CS 61C: Great Ideas in Computer Architecture (Machine Structures)
Lecture 38: IO Disks

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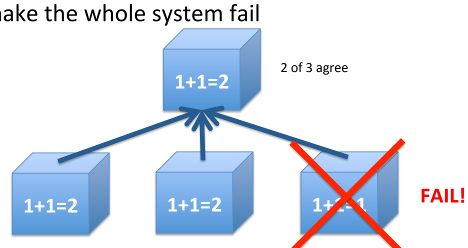
http://inst.eecs.Berkeley.edu/~cs61c/sp13

Review - 6 Great Ideas in Computer Architecture

1. Layers of Representation/Interpretation
2. Moore's Law
3. Principle of Locality/Memory Hierarchy
4. Parallelism
5. Performance Measurement & Improvement
6. **Dependability via Redundancy**

Review - Great Idea #6: Dependability via Redundancy

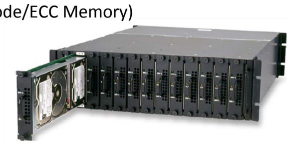
- Redundancy so that a failing piece doesn't make the whole system fail



Increasing transistor density reduces the cost of redundancy

Review - Great Idea #6: Dependability via Redundancy

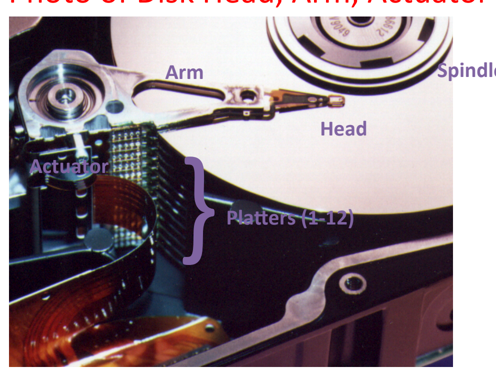
- Applies to everything from datacenters to memory
  - Redundant datacenters so that can lose 1 datacenter but Internet service stays online
  - Redundant routes so can lose nodes but Internet doesn't fail
  - Redundant disks so that can lose 1 disk but not lose data (Redundant Arrays of Independent Disks/RAID)
  - Redundant memory bits of so that can lose 1 bit but no data (Error Correcting Code/ECC Memory)

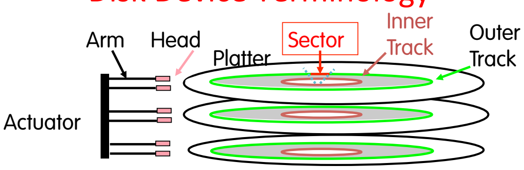
Magnetic Disk – common I/O device

- 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, Actuator



Disk Device Terminology



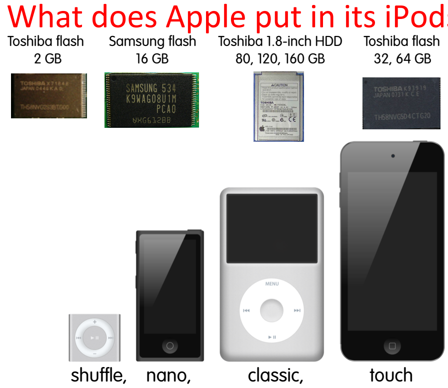
- Several platters, with information recorded magnetically on both surfaces (usually)
- **Bits recorded in tracks, which in turn divided into sectors (e.g., 512 Bytes)**
- **Actuator moves head (end of arm) over track ("seek"), wait for sector rotate under head, then read or write**

Where does Flash memory come in?

- Microdrives and Flash memory (e.g., CompactFlash) 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.

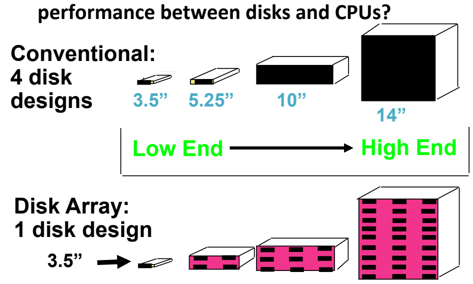
en.wikipedia.org/wiki/Ipod www.apple.com/ipod

What does Apple put in its iPods?



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?**



Replace Small # of Large Disks with Large # of Small!

(1988 Disks)

	IBM 3390K	IBM 3.5" 0061
Capacity	20 GBytes	320 MBytes
Volume	97 cu. ft.	0.1 cu. ft.
Power	3 KW	11 W
Data Rate	15 MB/s	1.5 MB/s
I/O Rate	600 I/Os/s	55 I/Os/s
MTTF	250 KHrs	50 KHrs
Cost	$250K	$2K

Disk Arrays potentially high performance, high MB per cu. ft., high MB per KW, but what about reliability?

Replace Small # of Large Disks with Large # of Small!

(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 I/Os/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

RAID : Redundant Array of Inexpensive Disks

- Invented @ Berkeley (1989)
- A multi-billion industry 80% non-PC disks sold in RAIDs
- Idea:
  - Files are "striped" across multiple disks
  - Redundancy yields high data availability
    - Disks will still fail
  - Contents reconstructed from data redundantly stored in the array
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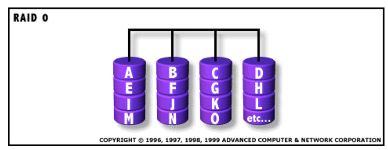
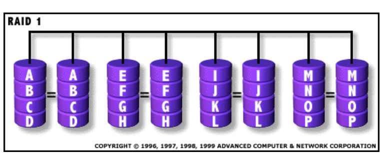
"RAID 0": No redundancy = "AID"



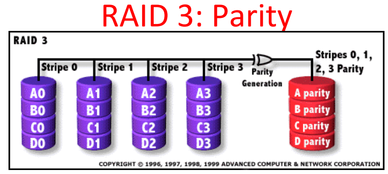
- Assume have 4 disks of data for this example, organized in blocks
- Large accesses faster since transfer from several disks at once

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

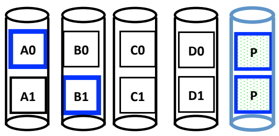


- Spindles synchronized, each sequential byte on a diff. drive
- Parity computed across group to protect against hard disk failures, stored in P disk
- Logically, a single high capacity, high transfer rate disk
- 25% capacity cost for parity in this example vs. 100% for RAID 1 (5 disks vs. 8 disks)
- Q: How many drive failures can be tolerated?

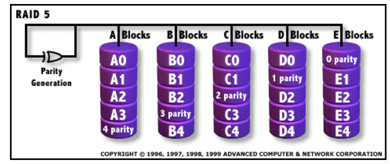
Inspiration for RAID 5 (RAID 4 block-striping)

- 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 4 block-striping)



RAID 5: Rotated Parity, faster small writes

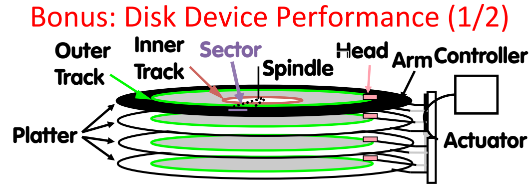


- Independent writes possible because of interleaved parity
  - Example: write to A0, B1 uses disks 0, 1, 4, 5, so can proceed in parallel
  - Still 1 small write = 4 physical disk accesses

"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 vs. Interrupts
- Networks are another form of I/O
- Protocol suites allow networking of heterogeneous components
  - Another form of principle of abstraction
- RAID
  - Higher performance with more disk arms per $
  - More disks == More disk failures
  - Different RAID levels provide different cost/speed/reliability tradeoffs

Bonus: Disk Device Performance (1/2)

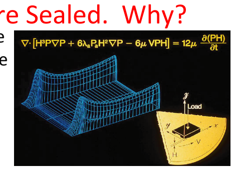


- **Disk Latency = Seek Time + Rotation Time + Transfer Time + Controller Overhead**
  - Seek Time? depends on no. tracks to move arm, speed of actuator
  - Rotation Time? depends on speed disk rotates, how far sector is from head
  - Transfer Time? depends on data rate (bandwidth) of disk (f(bit density,rpm)),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

Bonus: 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

BONUS : Hard Drives are Sealed. Why?



- The closer the head to the disk, the smaller the "spot size" and thus the denser the recording.
  - Measured in Gbit/in2. ~60 is state of the art.
- Disks are sealed to keep the dust out.
  - Heads are designed to "fly" at around 5-20nm above the surface of the disk.
  - 99.999% of the head/arm weight is supported by the air bearing force (air cushion) developed between the disk and the head.