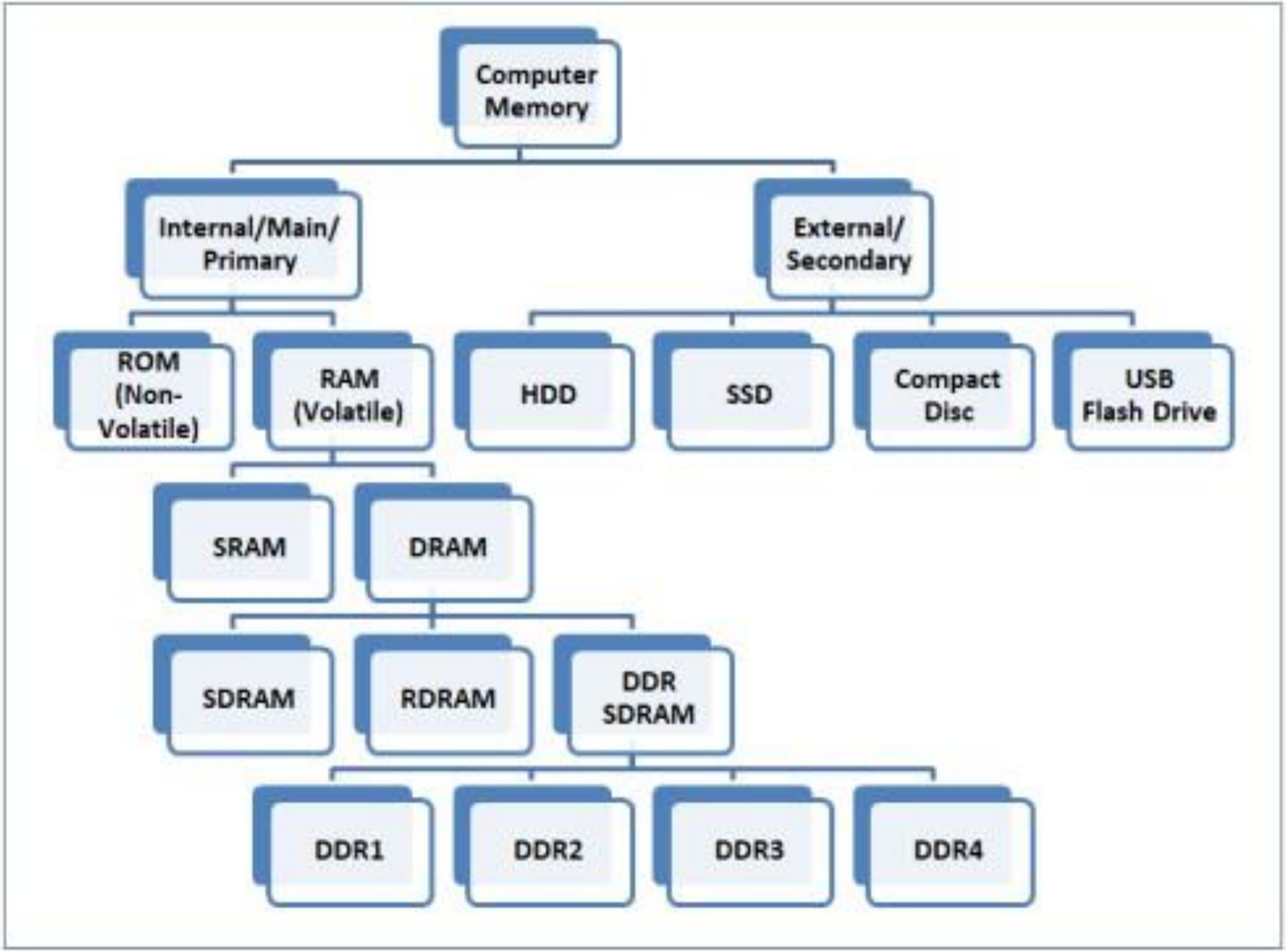
06_02_storage technologies

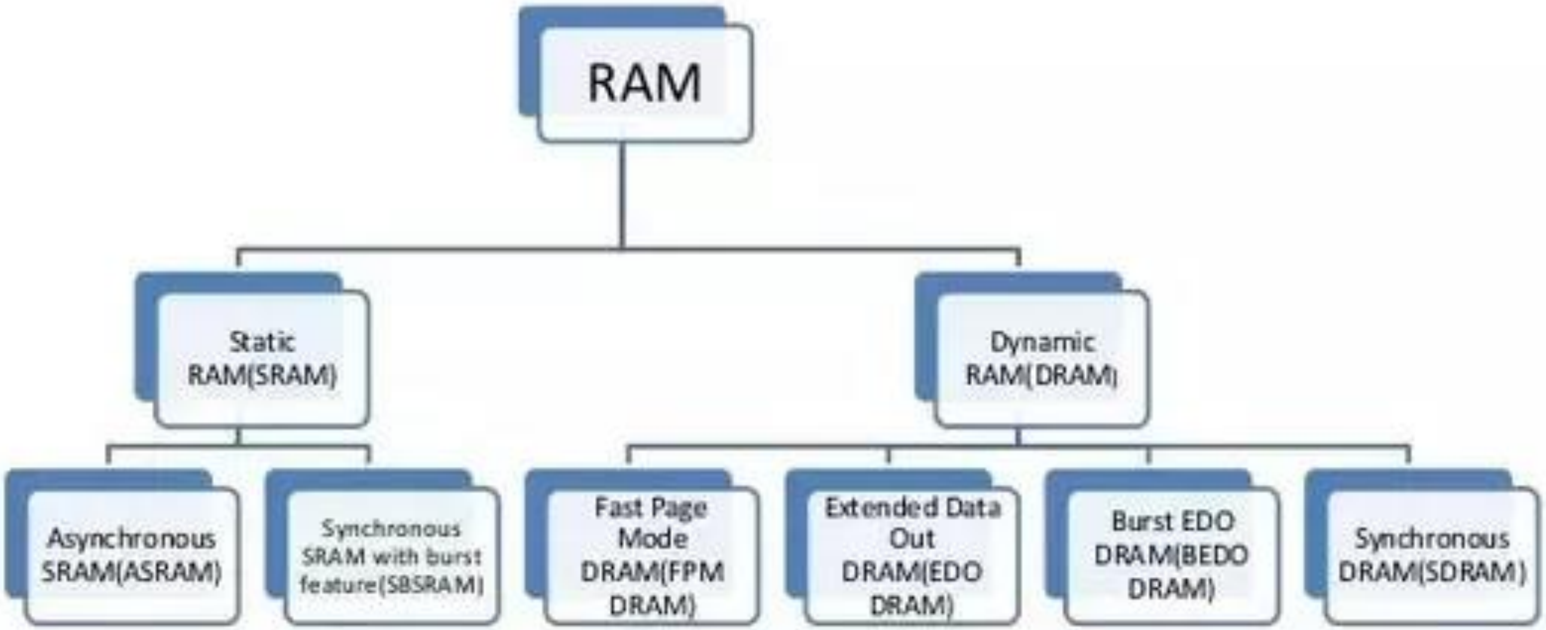
Memory Hierarchy

- Overview. Asymmetry.
- The details:
  - **RAM**
  - Disks



Computer Memory
Internal/Main/ Primary
External/ Secondary
ROM (Non-Volatile)
RAM (Volatile)
HDD
SSD
Compact Disc
USB Flash Drive
SRAM
DRAM
SDRAM
RDRAM
DDR SDRAM
DDR1
DDR2
DDR3
DDR4

Types of Random-Access Memory(RAM)



Random Access Memory. RAM.

- Random Access?
- SRAM – *static* RAM
- DRAM – *dynamic* RAM

SRAM

- Fast
- Expensive
- Used in cache memory (on and off chip)
- How much? A few MB
- More transistors/circuit
- Stable. Retain value as long as there’s power
- No need for refresh

DRAM

- Used in main memory, graphics framebuffer
- “Stores each bit as a charge on a capacitor”
- Sensitive to disturbance (elec. noise, radiation)
  - Use as digital cam sensor
- Leakage:
  - Needs to be refreshed every 10-100 ms
  - How? Just read value and write it again
- Slower than SRAM
- Cheaper than SRAM

SRAM vs DRAM

	transistors per bit	**access time**	**needs refresh?**	**cost**	**where?**
SRAM	6	1x	no	100x	cache memory (on or off chip)
DRAM	1	10x	yes	1x	main memory, graphics framebuffers

volatile vs. non-volatile storage

- volatile – value lost on power off
- non-volatile –
  - Hard disk
  - “ROMs”, “PROMs”, “firmware”
  - Solid state disks

Memory Hierarchy

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- The details:
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What’s Inside A Disk Drive?

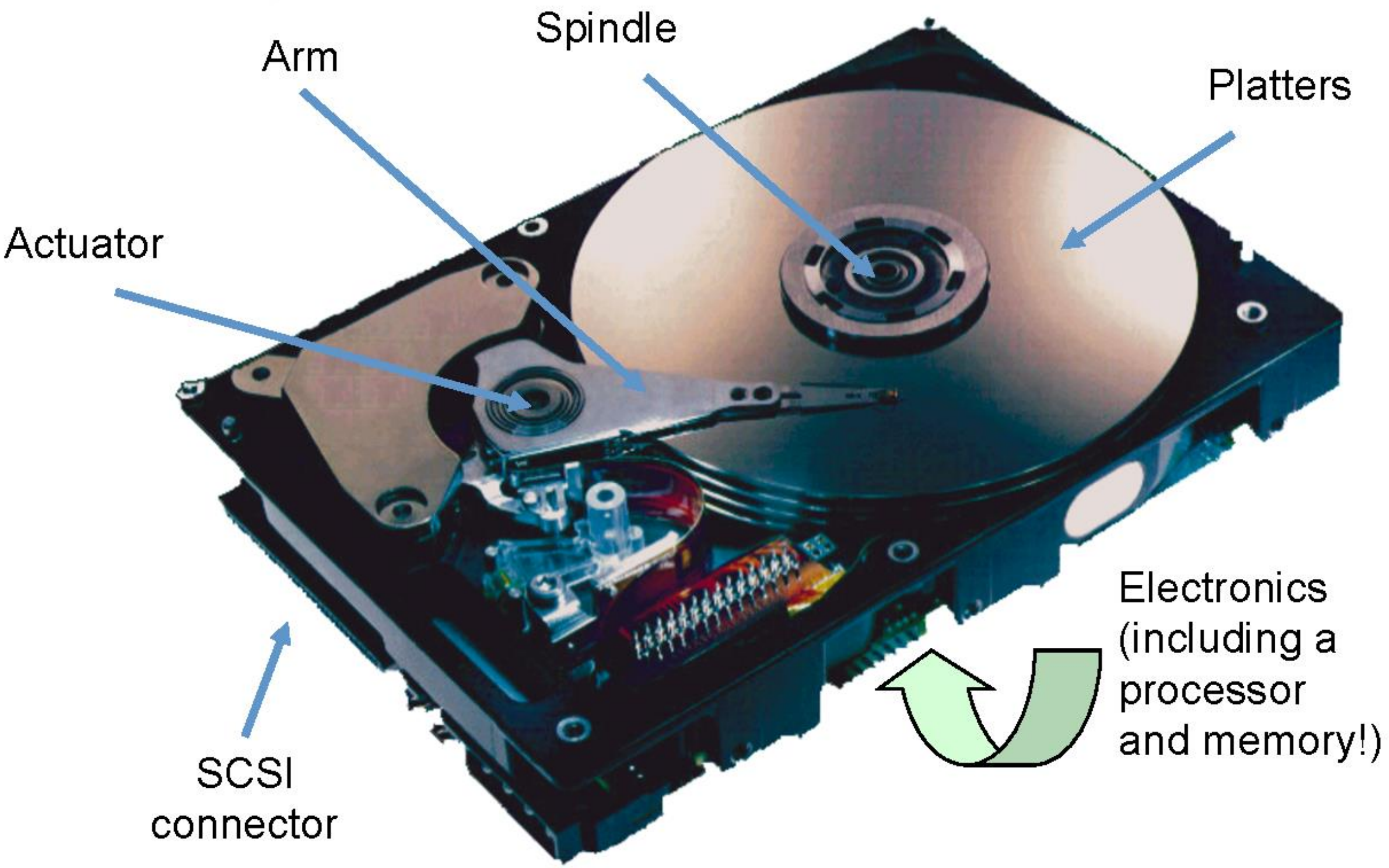
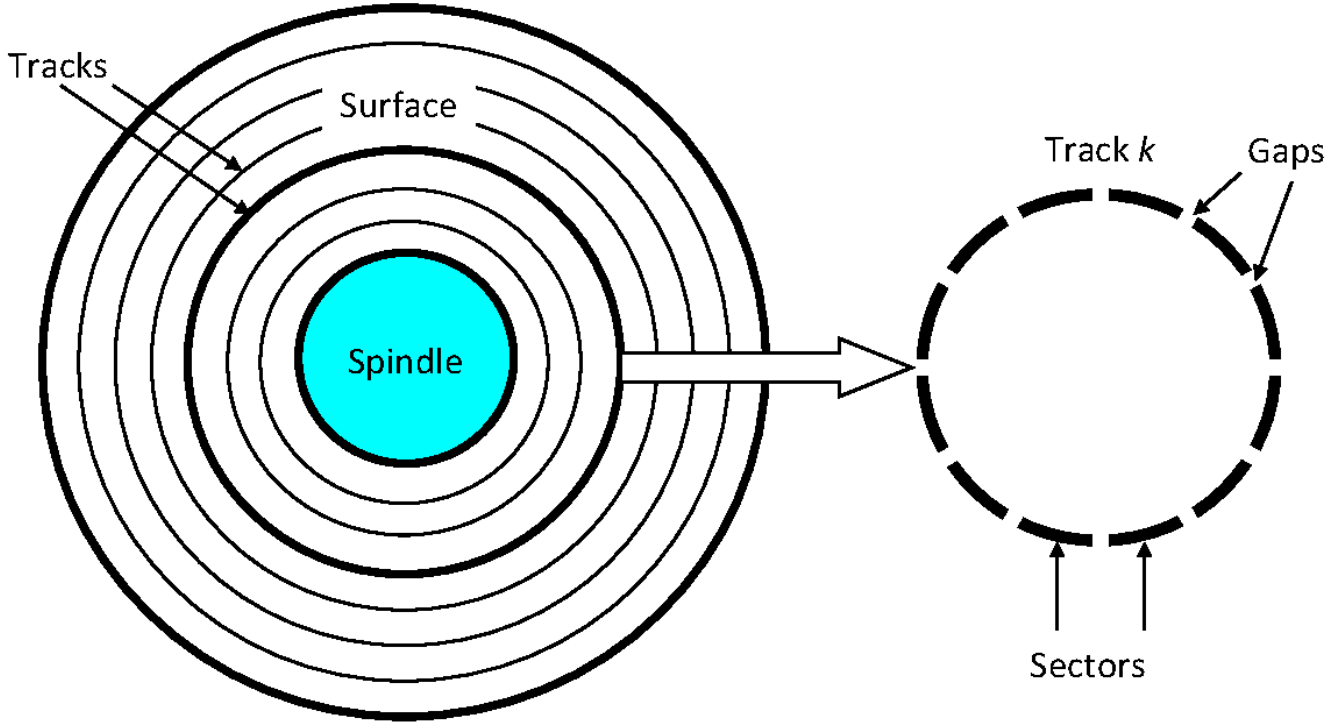


Image courtesy of Seagate Technology

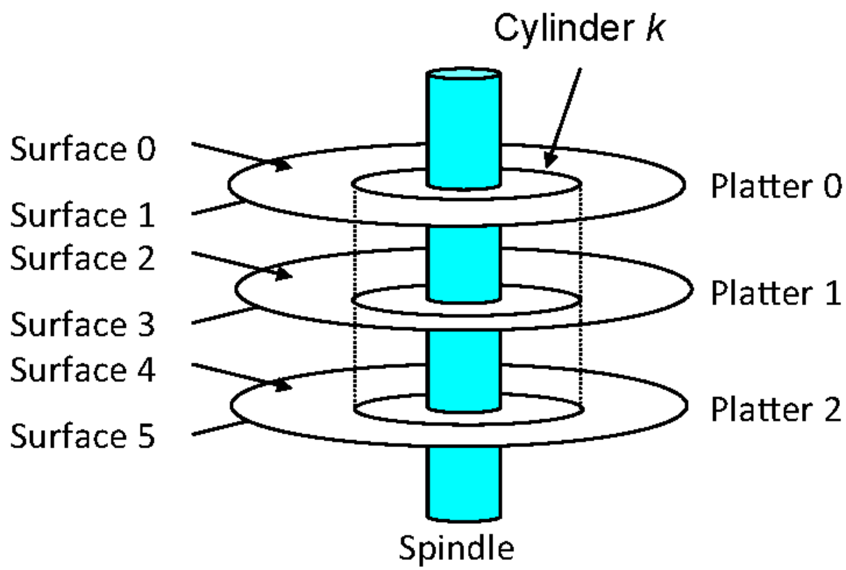
Disk Geometry

- Disks consist of platters, each with two surfaces.
- Each surface consists of concentric rings called tracks.
- Each track consists of sectors separated by gaps.



Disk Geometry (Muliple-Platter View)

- Aligned tracks form a cylinder.



The capacity of a disk is given by the following formula:

$$\text{Disk capacity} = \frac{\#\text{ bytes}}{\text{sector}} \times \frac{\text{average }\#\text{ sectors}}{\text{track}} \times \frac{\#\text{ tracks}}{\text{surface}} \times \frac{\#\text{ surfaces}}{\text{platter}} \times \frac{\#\text{ platters}}{\text{disk}}$$

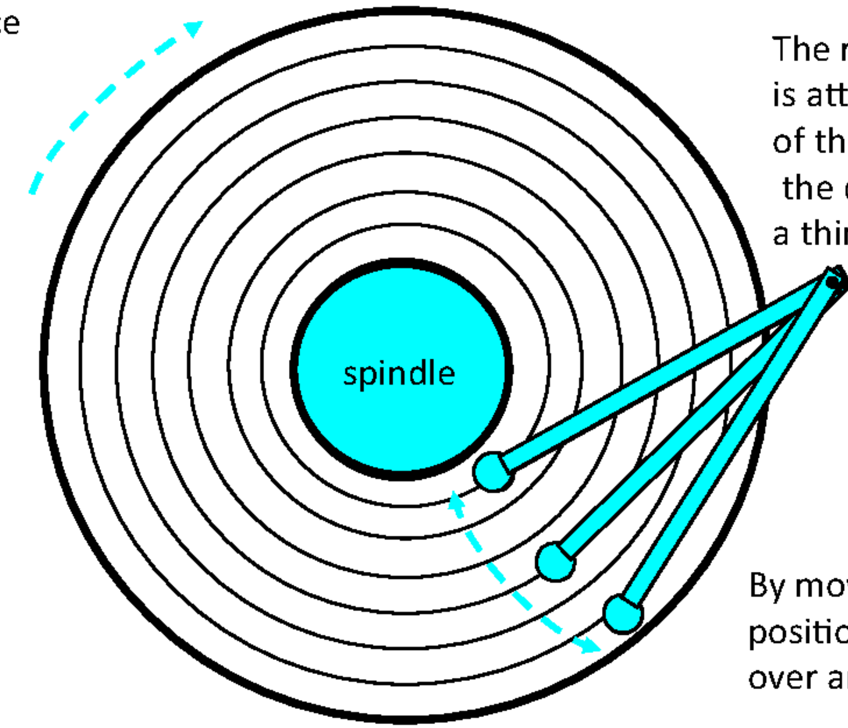
For example, suppose we have a disk with 5 platters, 512 bytes per sector, 20,000 tracks per surface, and an average of 300 sectors per track. Then the capacity of the disk is:

$$\begin{aligned}\text{Disk capacity} &= \frac{512\text{ bytes}}{\text{sector}} \times \frac{300\text{ sectors}}{\text{track}} \times \frac{20{,}000\text{ tracks}}{\text{surface}} \times \frac{2\text{ surfaces}}{\text{platter}} \times \frac{5\text{ platters}}{\text{disk}} \\ &= 30{,}720{,}000{,}000\text{ bytes} \\ &= 30.72\text{ GB}.\end{aligned}$$

Notice that manufacturers express disk capacity in units of gigabytes (GB), where $1\text{ GB} = 10^9$ bytes.

Disk Operation (Single-Platter View)

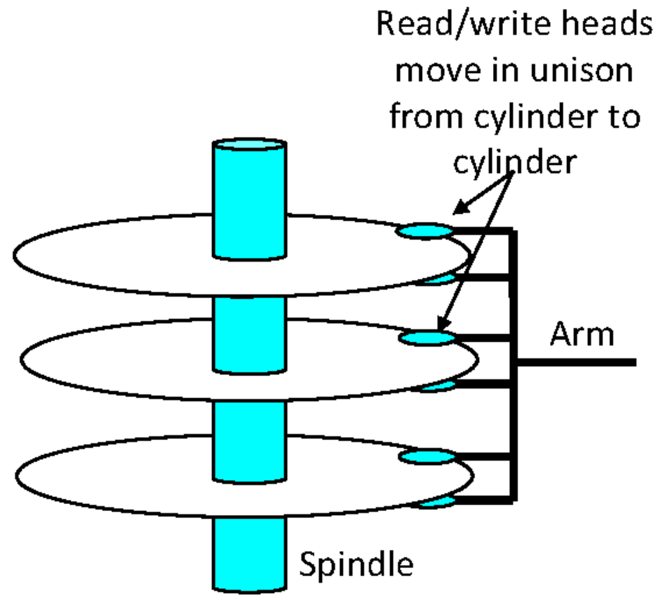
The disk surface spins at a fixed rotational rate



The read/write *head* is attached to the end of the *arm* and flies over the disk surface on a thin cushion of air.

By moving radially, the arm can position the read/write head over any track.

Disk Operation (Multi-Platter View)



spin

Rotation rate these days:

5400, 7200 RPM

from the book …

- equivalent of Sears Tower on its side:
  - 1 inch above the surface of the Earth
  - each orbit takes 8 seconds

- Speck of dust equivalent to a boulder
- Head crash

Logical Disk Blocks

- Modern disks present a simpler abstract view of the complex sector geometry:
  - The set of available sectors is modeled as a sequence of b-sized logical blocks (0, 1, 2, ...)
- Mapping between logical blocks and actual (physical) sectors
  - Maintained by hardware/firmware device called disk controller.
  - Converts requests for logical blocks into (surface,track,sector) triples.
- Allows controller to set aside spare cylinders for each zone.
  - Accounts for the difference in “formatted capacity” and “maximum capacity”.

Geometry attribute	Value
Platters	4
Surfaces (read/write heads)	8
Surface diameter	3.5 in.
Sector size	512 bytes
Zones	15
Cylinders	50,864
Recording density (max)	628,000 bits/in.
Track density	85,000 tracks/in.
Areal density (max)	53.4 Gbits/sq. in.
Formatted capacity	146.8 GB

Figure 6.13 **Seagate Cheetah 15K.4 geometry**

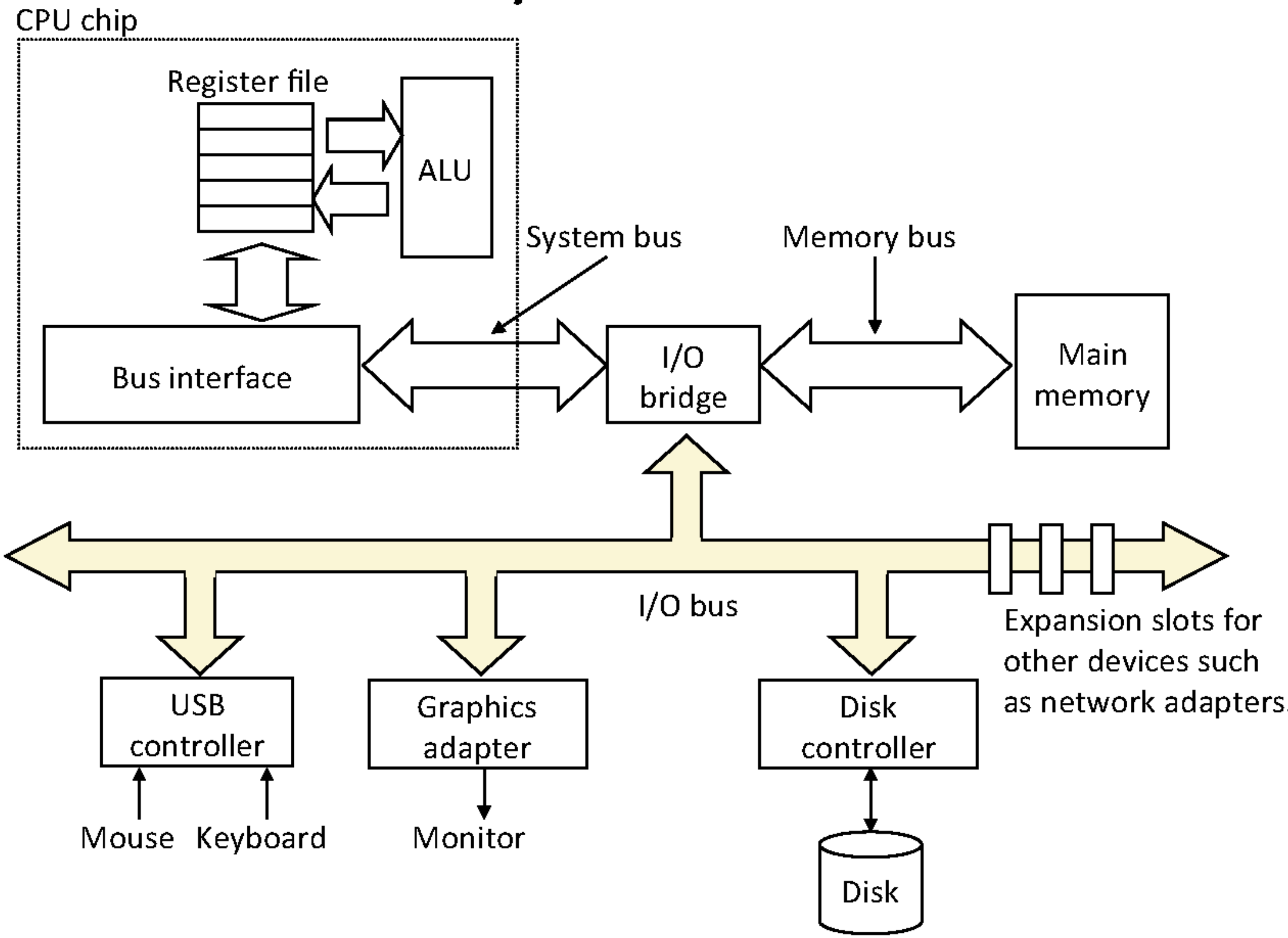
Performance attribute	Value
Rotational rate	15,000 RPM
Avg. rotational latency	2 ms
Avg. seek time	4 ms
Sustained transfer rate	58–96 MB/s

Figure 6.13 **Seagate Cheetah 15K.4 geometry and performance.** Source: `www.seagate.com`.

Zone number	Sectors per track	Cylinders per zone	Logical blocks per zone
(outer) 0	864	3201	22,076,928
1	844	3200	21,559,136
2	816	3400	22,149,504
3	806	3100	19,943,664
4	795	3100	19,671,480
5	768	3400	20,852,736
6	768	3450	21,159,936
7	725	3650	21,135,200
8	704	3700	20,804,608
9	672	3700	19,858,944
10	640	3700	18,913,280
11	603	3700	17,819,856
12	576	3707	17,054,208
13	528	3060	12,900,096
(inner) 14	—	—	—

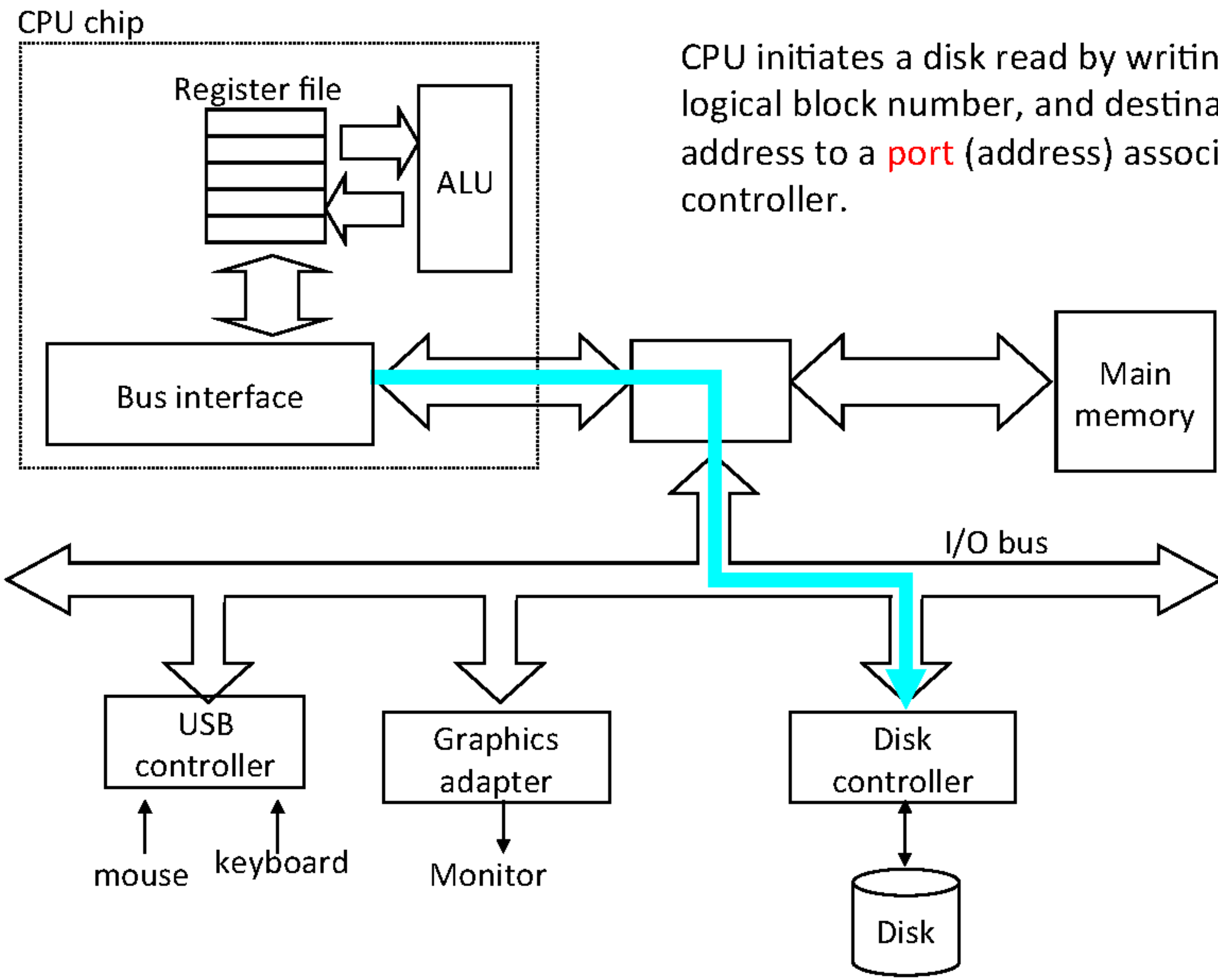
Figure 6.14 **Seagate Cheetah 15K.4 zone map.** Source: DIXtrac automatic disk drive characterization tool [92]. Data for zone 14 not available.

I/O Bus


CPU chip
Register file
ALU
System bus
Memory bus
Bus interface
I/O
bridge
Main
memory
I/O bus
Expansion slots for
other devices such
as network adapters.
USB
controller
Graphics
adapter
Disk
controller
Mouse
Keyboard
Monitor
Disk

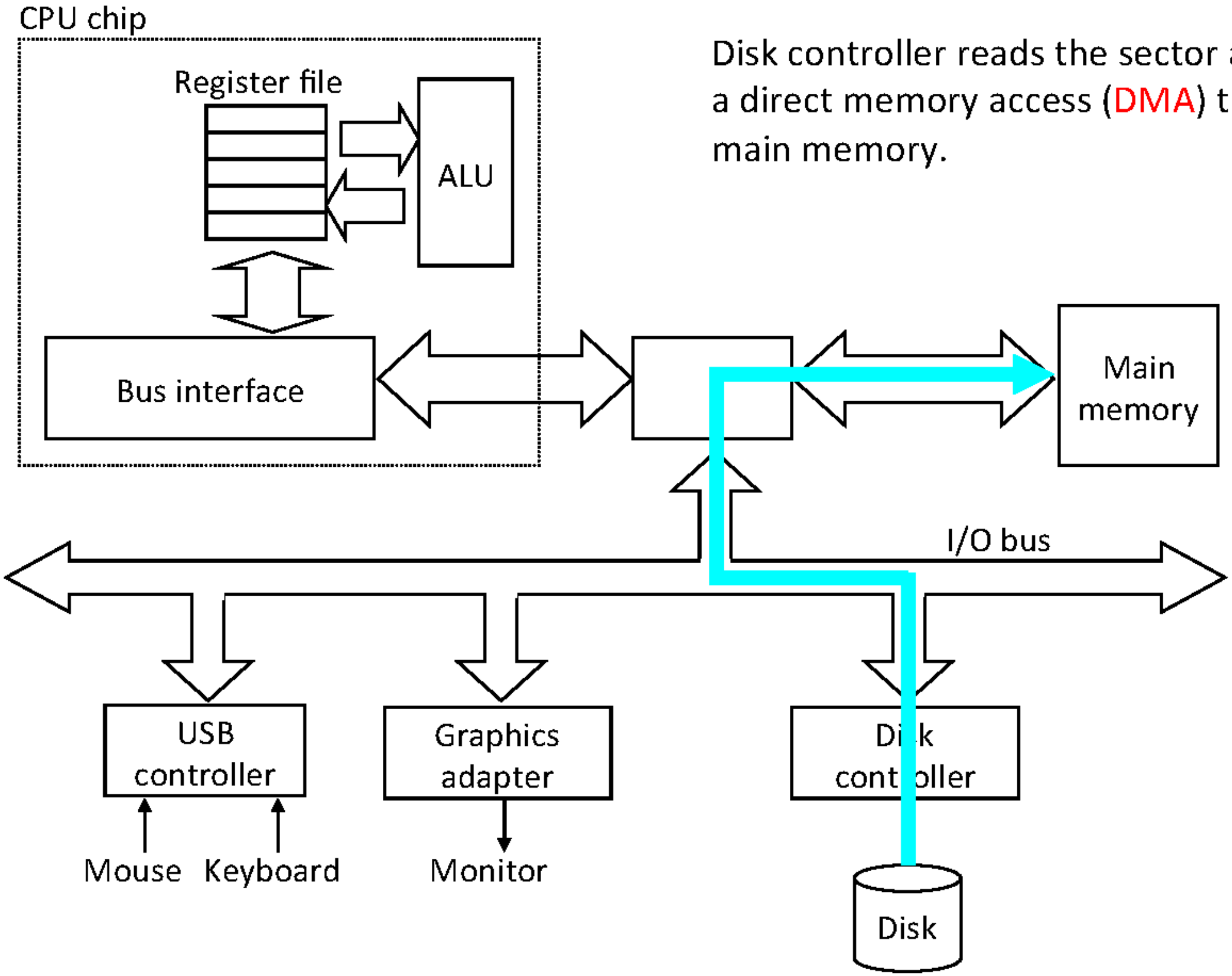
Reading a Disk Sector (1)

CPU initiates a disk read by writing a command, logical block number, and destination memory address to a port (address) associated with disk controller.



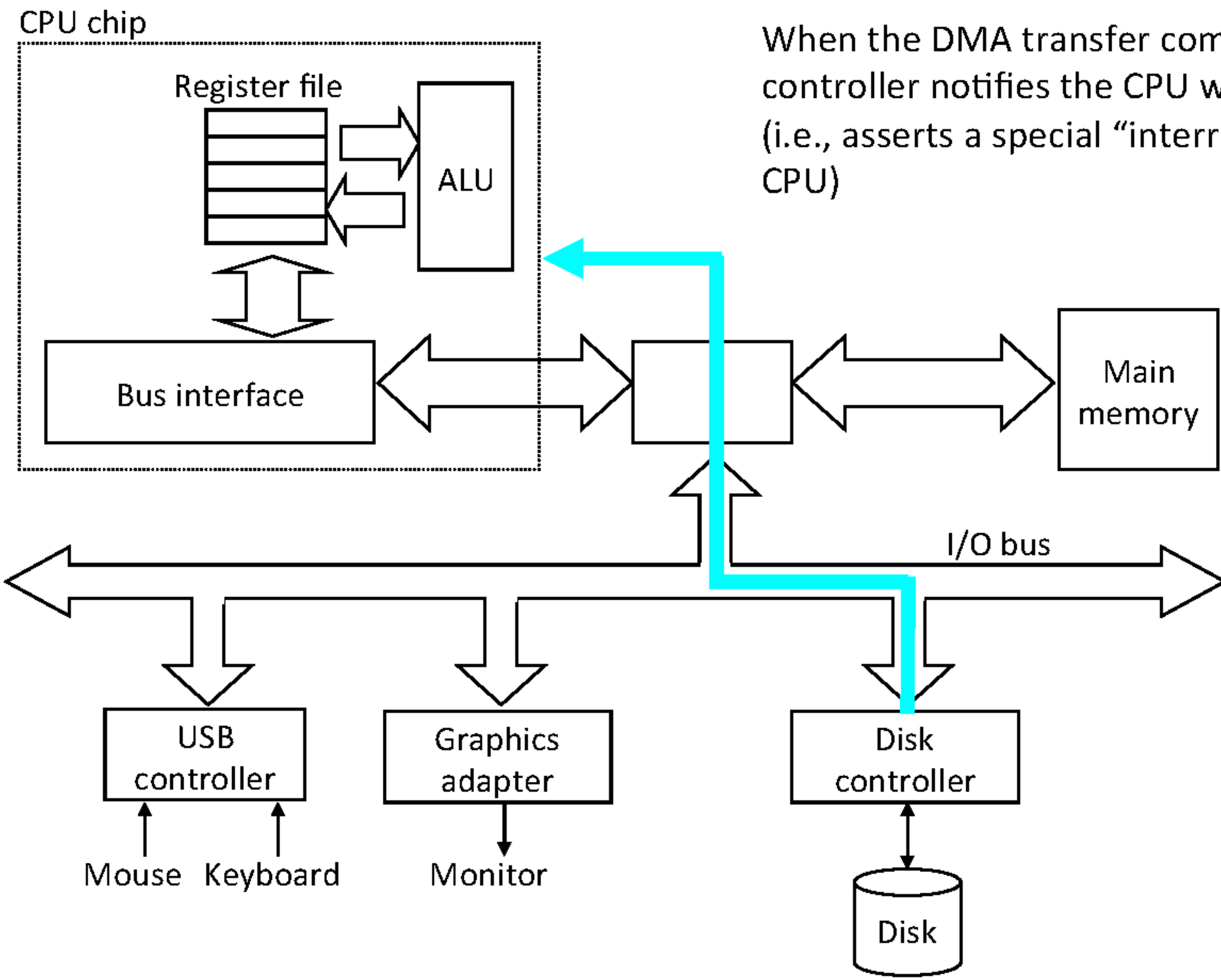
Reading a Disk Sector (2)

Disk controller reads the sector and performs a direct memory access (DMA) transfer into main memory.

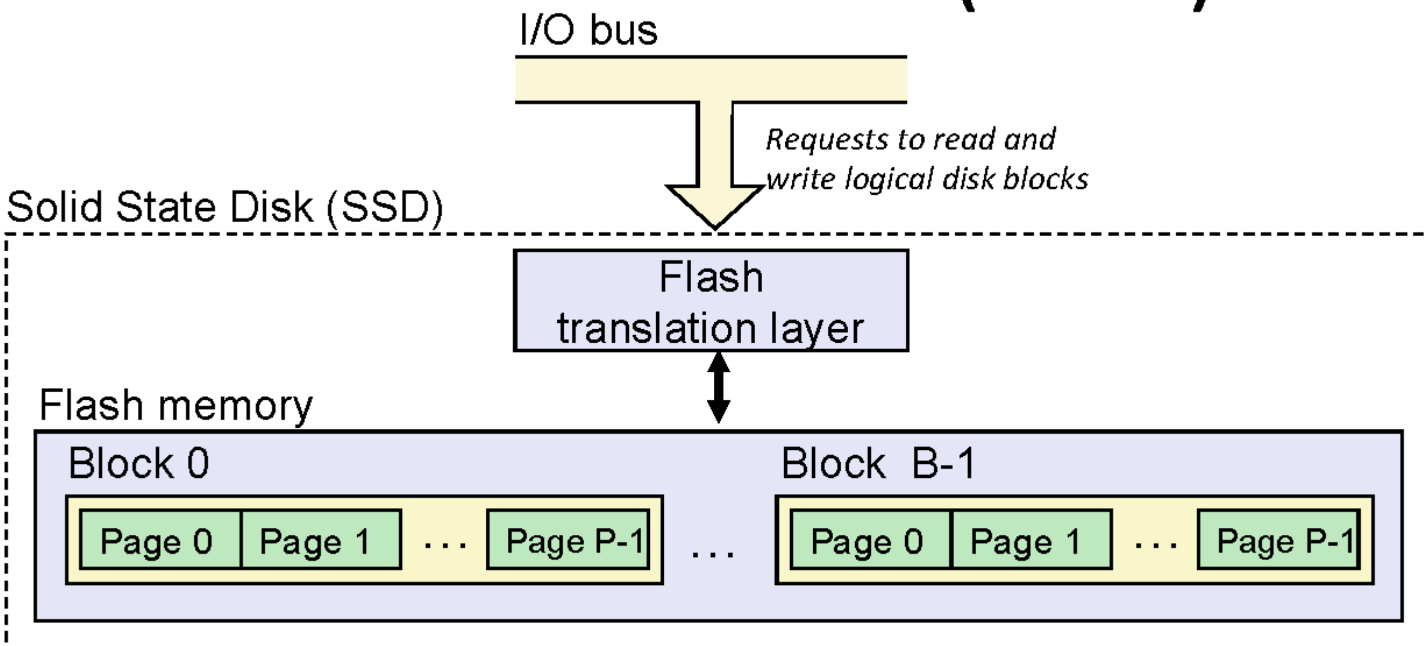


Reading a Disk Sector (3)

When the DMA transfer completes, the disk controller notifies the CPU with an *interrupt* (i.e., asserts a special “interrupt” pin on the CPU)



Solid State Disks (SSDs)



- Pages: 512KB to 4KB, Blocks: 32 to 128 pages
- Data read/written in units of pages.
- Page can be written only after its block has been erased
- A block wears out after 100,000 repeated writes.

SSD Performance Characteristics

Reads		Writes	
Sequential read throughput	250 MB/s	Sequential write throughput	170 MB/s
Random read throughput	140 MB/s	Random write throughput	14 MB/s
Random read access time	30 μs	Random write access time	300 μs

Figure 6.16 **Performance characteristics of a typical solid state disk.** Source: Intel X25-E SATA solid state drive product manual.

- Why are random writes so slow?
  - Erasing a block is slow (around 1 ms)
  - Write to a page triggers a copy of all useful pages in the block
    - Find an used block (new block) and erase it
    - Write the page into the new block
    - Copy other pages from old block to the new block

SSD Tradeoffs vs Rotating Disks

- Advantages
  - No moving parts → faster, less power, more rugged
- Disadvantages
  - Have the potential to wear out
    - Mitigated by "wear leveling logic" in flash translation layer
    - E.g. Intel X25 guarantees 1 petabyte (1015 bytes) of random writes before they wear out
  - In 2010, about 100 times more expensive per byte
- Applications
  - MP3 players, smart phones, laptops
  - Beginning to appear in desktops and servers

The CPU-Memory Gap

The gap widens between DRAM, disk, and CPU speeds.