What’s Inside A Disk Drive?

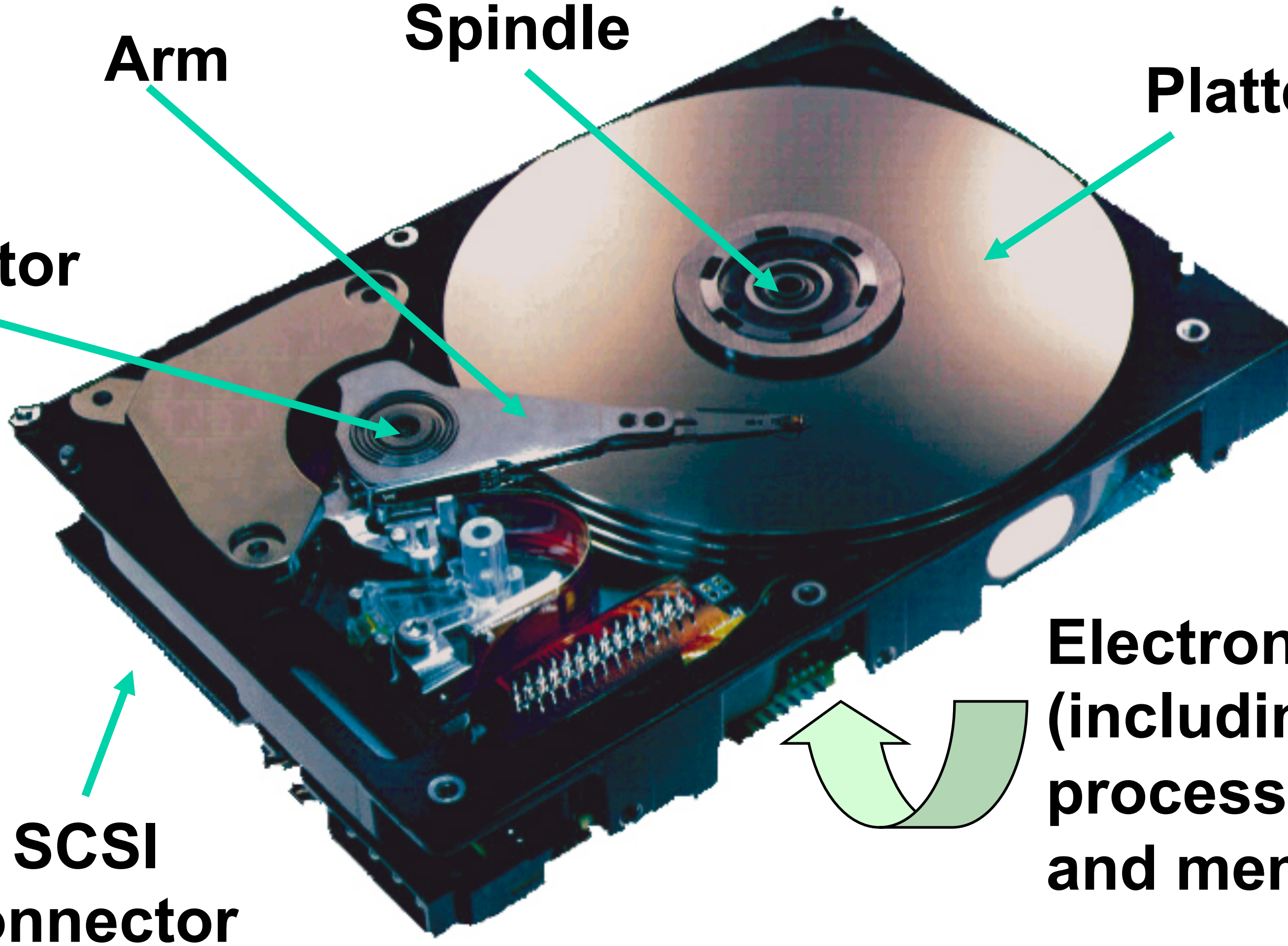
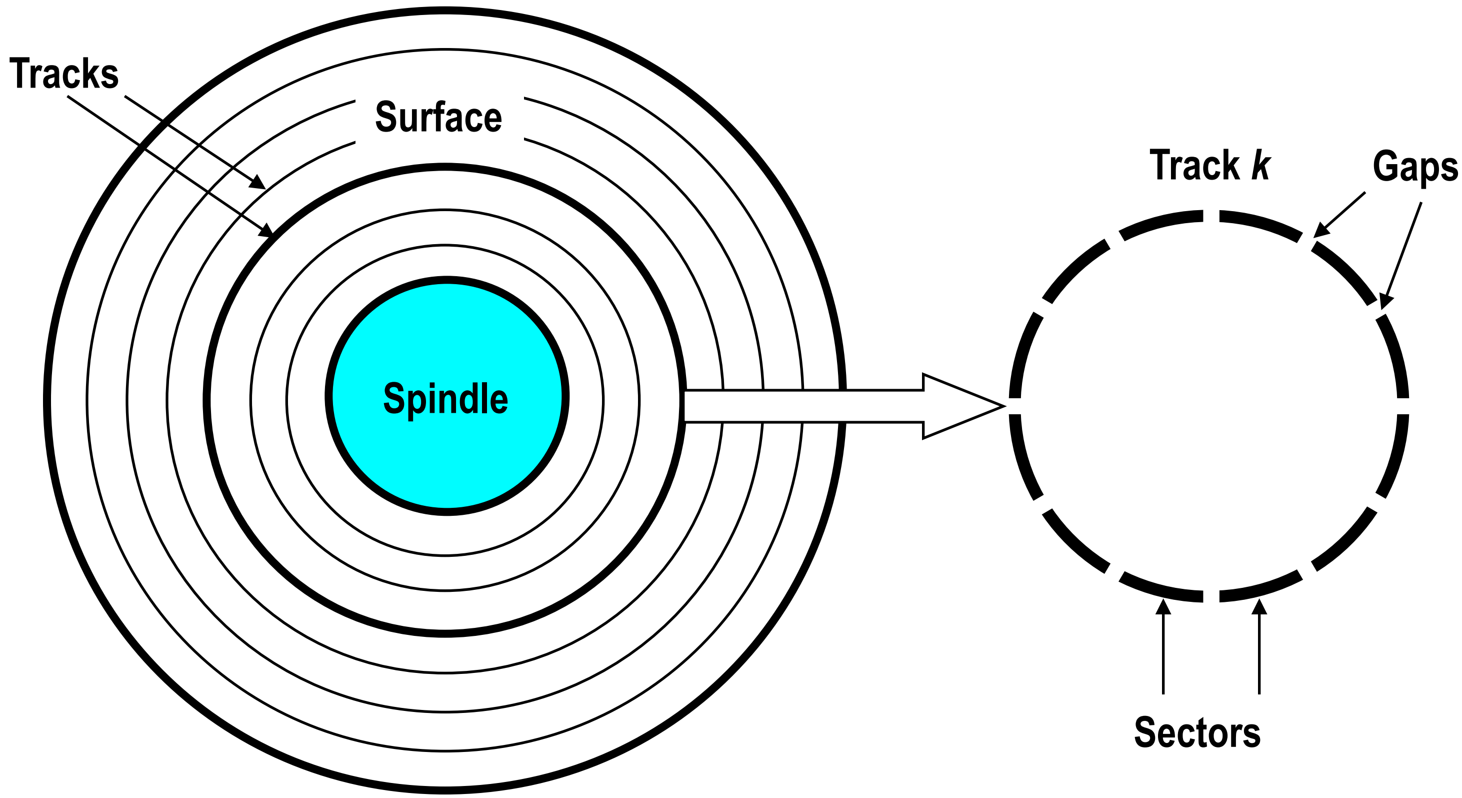


Image courtesy of Seagate Technology

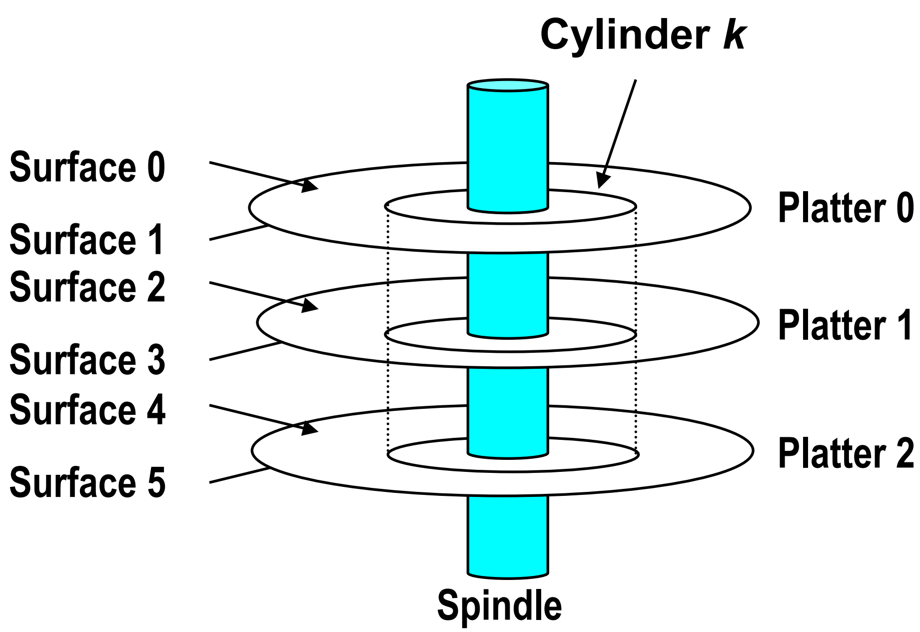
Disk Geometry

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



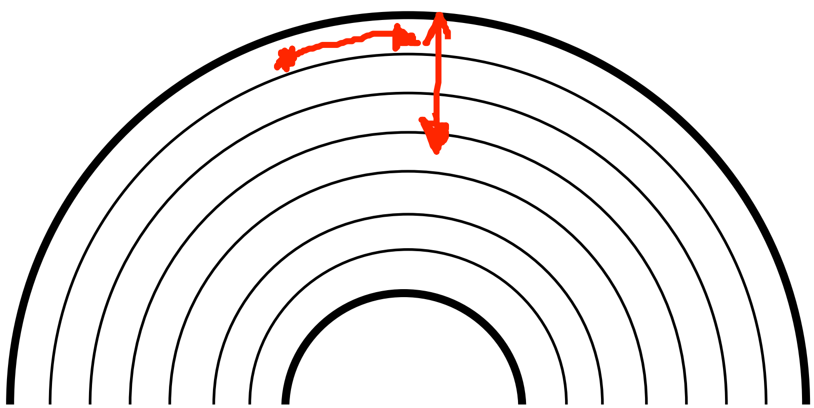
Disk Geometry (Muliple-Platter View)

- **Aligned tracks form a cylinder.**



Disk Capacity

- **Capacity: maximum number of bits that can be stored.**
  - Vendors express capacity in units of gigabytes (GB), where 1 GB = 10^9 Bytes.
- **Capacity is determined by these technology factors:**
  - Recording density (bits/in): number of bits that can be squeezed into a 1 inch segment of a track.
  - Track density (tracks/in): number of tracks that can be squeezed into a 1 inch radial segment.
  - Areal density (bits/in2): product of recording and track density.



Computing Disk Capacity

Capacity = (# bytes/sector) x (avg. # sectors/track) x
(# tracks/surface) x (# surfaces/platter) x
(# platters/disk)

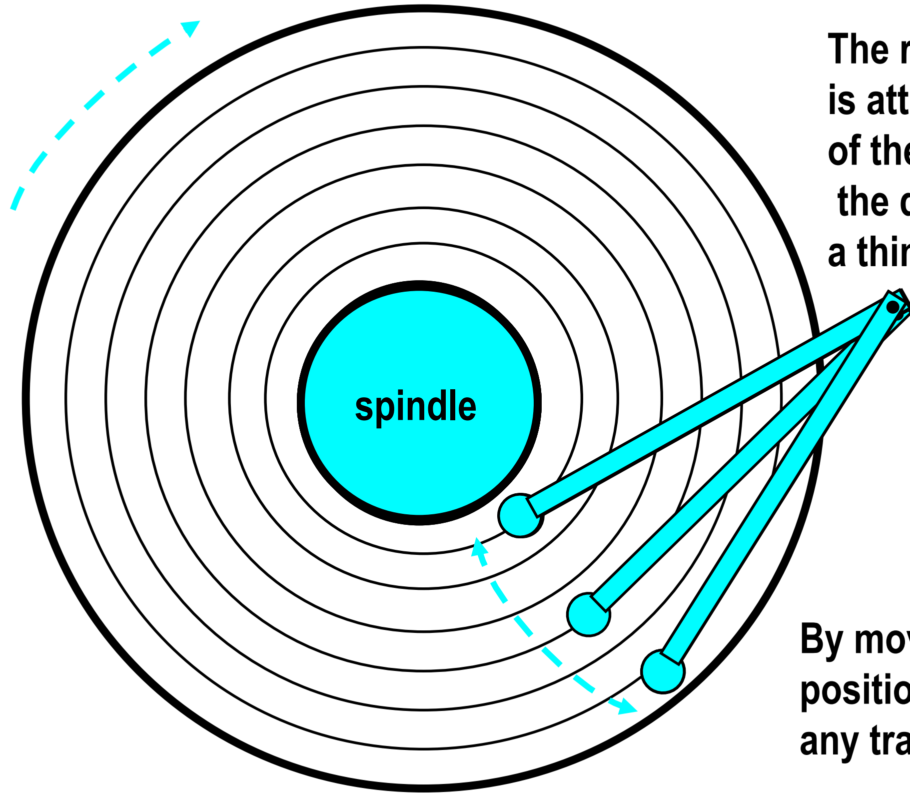
Example:

- 512 bytes/sector
- 300 sectors/track (on average)
- 20,000 tracks/surface
- 2 surfaces/platter
- 5 platters/disk

Capacity = 512 x 300 x 20000 x 2 x 5
= 30,720,000,000
= 30.72 GB

Disk Operation (Single-Platter View)

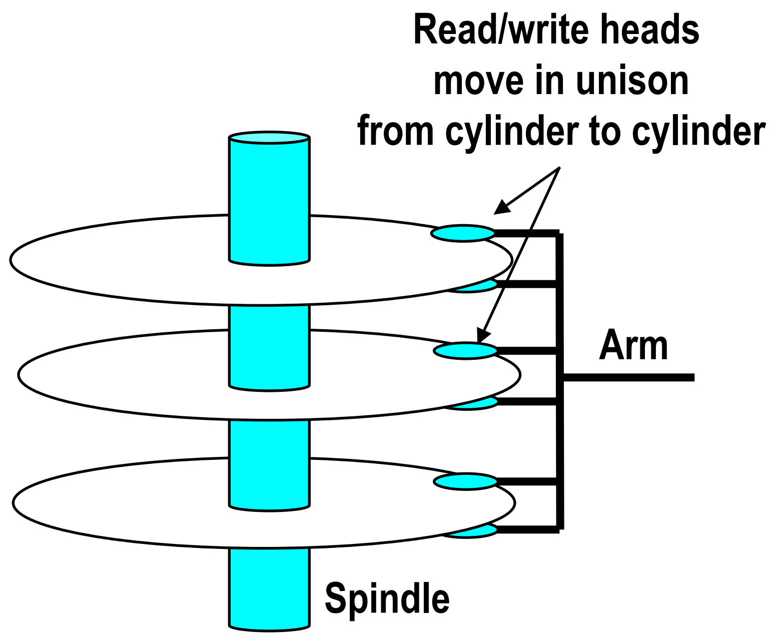
The disk surface spins at a fixed rotational rate



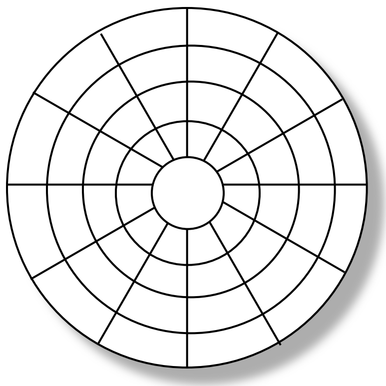
The read/write *head* is attached to the end of the *arm* and flies over the disk surface on a thin cushion of air.

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

Disk Operation (Multi-Platter View)



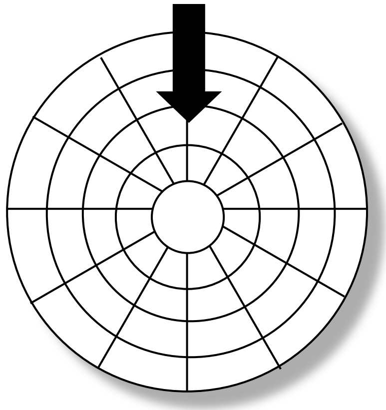
Disk Structure - top view of single platter



Surface organized into tracks

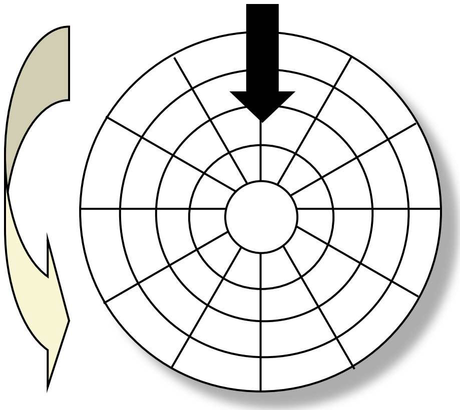
Tracks divided into sectors

Disk Access



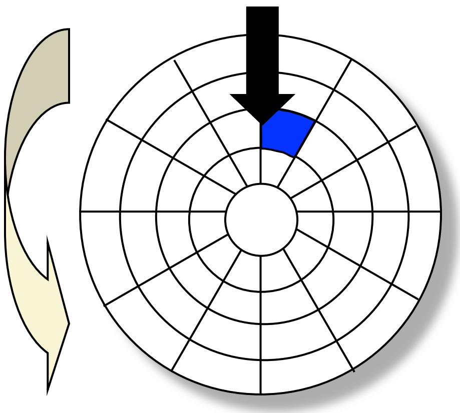
Head in position above a track

Disk Access



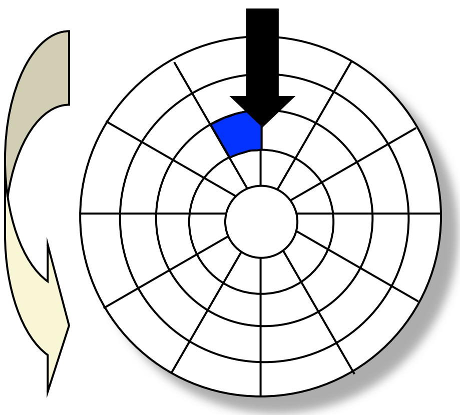
Rotation is counter-clockwise

Disk Access – Read



About to read blue sector

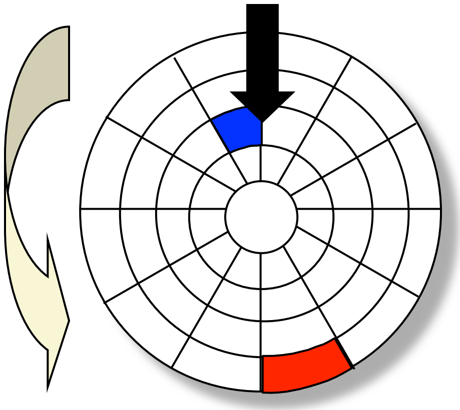
Disk Access – Read



After **BLUE** read

After reading blue sector

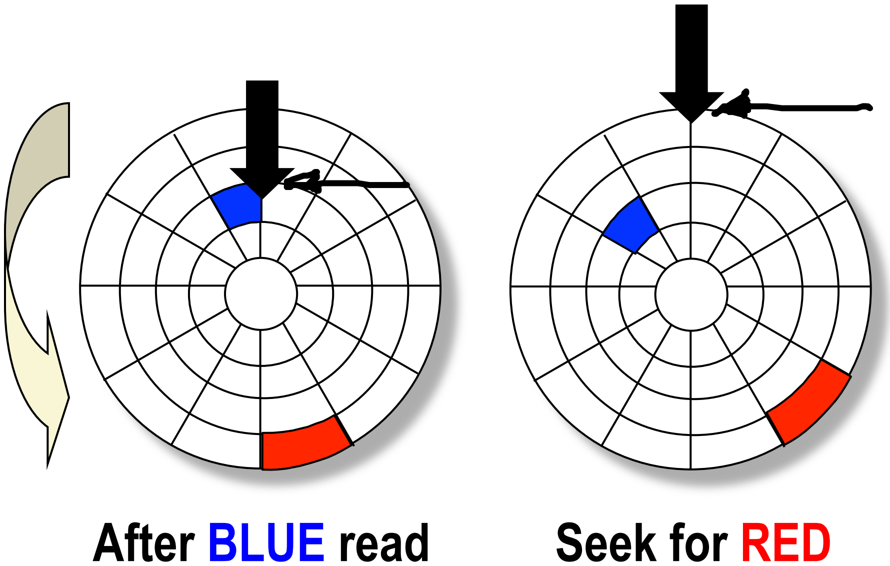
Disk Access – Read



After **BLUE** read

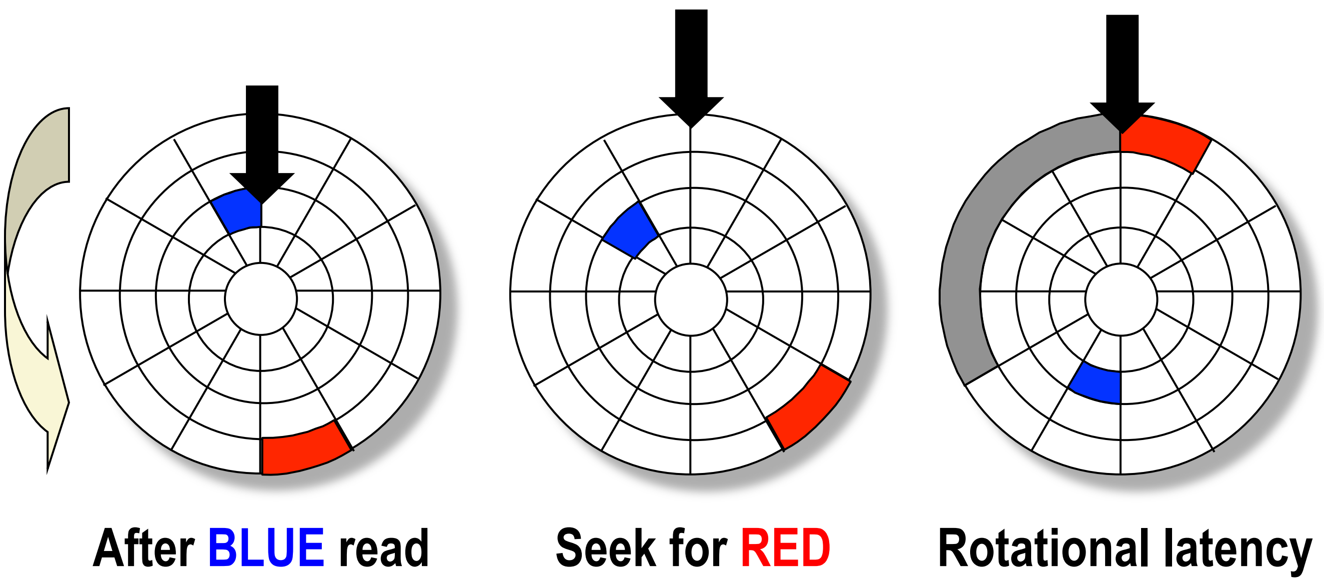
Red request scheduled next

Disk Access – Seek



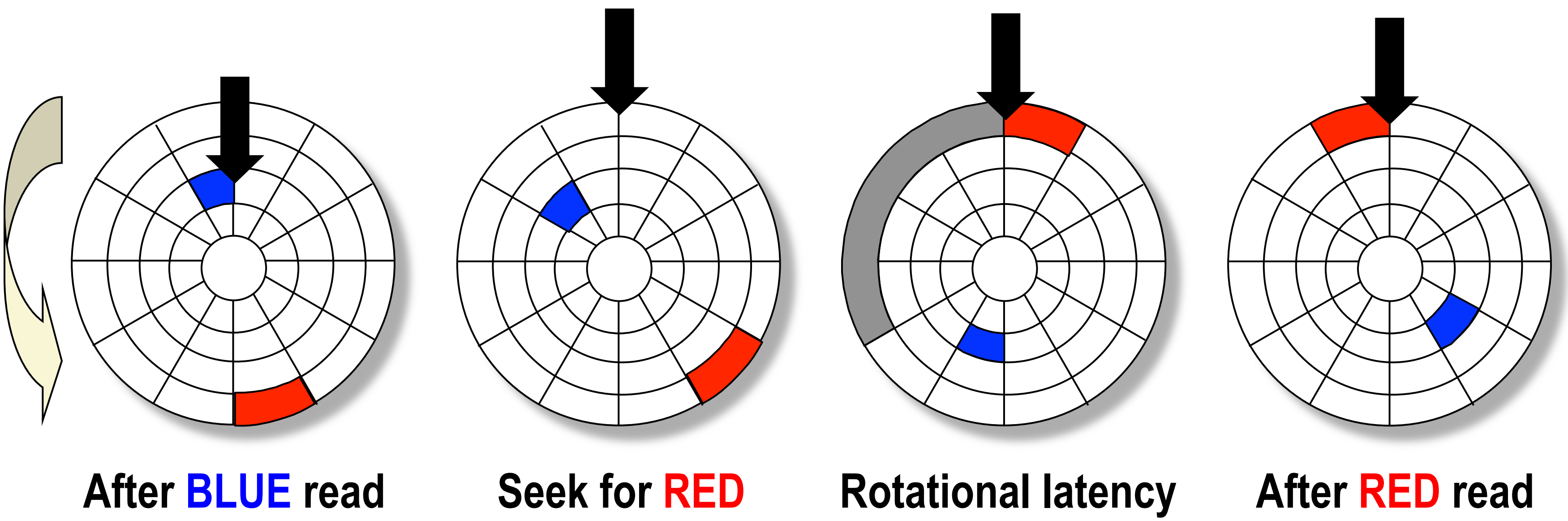
Seek to red's track

Disk Access – Rotational Latency



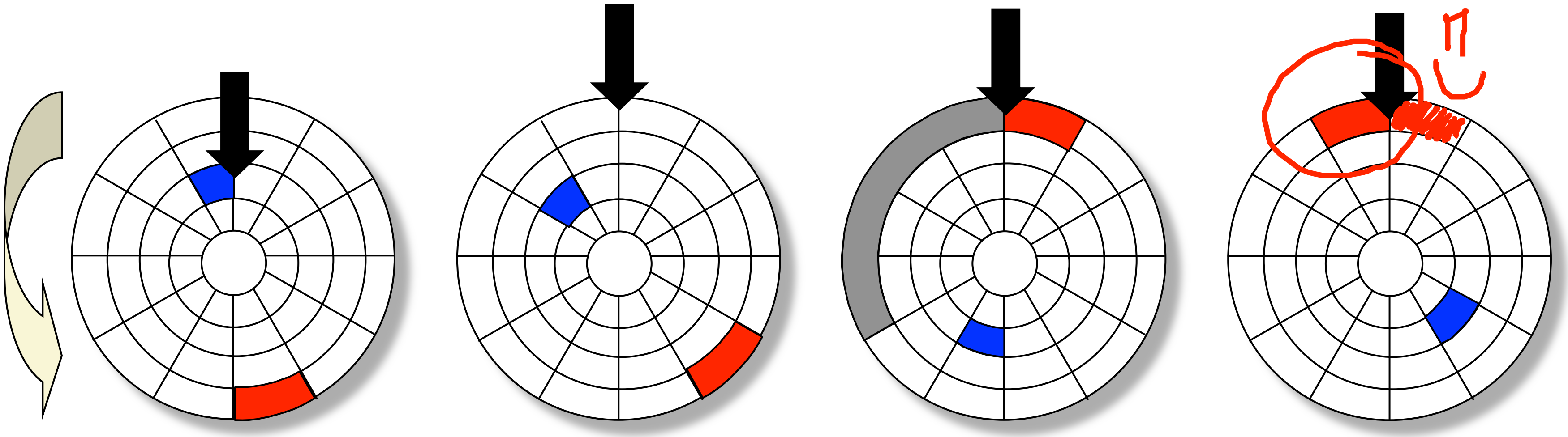
Wait for red sector to rotate around

Disk Access – Read



Complete read of red

Disk Access – Service Time Components



After **BLUE** read | Seek for **RED** | Rotational latency | After **RED** read

↑ Data transfer | ↑ Seek | ↑ Rotational latency | ↑ Data transfer

Disk Access Time

- **Average time to access some target sector approximated by :**
  - Taccess = Tavg seek + Tavg rotation + Tavg transfer
- **Seek time (Tavg seek)**
  - Time to position heads over cylinder containing target sector.
  - Typical Tavg seek is 3—9 ms
- **Rotational latency (Tavg rotation)**
  - Time waiting for first bit of target sector to pass under r/w head.
  - Tavg rotation = 1/2 x 1/RPMs x 60 sec/1 min
  - Typical Tavg rotation = 7200 RPMs
- **Transfer time (Tavg transfer)**
  - Time to read the bits in the target sector.
  - Tavg transfer = 1/RPM x 1/(avg # sectors/track) x 60 secs/1 min.

Disk Performance

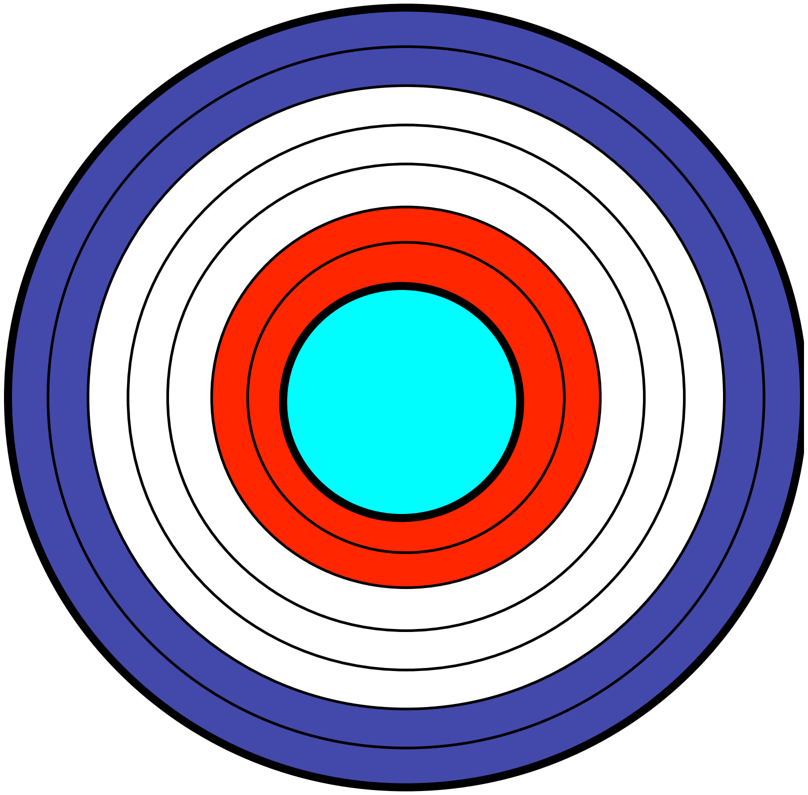
- **Two scenarios:**
  - **Random Access:** no locality in sectors accessed
    - Taccess = Tavg seek + Tavg rotation + Tavg transfer
  - **Sequential Access:** accessing consecutive sectors
    - No seek time or rotational delay!! Just transfer time.

- **Data from a representative disk:**

Access Type	Throughput (MB/s)
Random Access, 8kB blocks	1.26
Random Access, 64kB blocks	9.18
Sequential Access, 64kB blocks	111

Recording Zones:

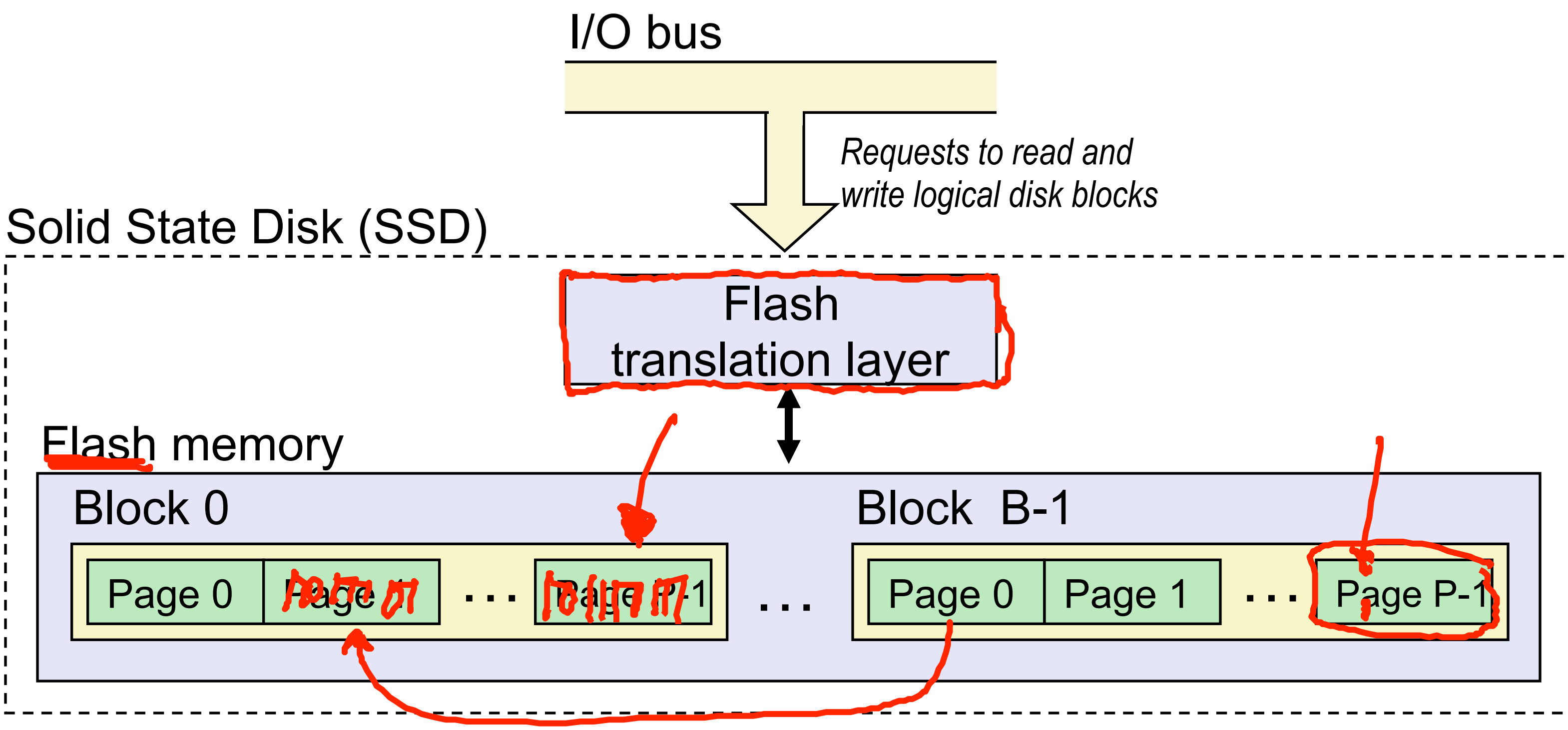
- **Modern disks partition tracks into disjoint subsets called recording zones**
  - Each track in a zone has the same number of sectors, determined by the circumference of innermost track.
  - Each zone has a different number of sectors/track
- **Outside tracks have more sectors**
  - Same rotation speed
  - Higher MB/sec



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”.

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

Sequential read tput	250 MB/s	Sequential write tput	170 MB/s
Random read tput	140 MB/s	Random write tput	14 MB/s
Rand read access	30 us	Random write access	300 us

- **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 (10^{15} 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

Storage Trends

SRAM

Metric	1980	1985	1990	1995	2000	2005	2010	*2010:1980*
$/MB	19,200	2,900	320	256	100	75	60	*320*
access (ns)	300	150	35	15	3	2	1.5	*200*

DRAM

Metric	1980	1985	1990	1995	2000	2005	2010	*2010:1980*
$/MB	8,000	880	100	30	1	0.1	0.06	*130,000*
access (ns)	375	200	100	70	60	50	40	*9*
typical size (MB)	0.064	0.256	4	16	64	2,000	8,000	*125,000*

Disk

Metric	1980	1985	1990	1995	2000	2005	2010	*2010:1980*
$/MB	500	100	8	0.30	0.01	0.005	0.0003	*1,600,000*
access (ms)	87	75	28	10	8	*4*	*3*	*29*
typical size (MB)	1	10	160	1,000	20,000	160,000	1,500,000	*1,500,000*

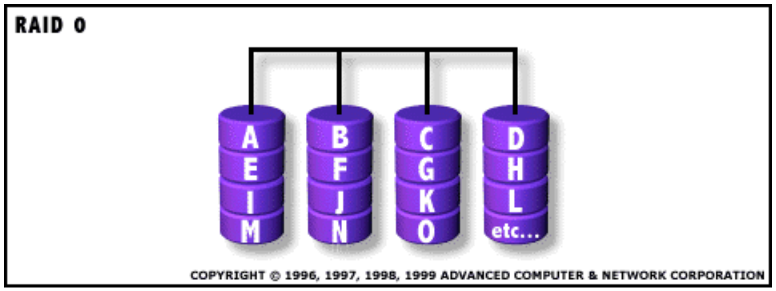
RAID : Redundant Array of Inexpensive Disks

- **Problem: Disks fail -> total data loss**
  - Improving reliability of a disk is expensive.
  - Cheaper just to buy a few extra disks.
- **Idea: ECC for your disks**
  - Files are "striped" across multiple disks
  - Redundancy yields high data availability
    - Disks will still fail
  - Contents reconstructed from data redundantly stored in the array
    - $\Rightarrow$ Capacity penalty to store redundant info
    - $\Rightarrow$ Bandwidth penalty to update redundant info

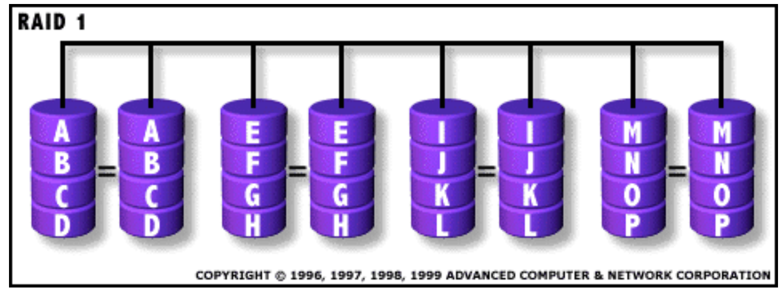
- **A multi-billion industry 80% non-PC disks sold in RAIDs**

Common RAID configurations

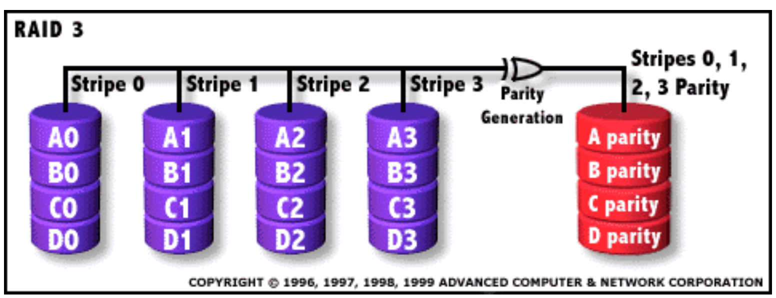
RAID 0
No redundancy, Fast access



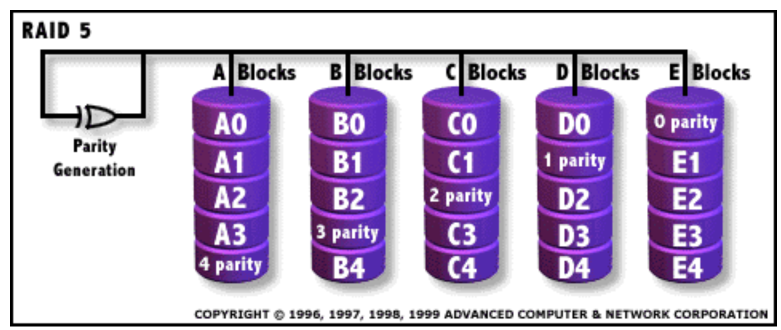
RAID 1
Mirror Data, most expensive sol'n



RAID 3/4
Parity drive protects against 1 failure



RAID 5
Rotated parity across all drives



Summary

- **I/O devices are much slower than processors.**
  - Engineered to be accessible, but to not slow down computation
- **Spindle-based devices:**
  - Access time = seek time + rotational delay + transfer time
  - Lay files out contiguously!
- **RAID: Redundant Array of Inexpensive Disks**
  - Achieve reliable storage, but not by making reliable disks
  - Use redundancy (e.g., parity) to reconstruct lost disk