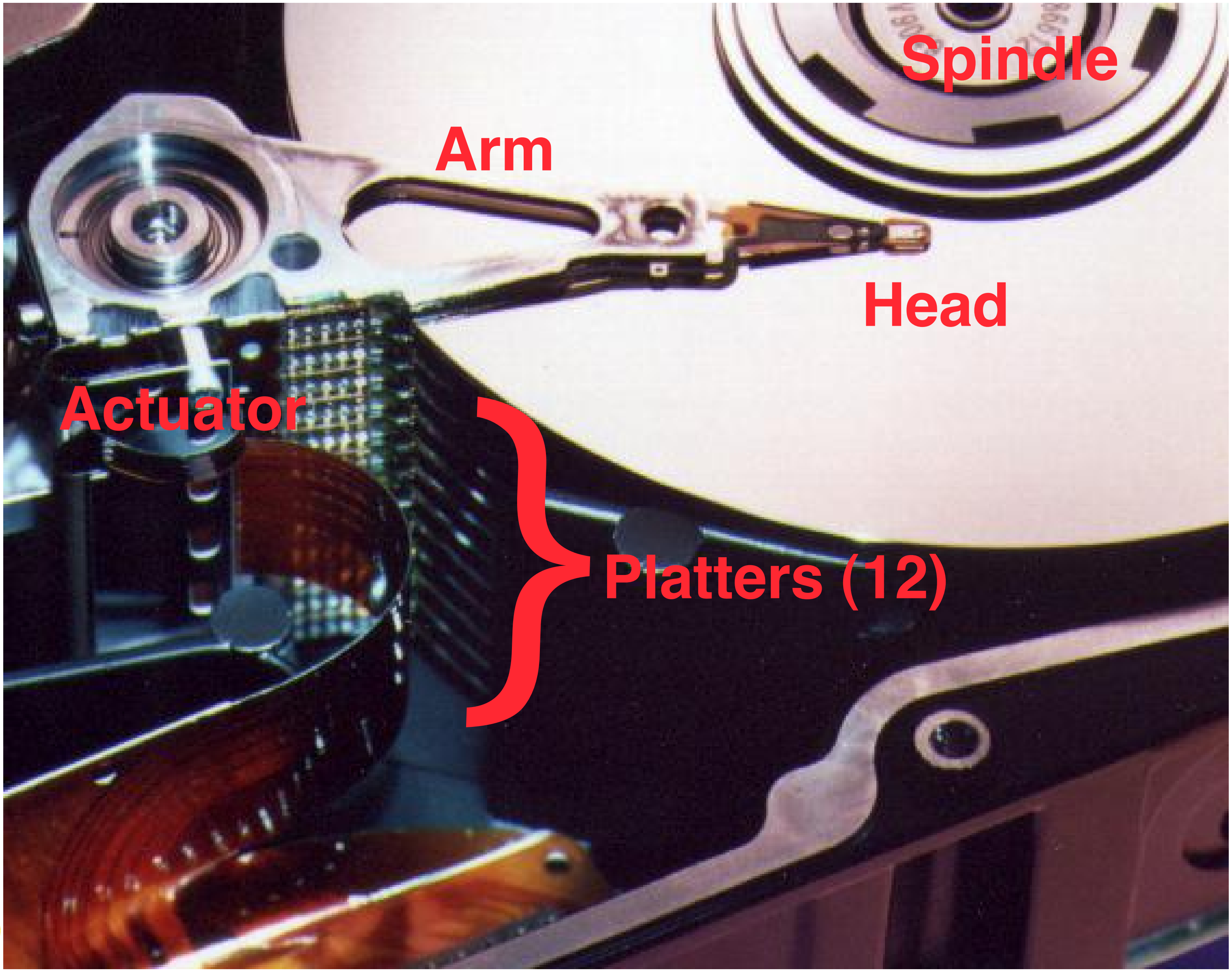
- Protocol suites allow heterogeneous networking
  - Another form of principle of abstraction
  - Protocols ⇒ operation in presence of failures
  - Standardization key for LAN, WAN
- Integrated circuit ("Moore's Law") revolutionizing network switches as well as processors
  - Switch just a specialized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

Magnetic Disks

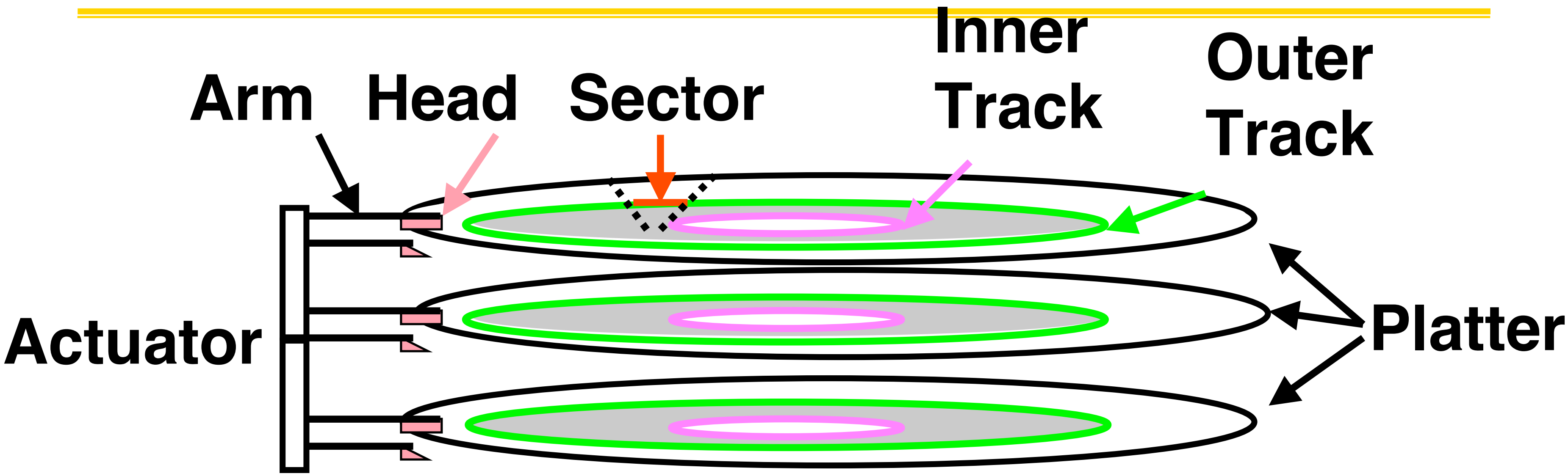


- **Purpose:**
  - **Long-term, nonvolatile, inexpensive storage for files**
  - **Large, inexpensive, slow level in the memory hierarchy (discuss later)**

Photo of Disk Head, Arm, Actuator

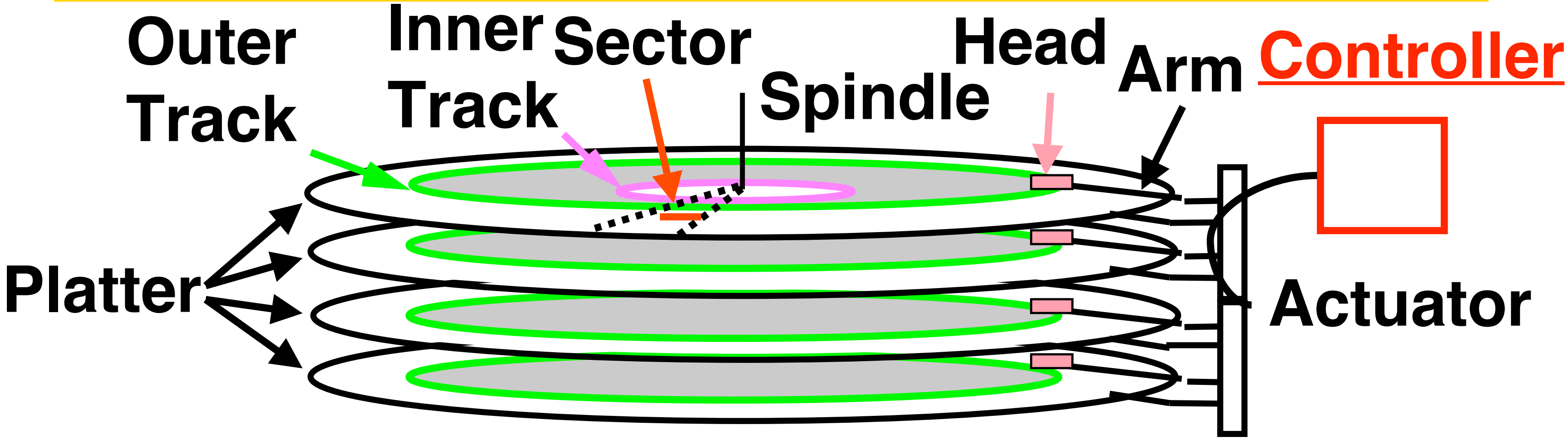


Disk Device Terminology



- 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)

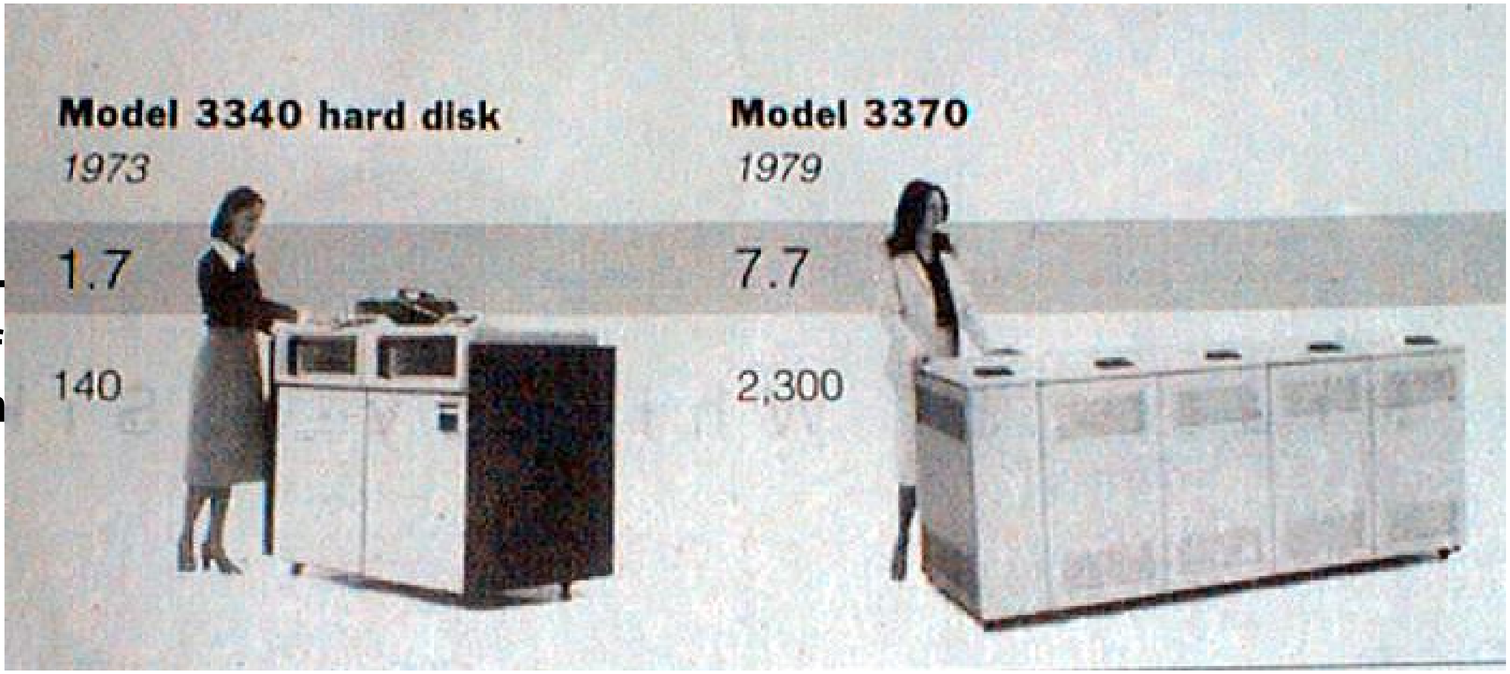
  Over time, grown so fast that # of platters has reduced (some even use only 1 now!)

- 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 Mibit/sq. in.

Capacity of Unit Shown Mibytes

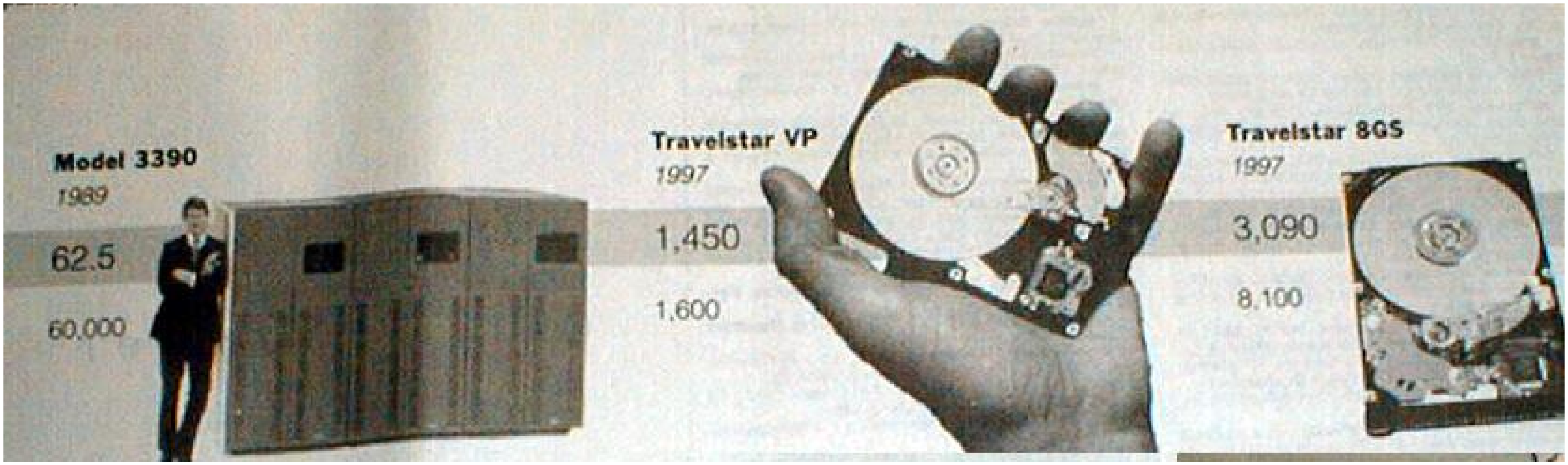


1973:
1. 7 Mibit/sq. in
0.14 GiBytes

1979:
7. 7 Mibit/sq. in
2.3 GiBytes

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

Disk History



1989:	**1997:**	**1997:**
63 Mibit/sq. in	**1450 Mibit/sq. in**	**3090 Mibit/sq. in**
60 GiBytes	**2.3 GiBytes**	**8.1 GiBytes**

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

Historical Perspective

- Form factor and capacity drives market, more than performance
- 1970s: Mainframes ⇒ 14" diam. disks
- 1980s: Minicomputers, Servers ⇒ 8", 5.25" diam. disks
- Late 1980s/Early 1990s:
  - Pizzabox PCs ⇒ 3.5 inch diameter disks
  - Laptops, notebooks ⇒ 2.5 inch disks
  - Palmtops didn't use disks, so 1.8 inch diameter disks didn't make it

State of the Art: 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;

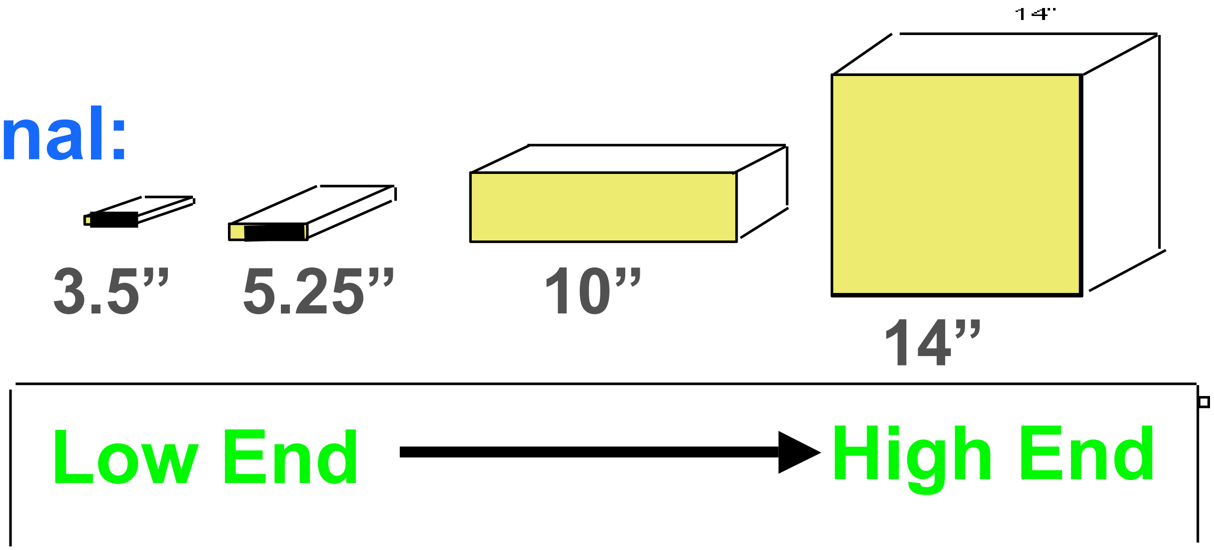
1 inch disk drive!

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

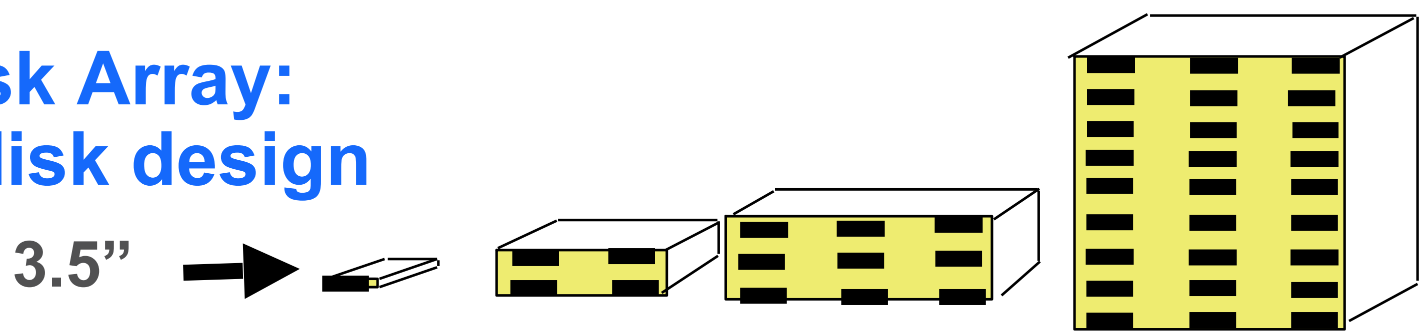
Use Arrays of Small Disks…

- Katz and Patterson asked in 1987:
  - Can smaller disks be used to close gap in performance between disks and CPUs?

Conventional: 4 disk designs



Disk Array: 1 disk design



Replace Small Number of Large Disks with Large Number of Small Disks! (1988 Disks)

	IBM 3390K	IBM 3.5" 0061	x70	
Capacity	20 GBytes	320 MBytes	23 GBytes	
Volume	97 cu. ft.	0.1 cu. ft.	11 cu. ft.	9X
Power	3 KW	11 W	1 KW	3X
Data Rate	15 MB/s	1.5 MB/s	120 MB/s	8X
I/O Rate	600 I/Os/s	55 I/Os/s	3900 IOs/s	6X
MTTF	250 KHrs	50 KHrs	??? Hrs	
Cost	$250K	$2K	$150K	

Disk Arrays potentially high performance, high MB per cu. ft., high MB per KW,

but what about reliability?

Array Reliability

- Reliability - whether or not a component has failed
    - measured as Mean Time To Failure (MTTF)
- Reliability of N disks = Reliability of 1 Disk ÷ N (assuming failures independent)
    - 50,000 Hours ÷ 70 disks = 700 hour
- Disk system MTTF: Drops from 6 years to 1 month!
- Disk arrays too unreliable to be useful!

Redundant Arrays of (Inexpensive) Disks

- Files are "striped" across multiple disks
- Redundancy yields high data availability
  - **Availability**: service still provided to user, even if some components failed
- Disks will still fail
- Contents reconstructed from data redundantly stored in the array

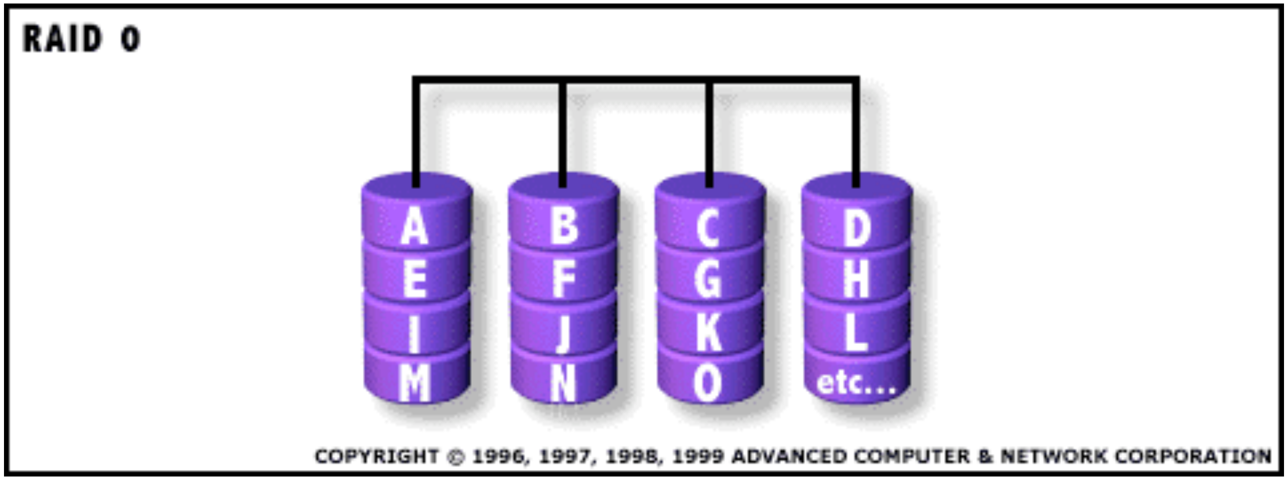
  ⇒ Capacity penalty to store redundant info

  ⇒ Bandwidth penalty to update redundant info

Berkeley History, RAID-I

- RAID-I (1989)
  - Consisted of a Sun 4/280 workstation with 128 MB of DRAM, four dual-string SCSI controllers, 28 5.25-inch SCSI disks and specialized disk striping software
- Today RAID is > $27 billion dollar industry, 80% nonPC disks sold in RAIDs

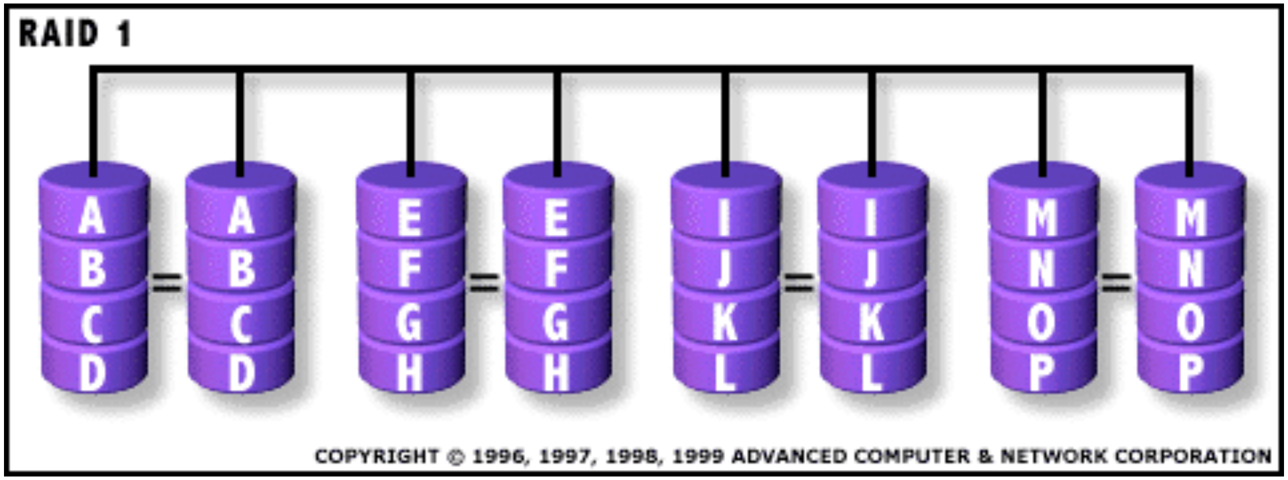
“RAID 0”: No redundancy = “AID”



- Assume have 4 disks of data for this example, organized in blocks
- Large accesses faster since transfer from several disks at once

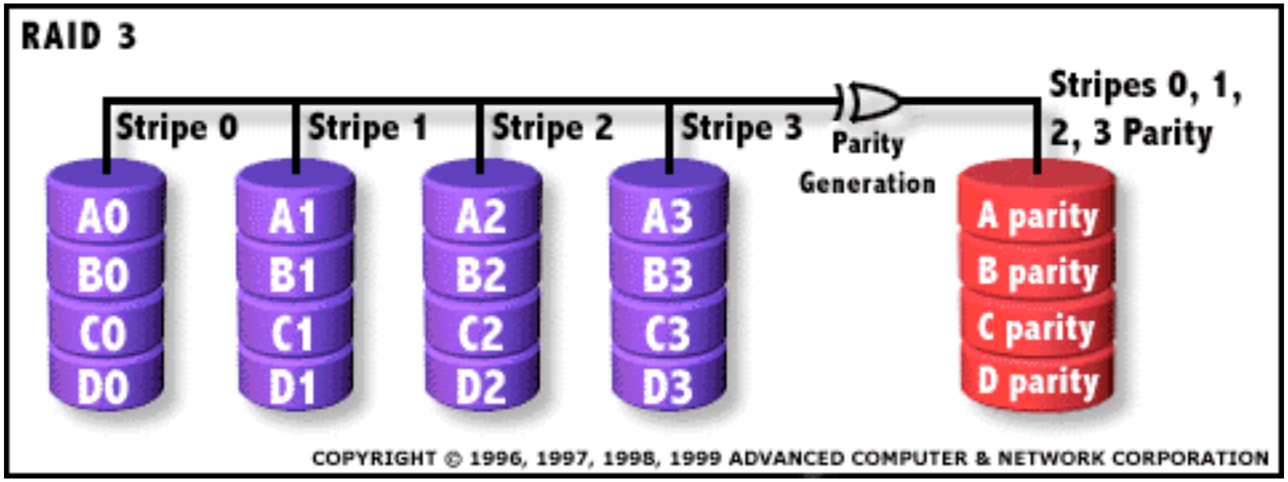
This and next 5 slides from RAID.edu, http://www.acnc.com/04_01_00.html

RAID 1: Mirror data



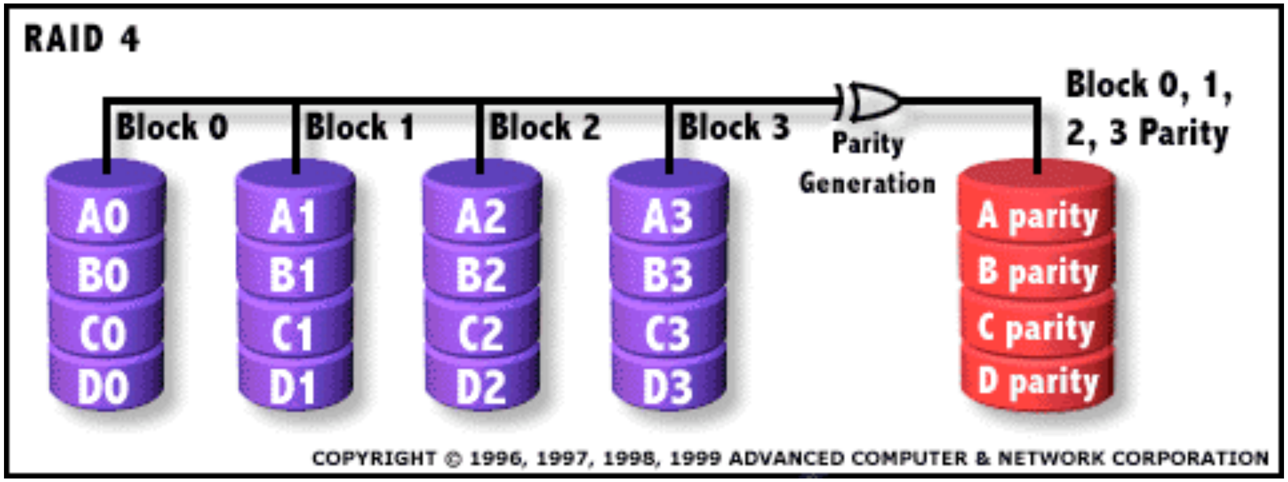
- Each disk is fully duplicated onto its "mirror"
  - Very high availability can be achieved
- Bandwidth reduced on write:
  - 1 Logical write = 2 physical writes
- Most expensive solution: 100% capacity overhead

RAID 3: Parity



- Parity computed across group to protect against hard disk failures, stored in P disk
- Logically, a single high capacity, high transfer rate disk
- 25% capacity cost for parity in this example vs. 100% for RAID 1 (5 disks vs. 8 disks)

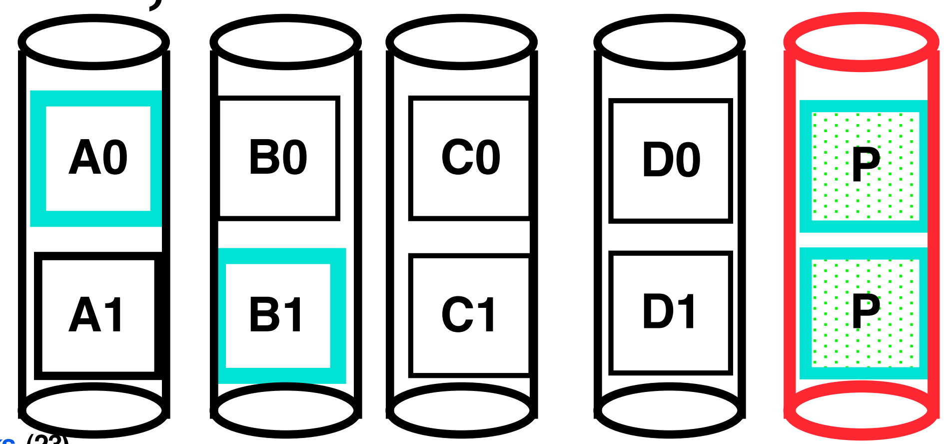
RAID 4: parity plus small sized accesses



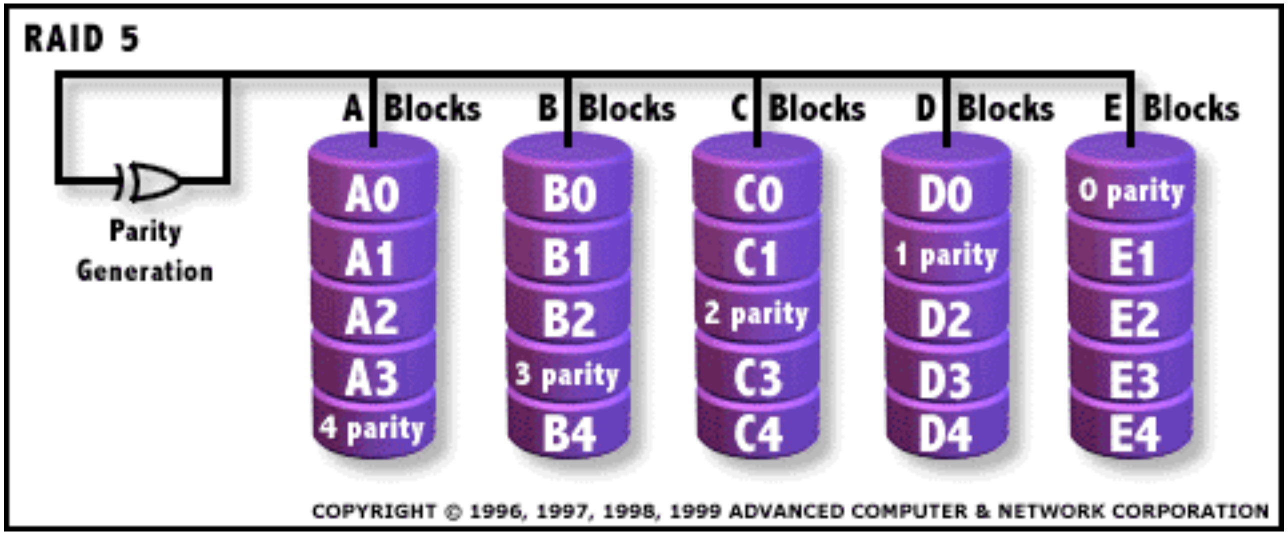
- RAID 3 relies on parity disk to discover errors on Read
- But every sector has an error detection field
- Rely on error detection field to catch errors on read, not on the parity disk
- Allows small independent reads to different disks simultaneously

Inspiration for RAID 5

- **Small writes (write to one disk):**
  - **Option 1: read other data disks, create new sum and write to Parity Disk (access all disks)**
  - **Option 2: since P has old sum, compare old data to new data, add the difference to P: 1 logical write = 2 physical reads + 2 physical writes to 2 disks**
- **Parity Disk is bottleneck for Small writes: Write to A0, B1 => both write to P disk**



RAID 5: Rotated Parity, faster small writes



- Independent writes possible because of interleaved parity
  - Example: write to A0, B1 uses disks 0, 1, 4, 5, so can proceed in parallel
  - Still 1 small write = 4 physical disk accesses

Peer Instruction

1. RAID 1 (mirror) and 5 (rotated parity) help with performance and availability
2. RAID 1 has higher cost than RAID 5
3. Small writes on RAID 5 are slower than on RAID 1

	ABC
1:	FFF
2:	FFT
3:	FTF
4:	FTT
5:	TFF
6:	TFT
7:	TTF
8:	TTT

"And In conclusion…"

- 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