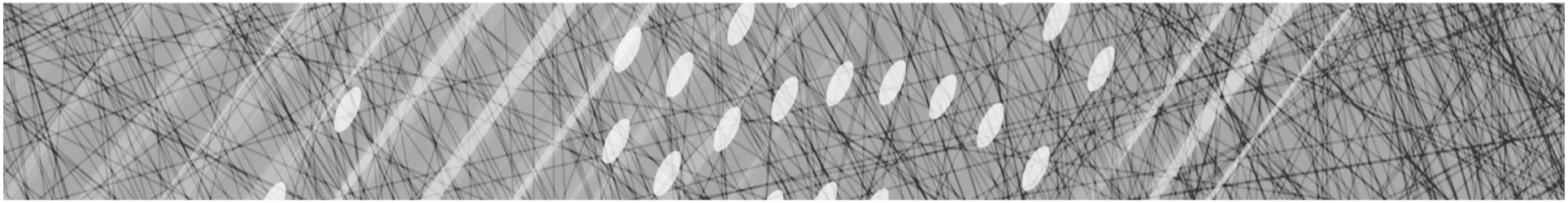


Storage

CS 3410
Computer System Organization & Programming

Cornell CIS
COMPUTING AND INFORMATION SCIENCE

These slides are the product of many rounds of teaching CS 3410 by Deniz Altinbuke, Kevin Walsh, and Professors Weatherspoon, Bala, Bracy, and Sirer.

Challenge

- How do we store lots of data for a long time
  - Disk (Hard disk, floppy disk, …)
  - Tape (cassettes, backup, VHS, …)
  - CDs/DVDs

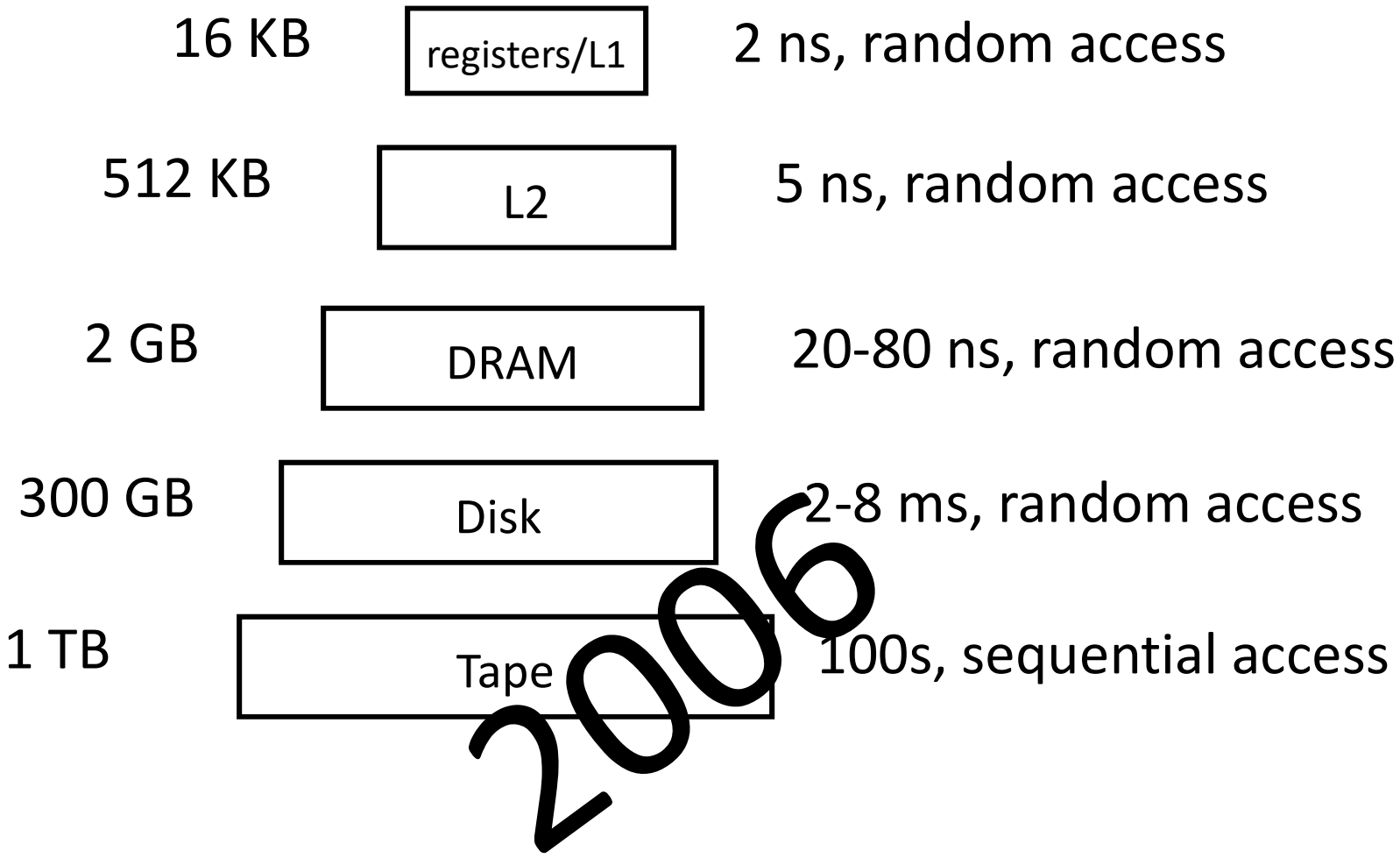
Challenge

- How do we store lots of data for a long time
  - Disk (~~Hard disk, floppy disk~~, …Solid State Disk (SSD)
  - ~~Tape (cassettes, backup, VHS, …)~~
  - ~~CDs/DVDs~~
  - Non-Volitile Persistent Memory (NVM; e.g. 3D Xpoint)

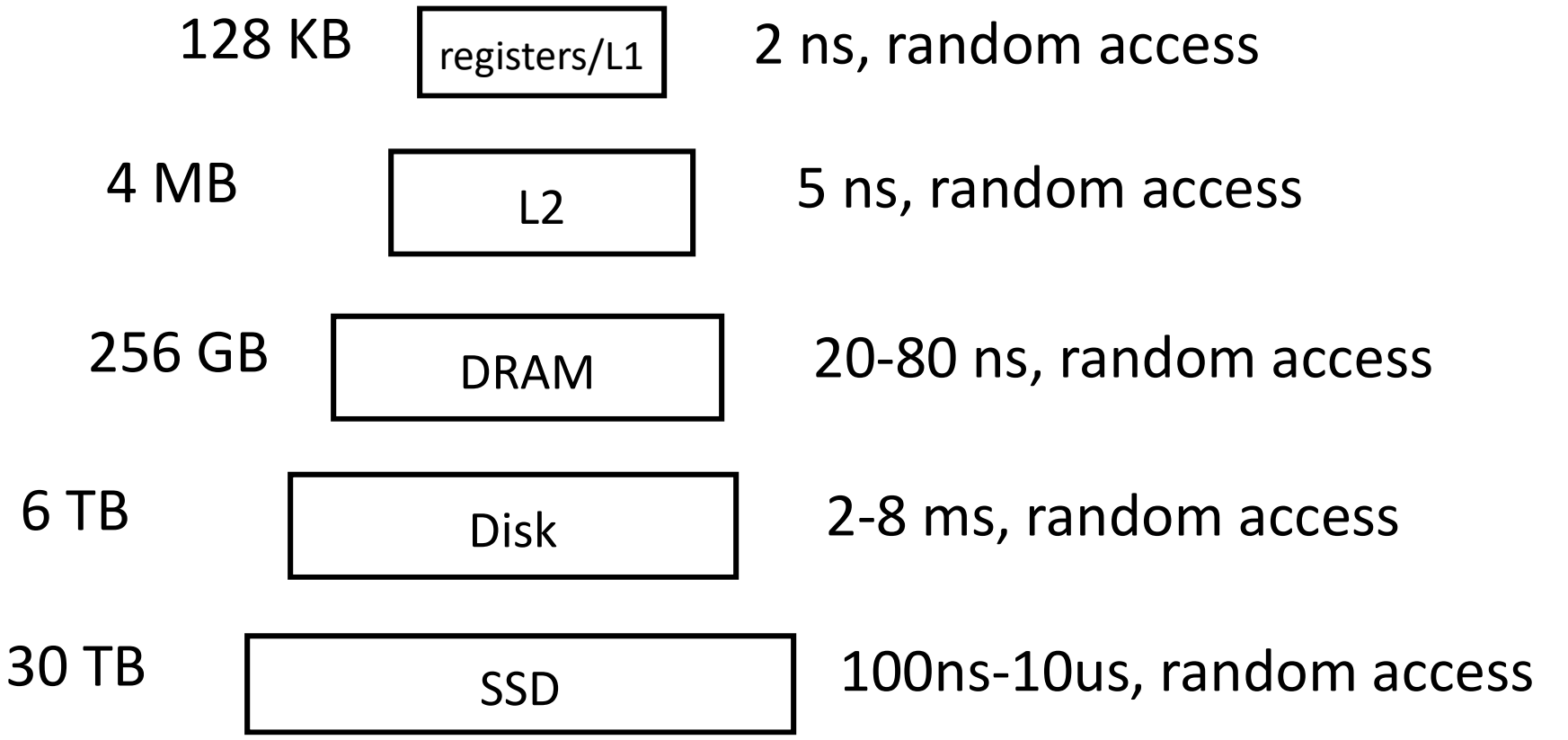
I/O System Characteristics

- Dependability is important
  - Particularly for storage devices
- Performance measures
  - Latency (response time)
  - Throughput (bandwidth)
  - Desktops & embedded systems
    - Mainly interested in response time & diversity of devices
  - Servers
    - Mainly interested in throughput & expandability of devices

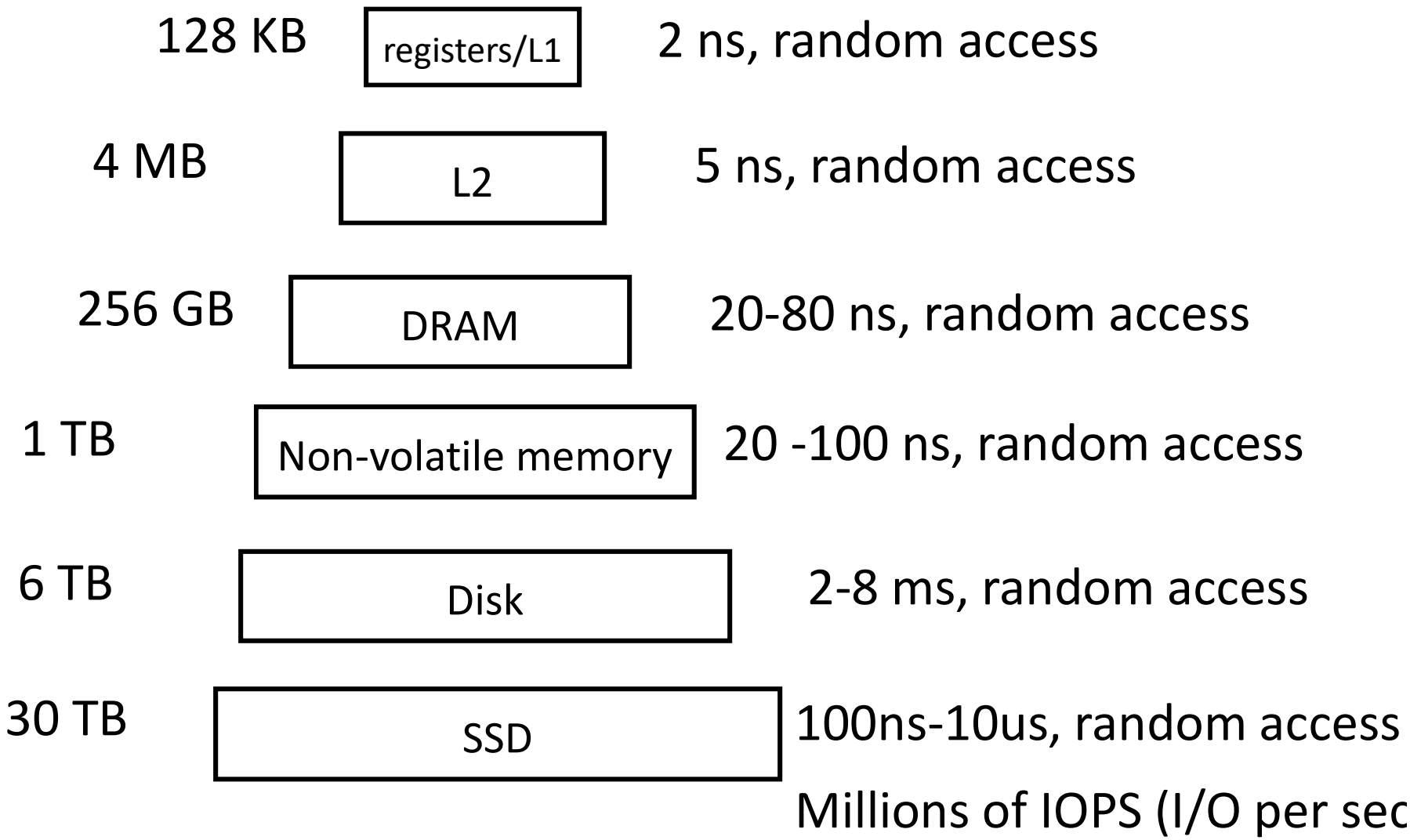
Memory Hierarchy



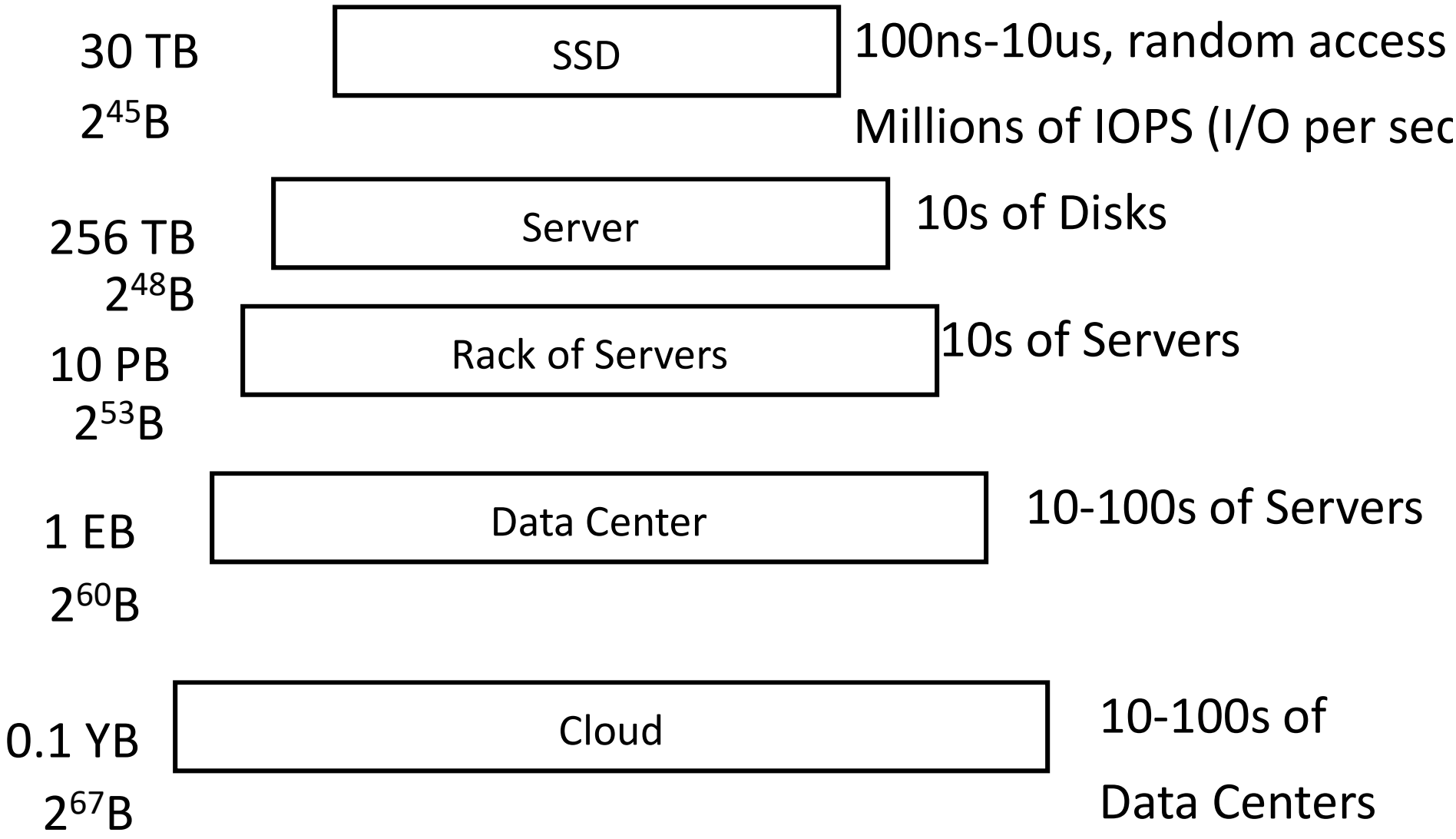
Memory Hierarchy



Memory Hierarchy

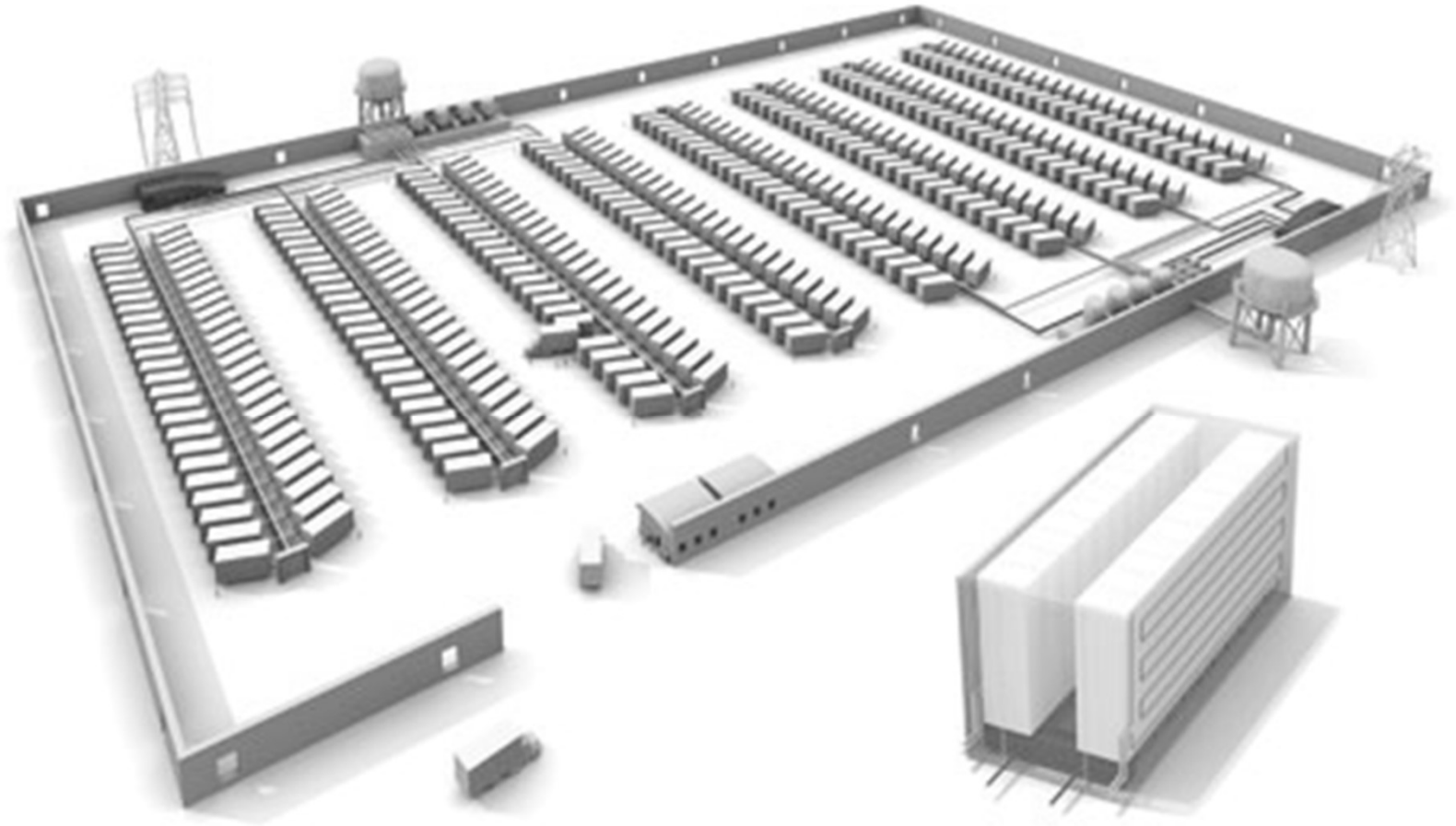


Memory Hierarchy



The Rise of Cloud Computing

- How big is Big Data in the Cloud?
  - Exabytes: Delivery of petabytes of storage daily



Titan tech boom, randy katz, 2008

The Rise of Cloud Computing

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  - Most of the worlds data (and computation) hosted by few companies

The Rise of Cloud Computing

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The Rise of Cloud Computing

- The promise of the Cloud
  - *ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.* NIST Cloud Definition

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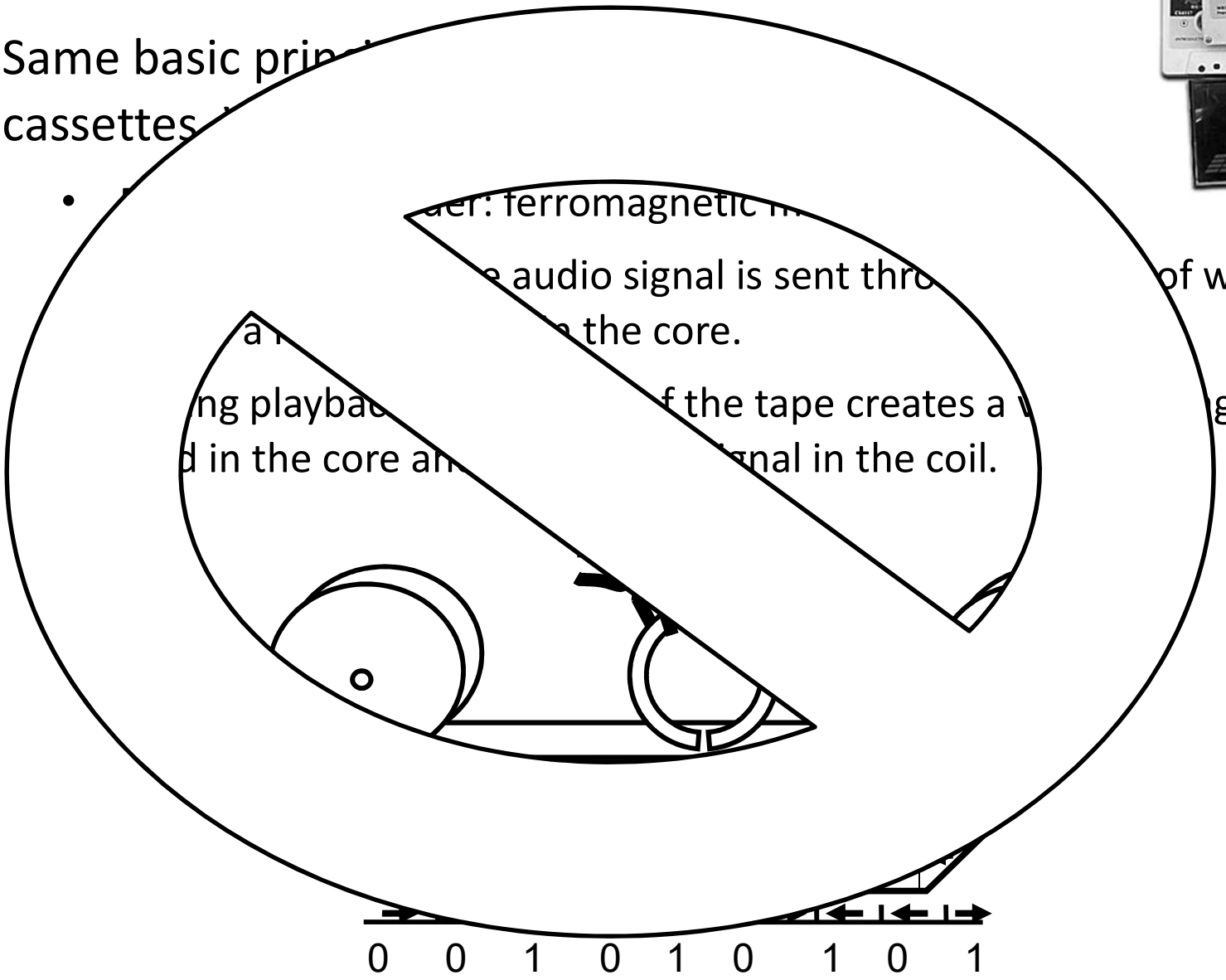
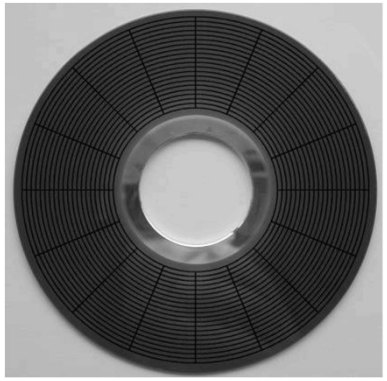
Tapes

- Same basic prin
  cassettes
  - der: ferromagnetic
    e audio signal is sent thro of wire to
    a the core.
    ng playba f the tape creates a gnetic
    d in the core a nal in the coil.

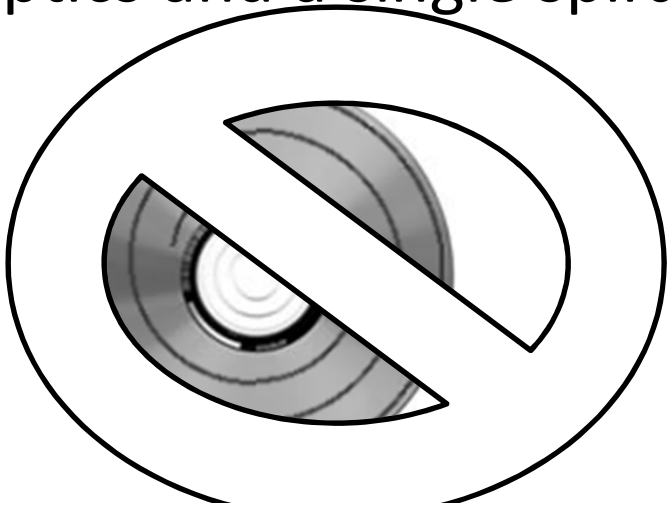


Disks & CDs

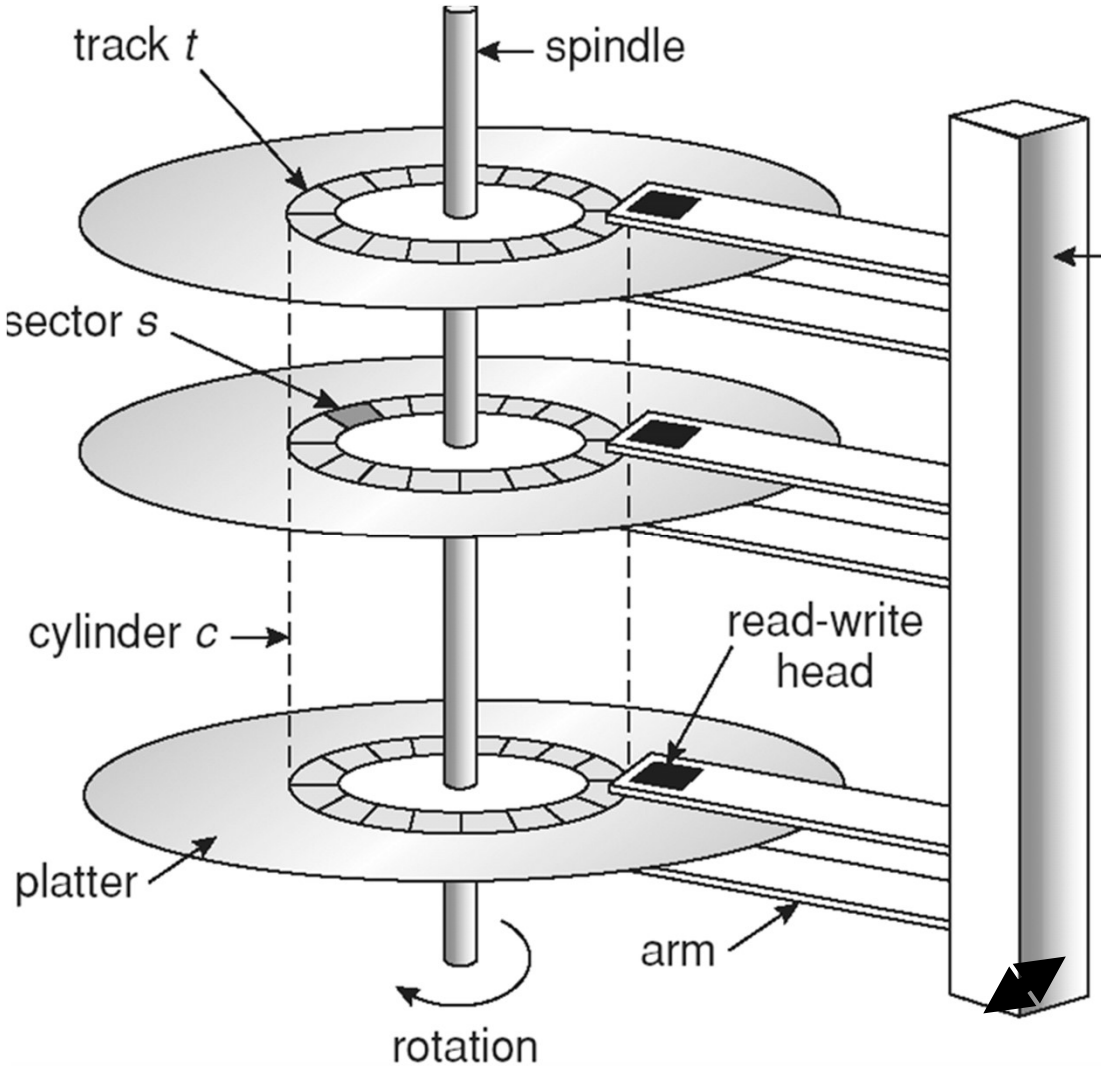
- Disks use same magnetic medium as tapes
  - concentric rings (not a spiral)



- CDs & DVDs use optics and a single spiral track



Disk Physics



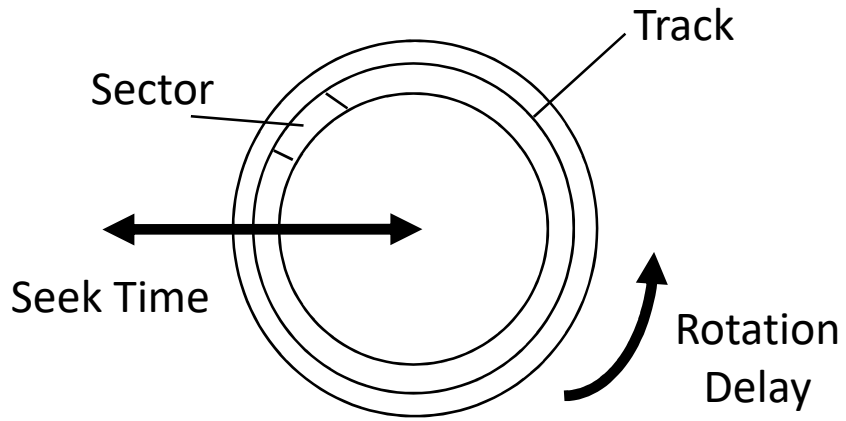
Typical parameters :

- 1 spindle
- 1 arm assembly
- 1-4 platters
- 1-2 sides/platter
- 1 head per side
  (but only 1 active head at a time)
- 700-20480 tracks/surface
- 16-1600 sectors/track

Disk Accesses

- Accessing a disk requires:
  - specify sector: C (cylinder), H (head), and S (sector)
  - specify size: number of sectors to read or write
  - specify memory address

- Performance:
  - seek time: move the arm assembly to track
  - Rotational delay: wait for sector to come around
  - transfer time: get the bits off the disk
  - Controller time: time for setup



Example

- Average time to read/write 512-byte sector
  - Disk rotation at 10,000 RPM
  - Seek time: 6ms
  - Transfer rate: 50 MB/sec
  - Controller overhead: 0.2 ms
- Average time:
  - Seek time + rotational delay + transfer time + controller overhead
  - 6ms + 0.5 rotation/(10,000 RPM) + 0.5KB/(50 MB/sec) + 0.2ms
  - 6.0 + 3.0 + 0.01 + 0.2 = 9.2ms

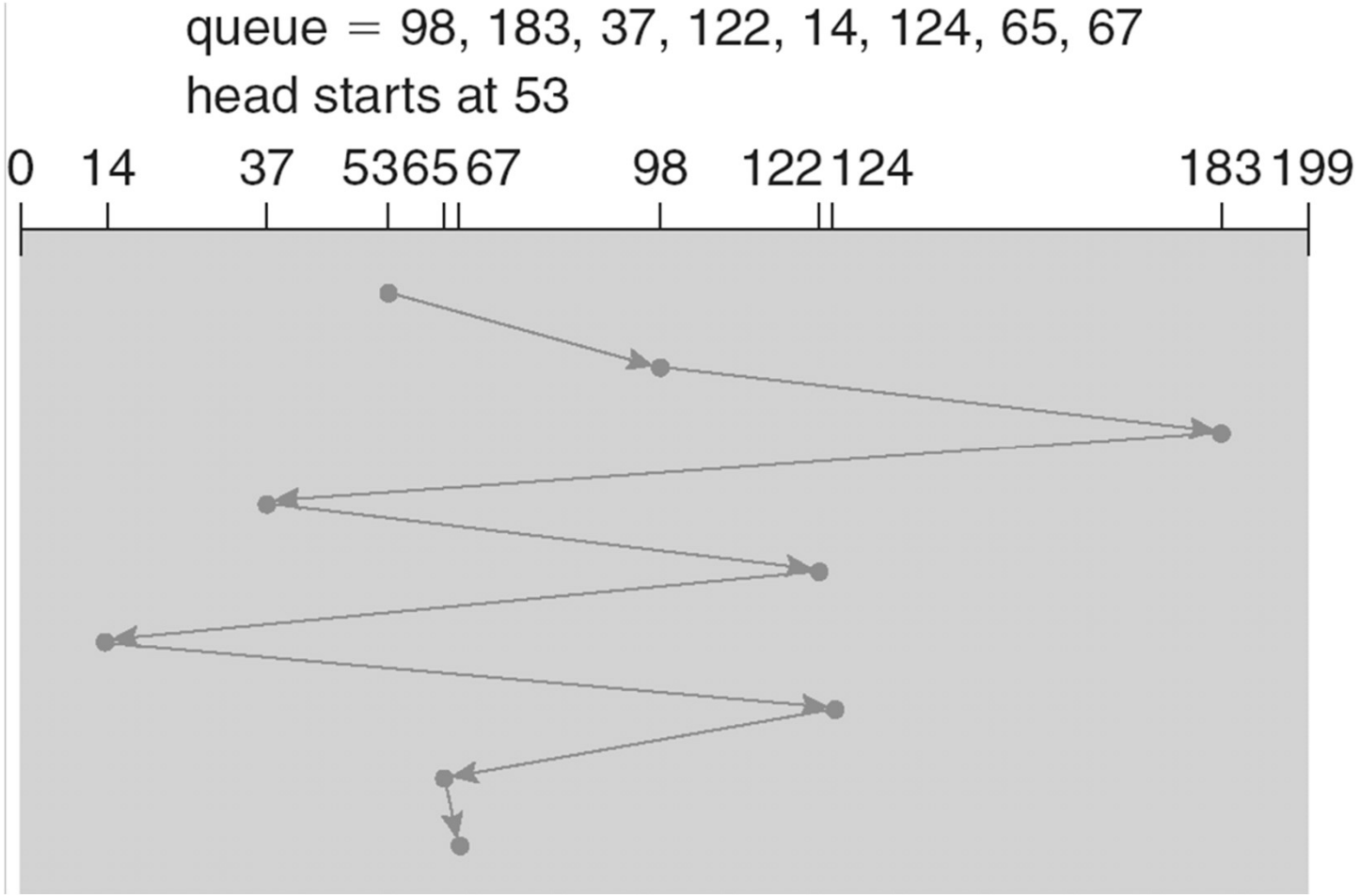
Disk Access Example

- If actual average seek time is 2ms
  - Average read time = 5.2ms

Disk Scheduling

- Goal: minimize seek time
  - secondary goal: minimize rotational latency
- FCFS (First come first served)
- Shortest seek time
- SCAN/Elevator
  - First service all requests in one direction
  - Then reverse and serve in opposite direction
- Circular SCAN
  - Go off the edge and come to the beginning and start all over again

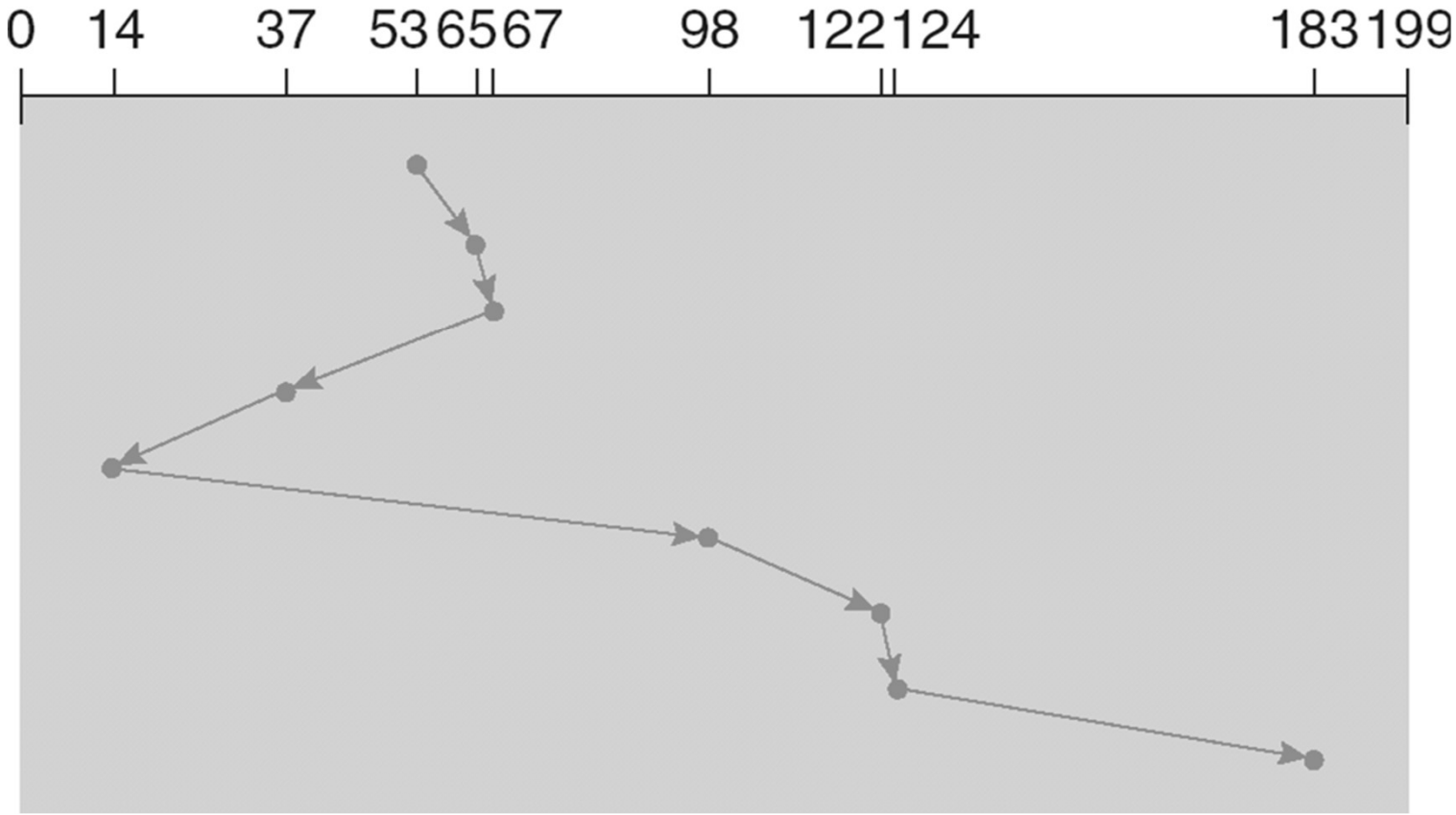
FCFS


queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0
14
37
53
65
67
98
122
124
183
199

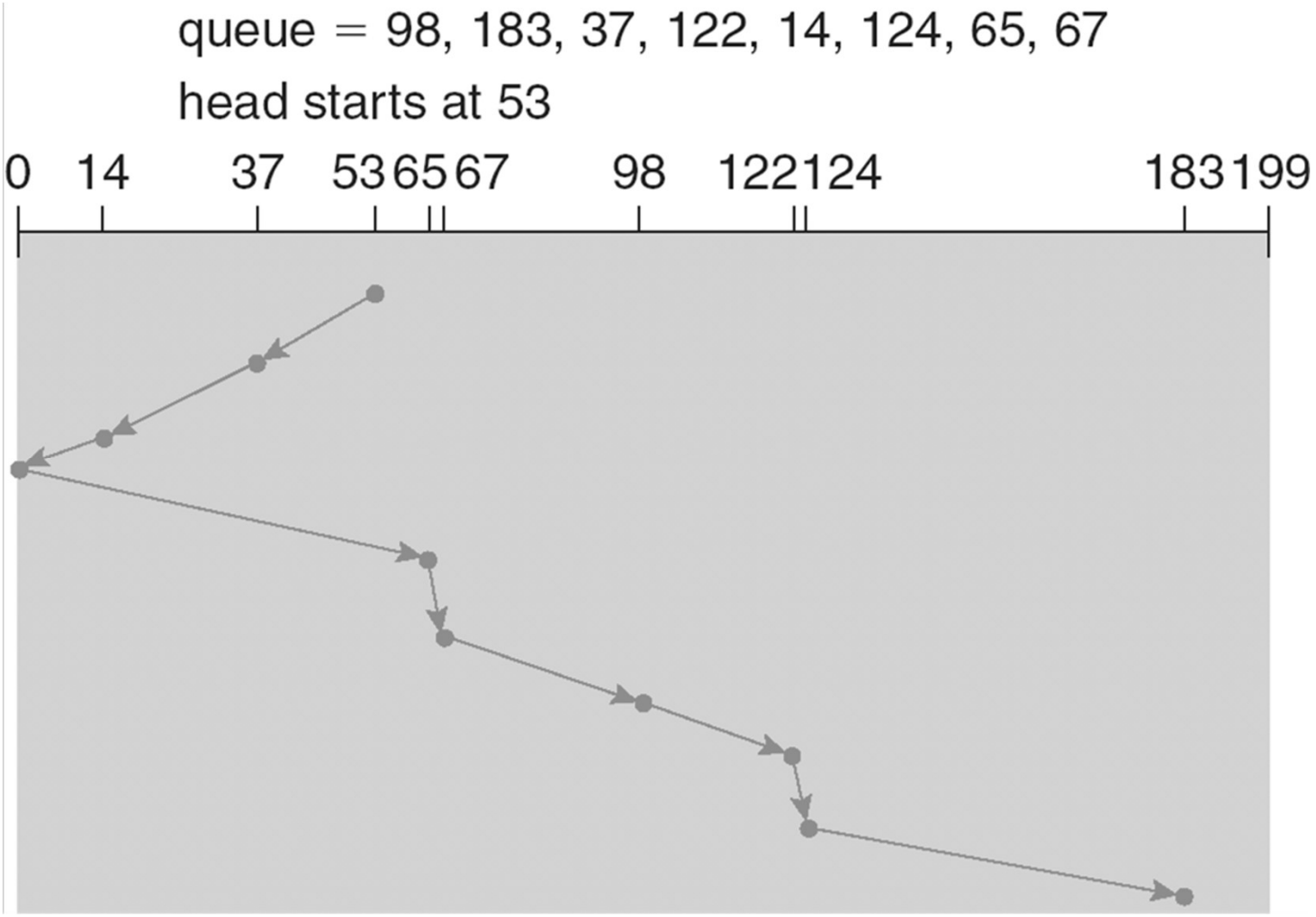
SSTF

queue = 98, 183, 37, 122, 14, 124, 65, 67

head starts at 53



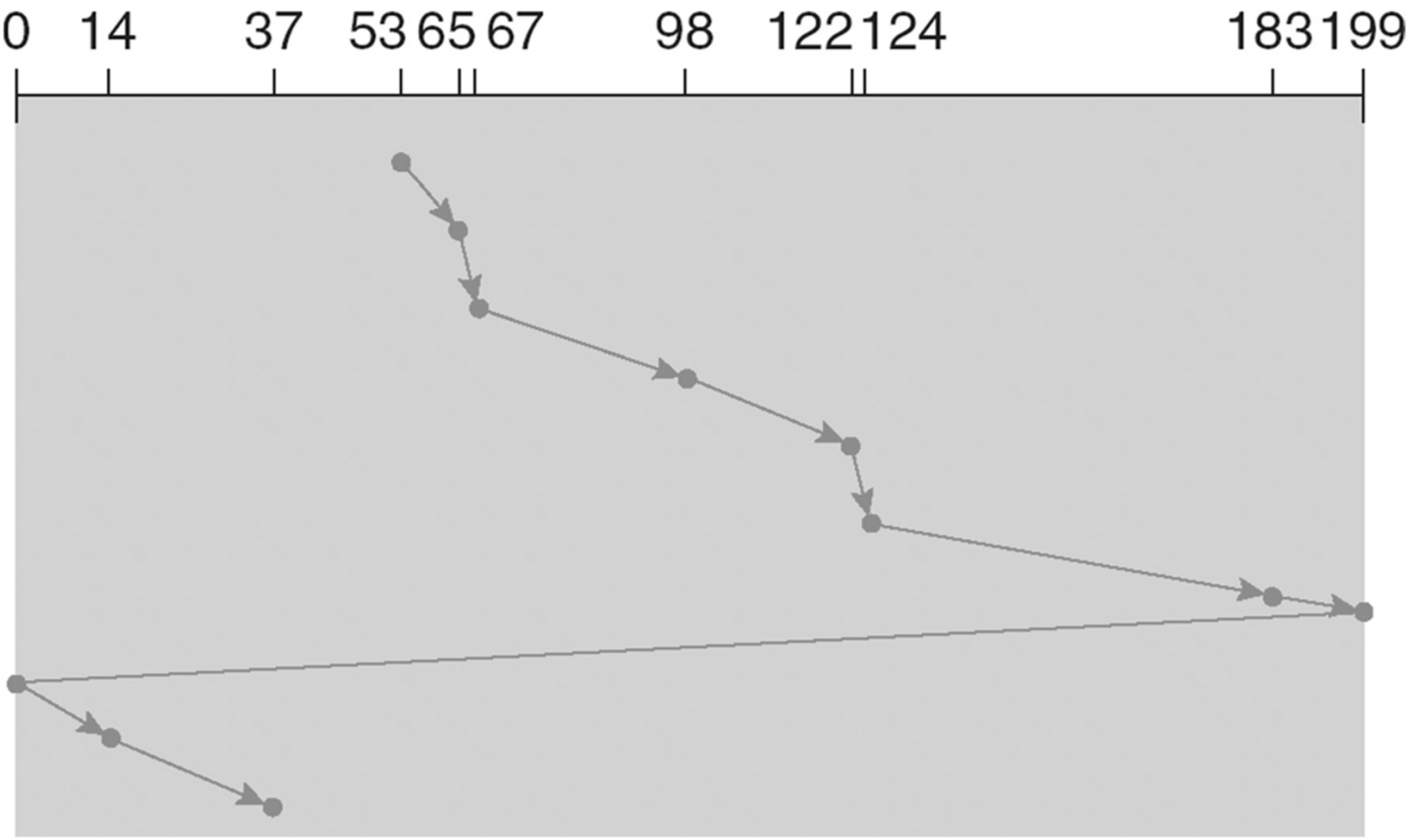
SCAN


queue = 98, 183, 37, 122, 14, 124, 65, 67
head starts at 53
0
14
37
53
65
67
98
122
124
183
199

C-SCAN

queue = 98, 183, 37, 122, 14, 124, 65, 67

head starts at 53

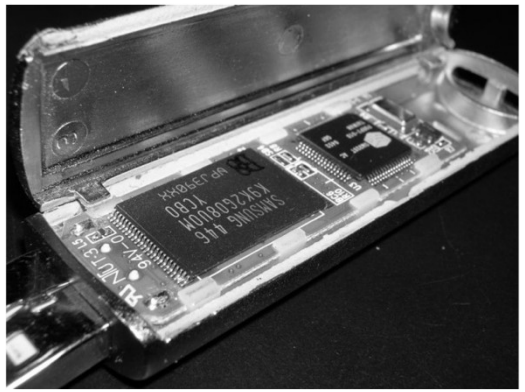


Disk Geometry: LBA

- New machines use *logical block addressing* instead of CHS
  - machine presents illusion of an array of blocks, numbered 0 to N
- Modern disks…
  - have varying number of sectors per track
    - roughly constant data density over disk
    - varying throughput over disk
  - remap and reorder blocks (to avoid defects)
  - completely obscure their actual physical geometry
  - have built-in caches to hide latencies when possible (but being careful of persistence requirements)
  - have internal software running on an embedded CPU

Flash Storage

- Nonvolatile semiconductor storage
  - 100 × – 1000 × faster than disk
  - Smaller, lower power
  - But more $/GB (between disk and DRAM)
  - But, price is dropping and performance is increasing faster than disk



Flash Types

- NOR flash: bit cell like a NOR gate
  - Random read/write access
  - Used for instruction memory in embedded systems
- NAND flash: bit cell like a NAND gate
  - Denser (bits/area), but block-at-a-time access
  - Cheaper per GB
  - Used for USB keys, media storage, …
- Flash bits wears out after 1000's of accesses
  - Not suitable for direct RAM or disk replacement
- Flash has unusual interface
  - can only "reset" bits in large blocks

I/O vs. CPU Performance

- Amdahl's Law
  - Don't neglect I/O performance as parallelism increases compute performance
- Example
  - Benchmark takes 90s CPU time, 10s I/O time
  - Double the number of CPUs/2 years
    - I/O unchanged

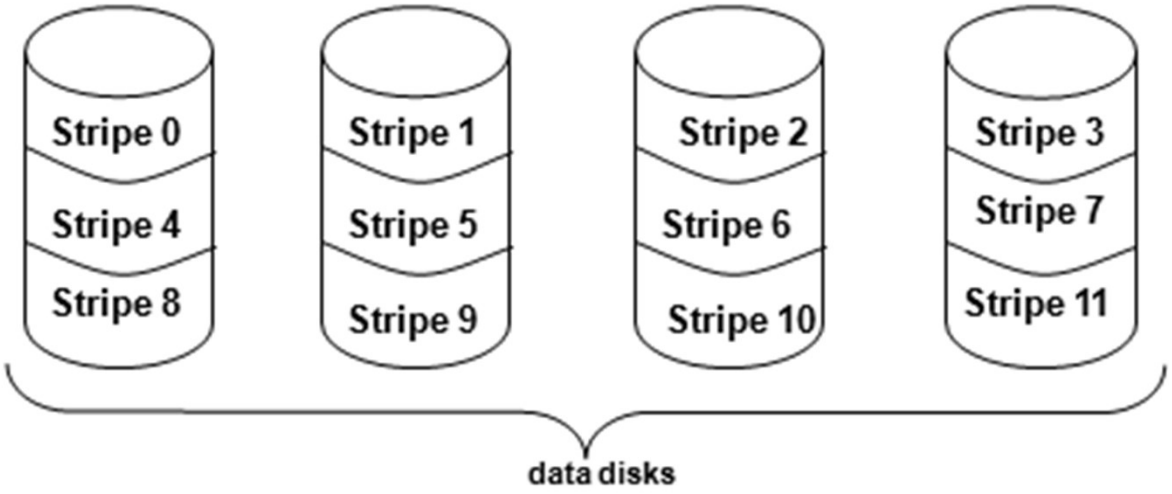
Year	CPU time	I/O time	Elapsed time	% I/O time
now	90s	10s	100s	10%
+2	45s	10s	55s	18%
+4	23s	10s	33s	31%
+6	11s	10s	21s	47%

RAID

- Redundant Arrays of Inexpensive Disks
- Big idea:
  - Parallelism to gain performance
  - Redundancy to gain reliability

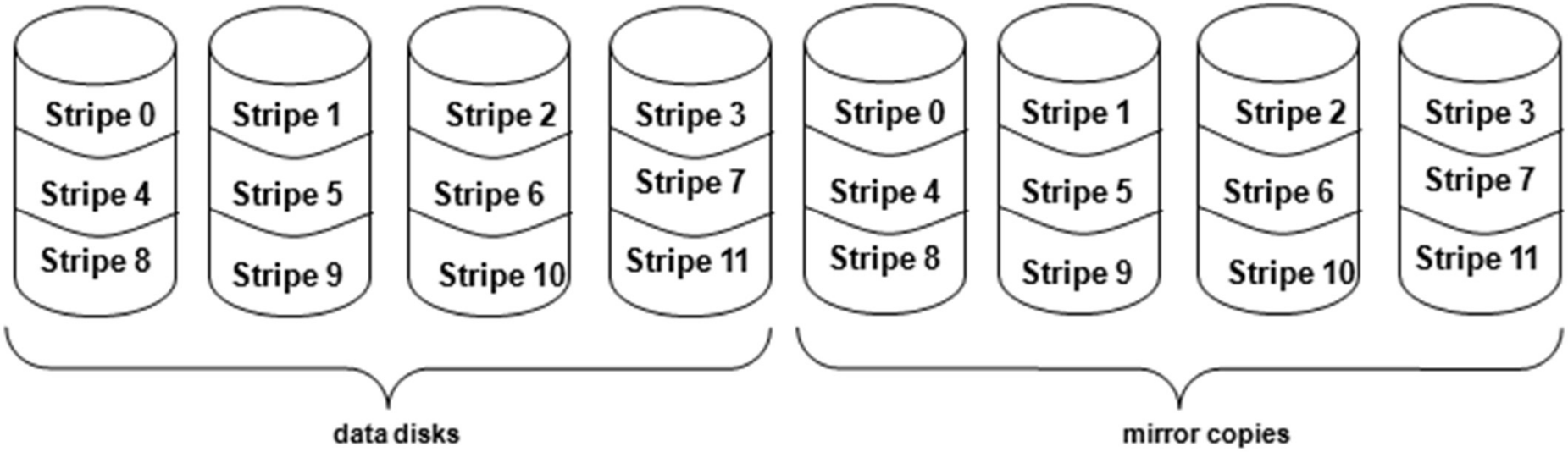
Raid 0

- Striping
  - Non-redundant disk array!



Raid 1

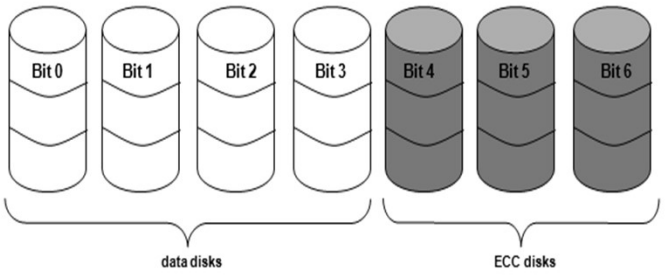
- Mirrored Disks!
  - More expensive
  - On failure use the extra copy



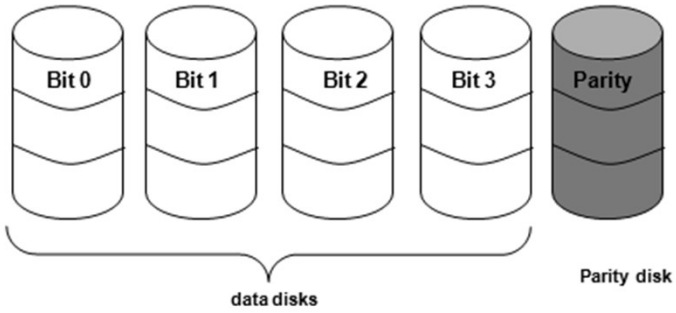
Raid 2-3-4-5-6

- Bit Level Striping and Parity Checks!
  - As level increases:
    - More guarantee against failure, more reliability
    - Better read/write performance

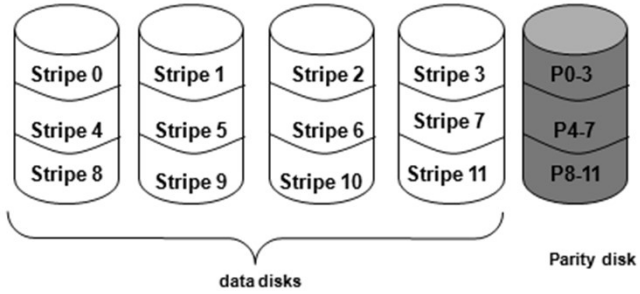
Raid 2



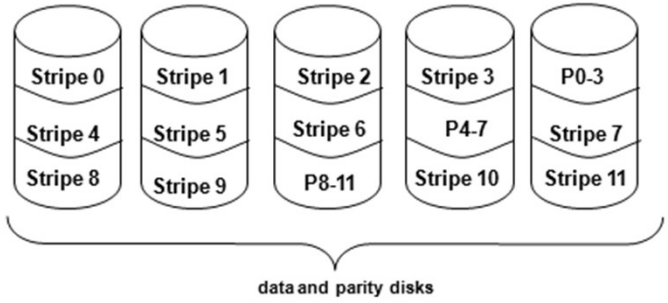
Raid 3



Raid 4



Raid 5



Summary

- Disks provide nonvolatile memory
- I/O performance measures
  - Throughput, response time
  - Dependability and cost very important
- RAID
  - Redundancy for fault tolerance and speed