Computer Architecture

Course Code: CSE360

Lecture - 5

External Memory

Types of External Memory

- Magnetic Disk
  - RAID (Redundant Array of Inexpensive Disks)
  - Removable
- Optical
  - CD-ROM
  - CD-Recordable (CD-R)
  - CD-R/W
  - DVD
- Magnetic Tape

Magnetic Disk

- A disk is a circular platter constructed of non-magnetic material, called substrate, coated with magnetisable material (iron oxide…rust (oxidation)
- Traditionally, substrate has been an aluminium
- Now, glass substrate have been introduced
  - Improved surface uniformity
    - Increases disk reliability
  - Reduction in surface defects
    - Reduces read/write errors
  - Better stiffness

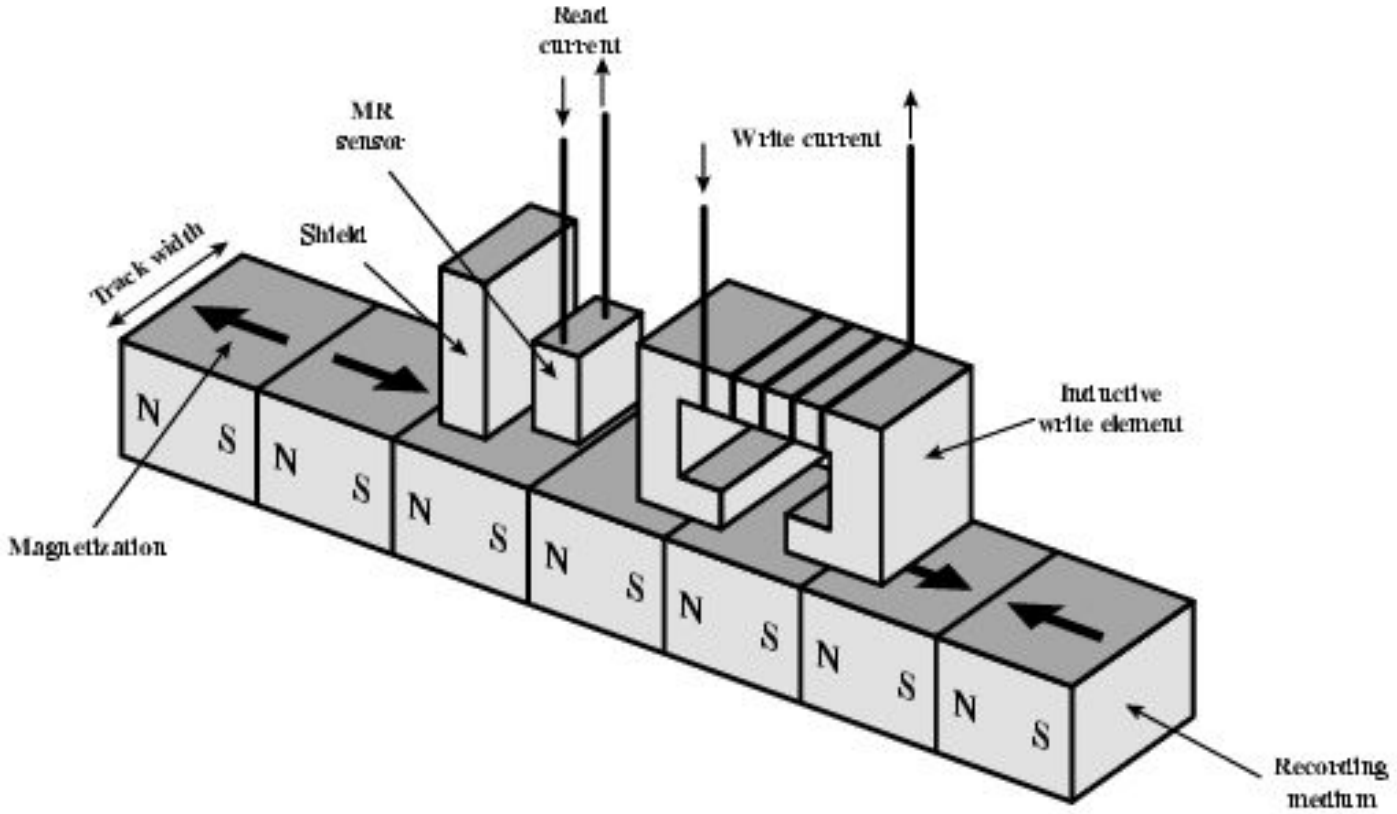
Read and Write Mechanisms

- Recording & retrieval of data via conductive coil called a head
- In many systems, there are two heads, a read head and a write head
- During read/write, head is stationary, platter rotates
- Write
  - Electricity flowing through a coil produces a magnetic field
  - Electric pulses are sent to write head
  - Resulting magnetic patterns are recorded on the surface below, with different patterns for positive and negative currents

Read and Write Mechanisms

- Read (traditional)
  - Magnetic field moving relative to a coil produces current in the coil
  - Coil is the same for read and write
- Read (contemporary)
  - Different read mechanism, requires separate read head, positioned close to the write head
  - The read head consists of a partially shielded magneto resistive (MR) sensor
  - The MR material has an electrical resistance that depends on direction of magnetic field
  - By passing a current through MR sensor, resistance changes are detected as voltage signals
  - The MR design allows high-frequency operation which equates to higher storage density and speed

Inductive Write MR Read Head

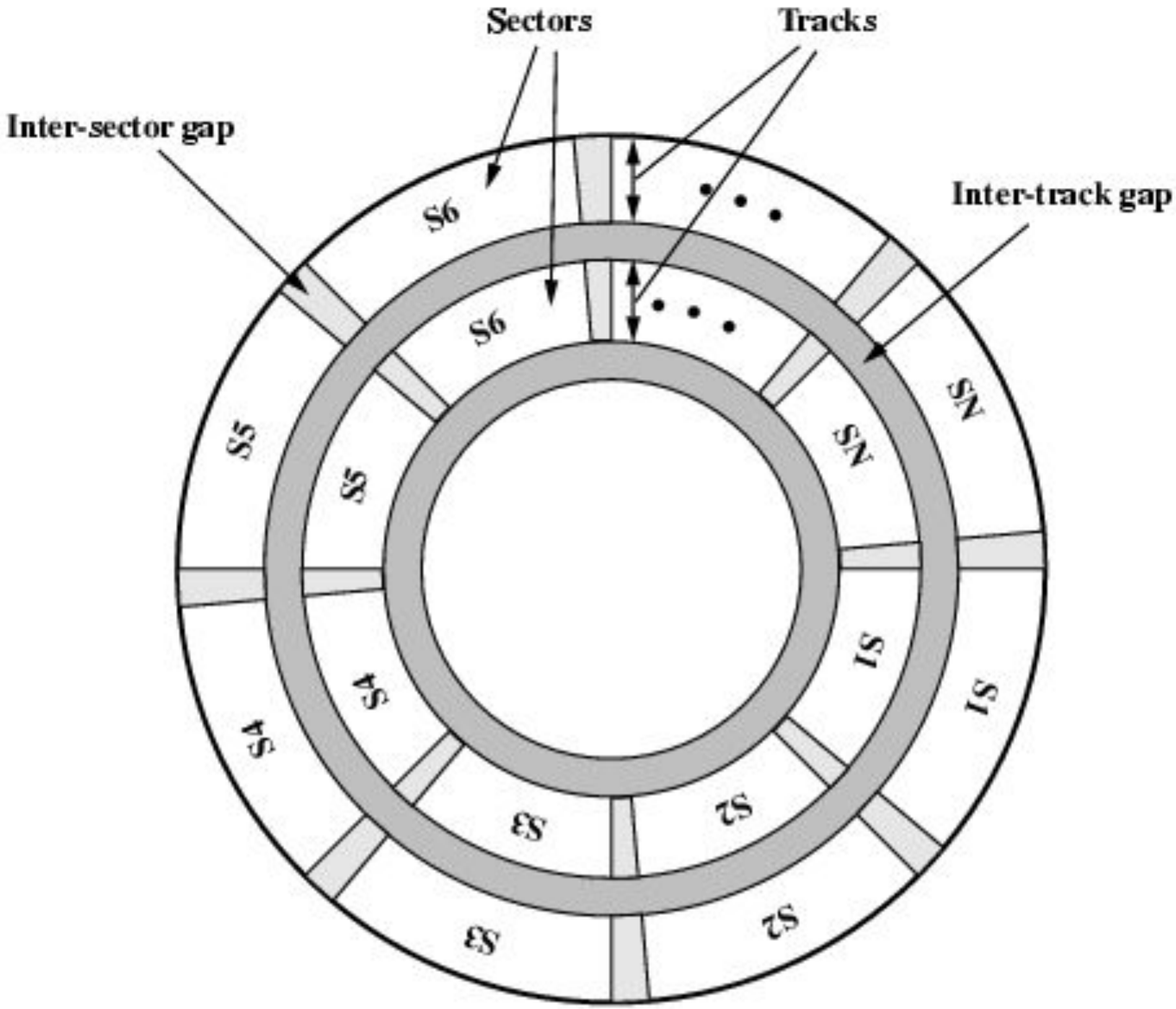


- **Inductive Write**
  - **An electric current in the wire induces a magnetic field, which in turn magnetizes a small area of the recording medium.**
  - **Reversing the direction of current reverses the direction of magnetization on the recoding medium**
- **MR Read**
  - **As discussed in previous slide**

Data Organization and Formatting

- The head is a small device capable of reading from or writing to a portion of the platter
- This gives organization of data on the platter in a concentric set of rings, called **tracks** *(there are thousands of tracks per surfaces)*
- Adjacent tracks are separated by **gaps** which prevents or reduces errors due to misalignment of head or simplify interference of magnetic fields
- Reduce gap to increase capacity
- Data are transferred to or from the disk in **sectors**
- There are hundreds of sectors per track, these may be either fixed or variable length
- In most contemporary systems, fixed length sectors are used, with 512 bytes being the universal sector size
- To avoid imposing unreasonable precision on system, adjacent sectors are separated by intratrack (**intersector**) gaps

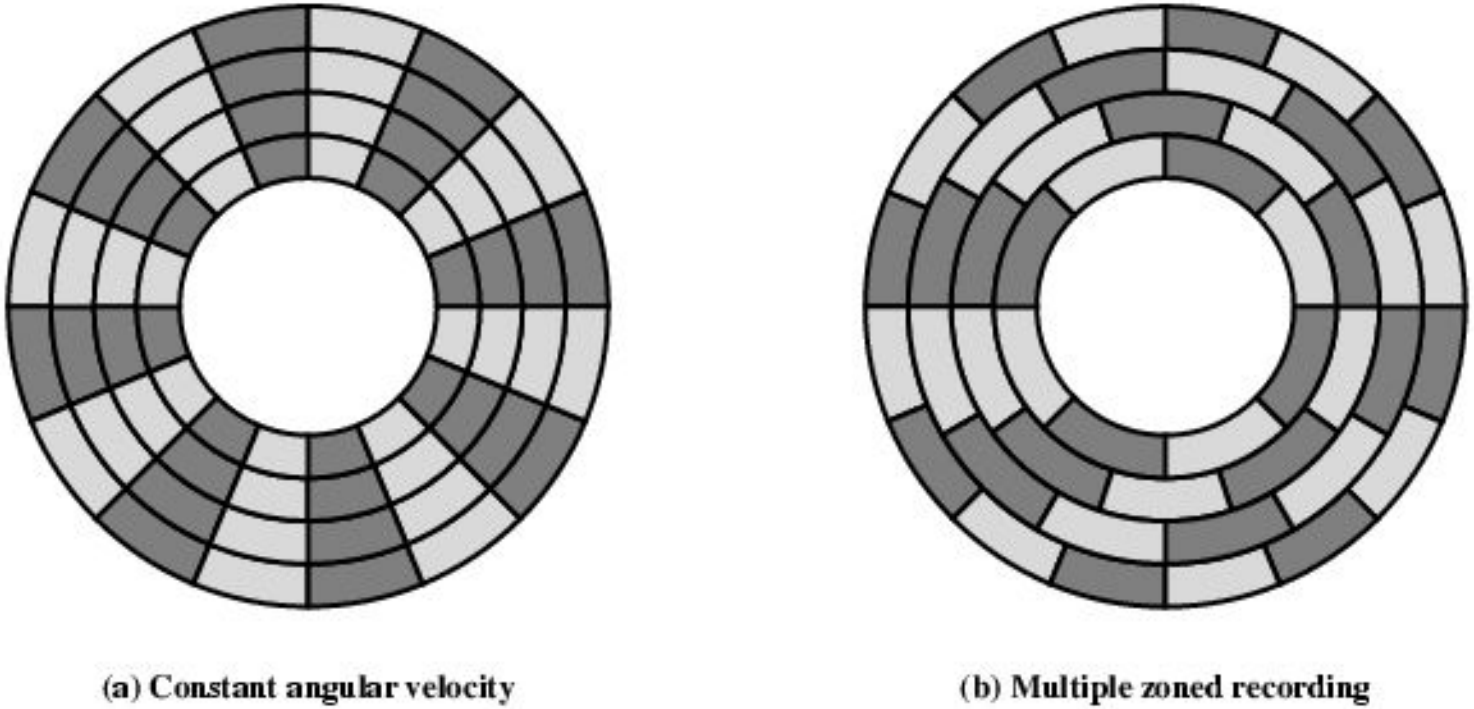
Disk Data Layout



Disk Velocity

- A bit near centre of rotating disk travels a fixed (such as read-write head) point slower than a bit on outside of disk
- Need to compensate for the variation in speed so that head can read all bits at the same rate
- This can be done by increasing spacing between bits in different tracks
- The information can then be scanned at the same rate by rotating disk at fixed speed, known as constant angular velocity (CAV)
  - Disk is divided into **pie-shaped sectors** and **concentric tracks**
  - Individual **blocks of data can be directly addressed by track** and **sector**
  - To move the head from its current location to a specific address, it only takes **short movement of the head to a specific track** and **short wait for given sector**

Disk Layout Methods Diagram



(a) Constant angular velocity

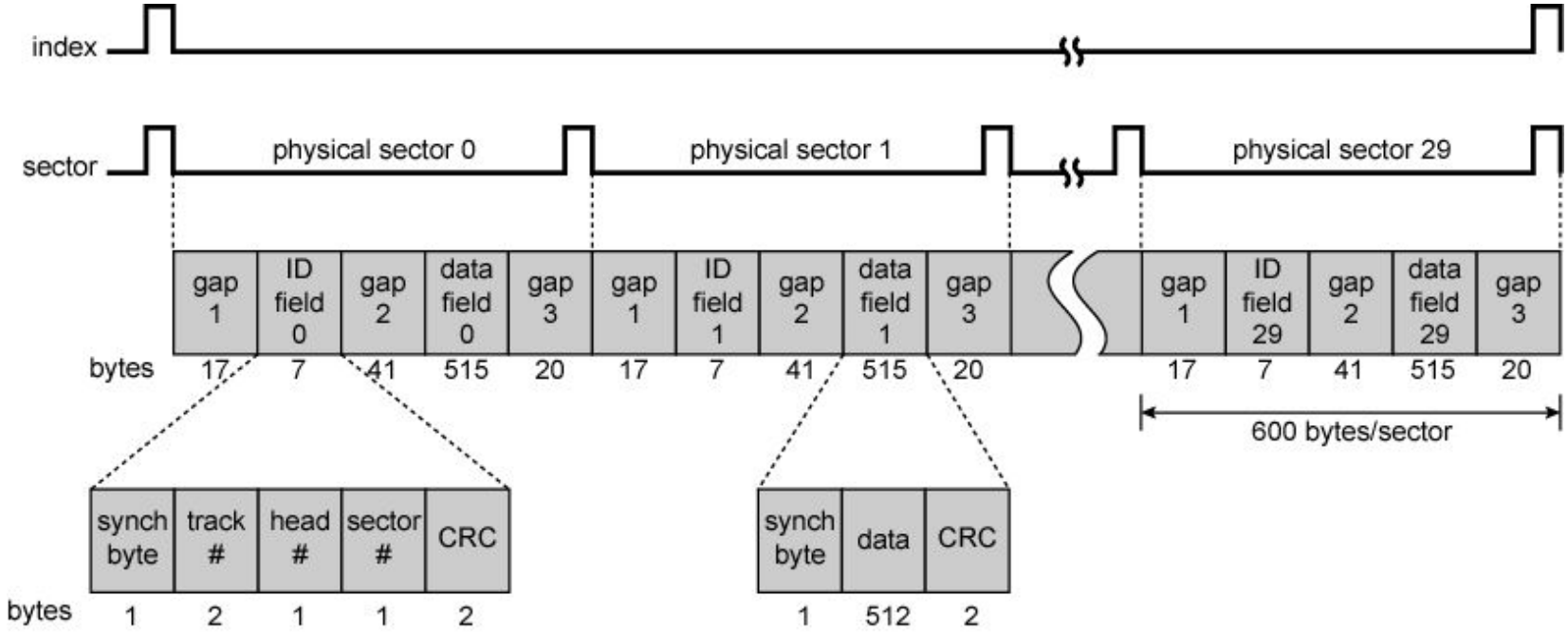
(b) Multiple zoned recording

- To increase density, modern hard disk systems use a technique known as **multiple zone recording,** in which **the surface is divided into number of concentric zones** (16 is typical)
  - **Within a zone the number of bits** per track is constant
  - **Zones farther from centre contain** more bits (**more sectors**) than zone closer to center
  - This allows greater storage capacity at the expense of somewhat more complex circuitry

Finding Sectors

- Some means is needed to locate sector positioned within a track
- Clearly, there must be some starting point on the track and a way of identifying the start and end of each sector
- Thus, **the disk is formatted with some extra data used** only by the disk drive and not accessible to the user

Winchester Disk Format
Seagate ST506



- **Each track contains 30 fixed-length sectors of 600 bytes each.**
  - **Each sector holds 512 bytes of data plus control information useful to the disk controller**
  - **The ID field a unique identifier or address used to locate a particular sector**
    - **The SYNCH byte is a special bit pattern that delimits the beginning of the field**
    - **The track number identifies a track on a surface**
    - **The head number identifies a head (because disk has multiple surfaces)**
    - **The ID and data fields each contain an error-detecting code.**

Physical Characteristics of Disk Systems

Head Motion
- Fixed head (one per track)
- Movable head (one per surface)

Disk Portability
- Nonremovable disk
- Removable disk

Sides
- Single sided
- Double sided

Platters
- Single platter
- Multiple platter

Head Mechanism
- Contact (floppy)
- Fixed gap
- Aerodynamic gap (Winchester)

Fixed/Movable Head Disk

- The head may be either fixed or movable with respect to the radial direction of the platter
- In a Fixed head disk
  - One read write head per track
  - Heads mounted on fixed ridged arm (rare today)
- In a Movable head disk
  - One read write head per side
  - Mounted on a movable arm (because, the head must be able to be positioned above any track)

Removable or Not

- The disk itself is mounted in a disk drive, which consists of arm, a spindle that rotates the disk
- Removable disk
  - Can be removed from drive and replaced with another disk
  - Provides unlimited storage capacity
  - Easy data transfer between systems
  - e.g. Floppy disk
- Nonremovable disk
  - Permanently mounted in the drive
  - e.g. hard disk in a personal computer is a nonremovable disk

Sides

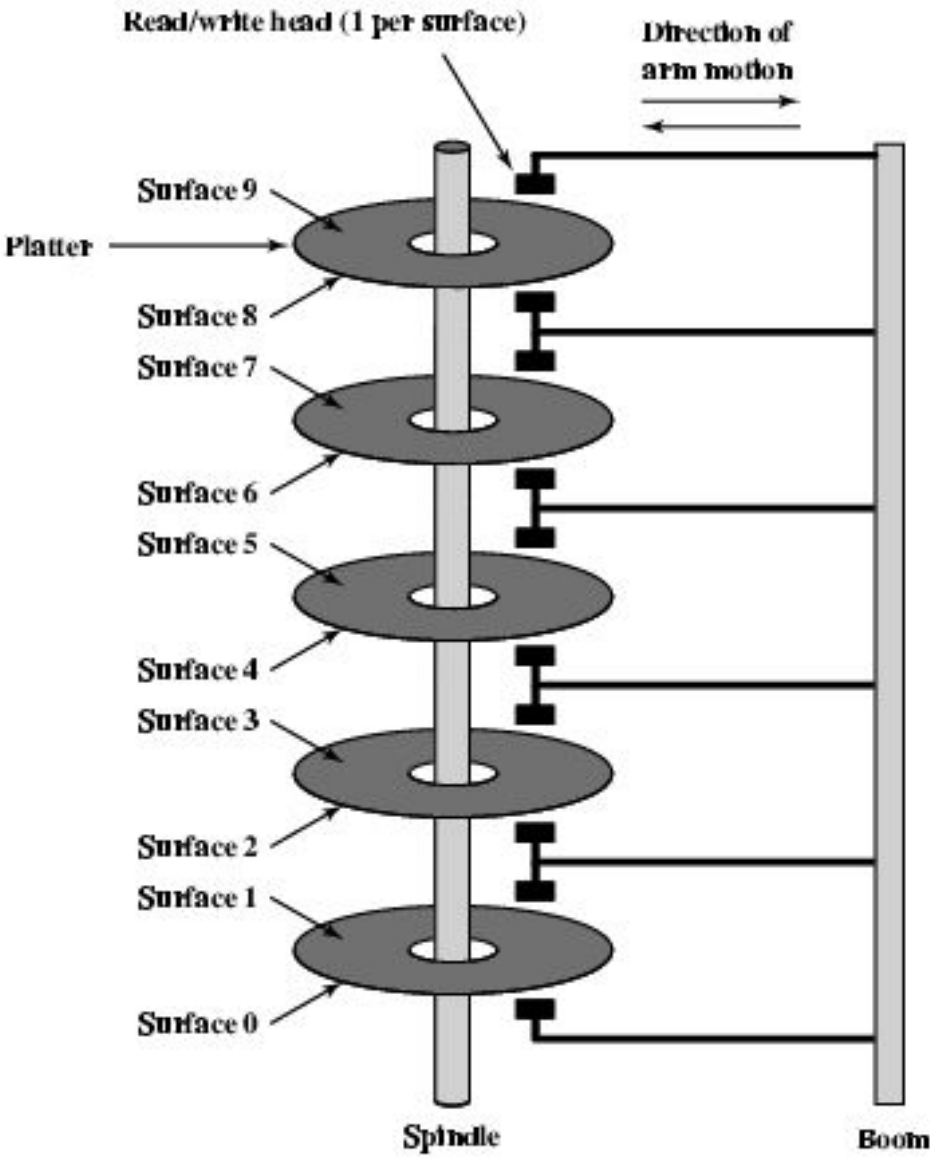
- For most disks, the magnetizable coating is applied to both sides of platter, which is then referred to as **double sided**.

- Some less expensive disk systems use **single-sided** disks

Multiple Platter

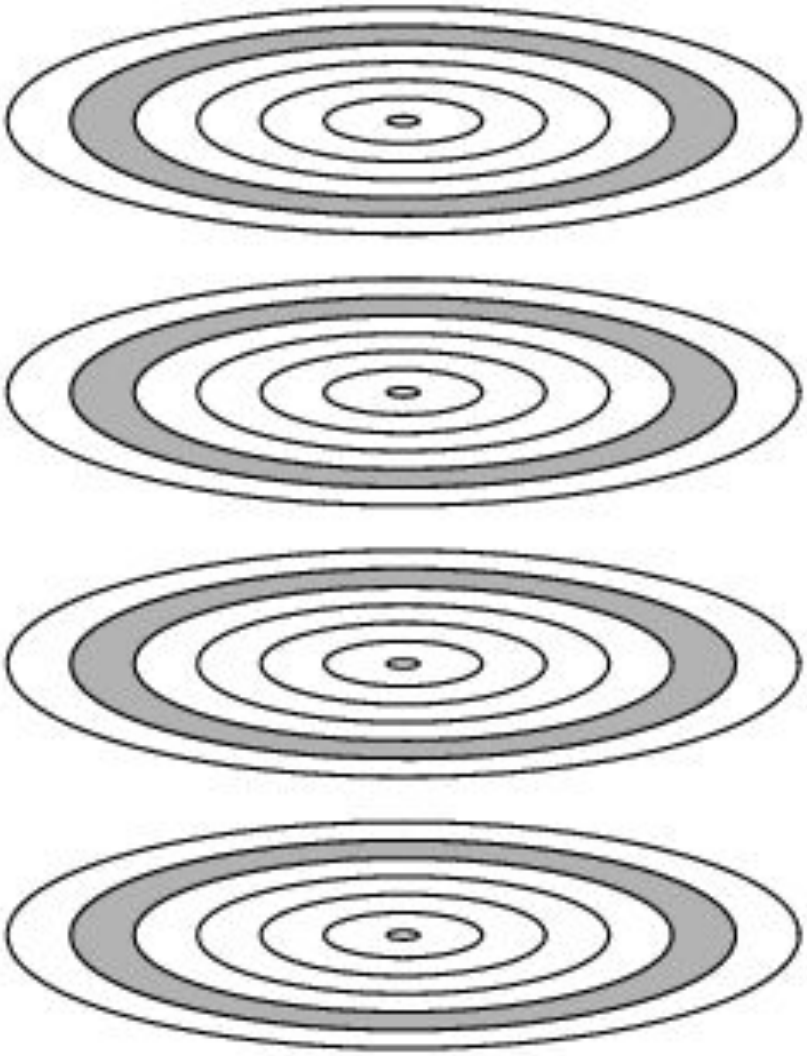
- Some disk drives accommodate multiple platters stacked vertically a fraction of an inch apart.
- **Multiple-platter disks employ a movable head**, with **one read-write head per platter surface**
- **All** of the **heads are mechanically fixed** so that **all are at the same distance from the centre of the disk** and **move together**
- **Thus, at any time, all of the heads are positioned over tracks that are of equal distance from the centre of the disk**
- **The set of all the tracks in the same relative position on the platter** is referred to as a **cylinder.**
- Data is striped by cylinder
  - reduces head movement
  - Increases speed (transfer rate)

Multiple Platters



- The read-write head has been positioned a fixed distance above the platter, allowing **air gap**
- The head actually comes into physical contact with the physical medium during read or write operation (e.g. this mechanism is used with the floppy disk)
- The narrower the head is, the closer it to the platter surface
- Narrower head means narrower tracks, therefore greater data density
- The closer the head to the disk, the greater the risk of error from imperfections
- To push the technology further, Winchester disk was developed (see later)

Tracks and Cylinders



- All of the shaded tracks are part of one cylinder

Floppy Disk

- 8″, 5.25″, 3.5″
- Small capacity
  - Up to 1.44Mbyte (2.88M never popular)
- Slow
- Universal
- Cheap
- Obsolete?

Winchester Hard Disk (1)

- Developed by IBM in Winchester (USA)
- **Winchester heads** are used in sealed-unit drive with **aerodynamic head design**
- **One or more platters (disks)**
- They are designed to operate **closer to the disk's surface** (**very small head to disk gap**) than conventional rigid disk heads, thus **allowing greater data density**
- The resulting noncontact system can be engineered to use **narrower heads that operate closer to the platter's surface** than conventional rigid disk heads.
- **Getting more robust**

Winchester Hard Disk (2)

- Universal (**Winchester disk is commonly found in personal computers and workstations, where it is referred to as a hard disk**)
- **Cheap**
- **Fastest external storage**
- **Getting larger all the time**
  - 2 Terabyte now easily available

Disk Performance Parameters: Speed

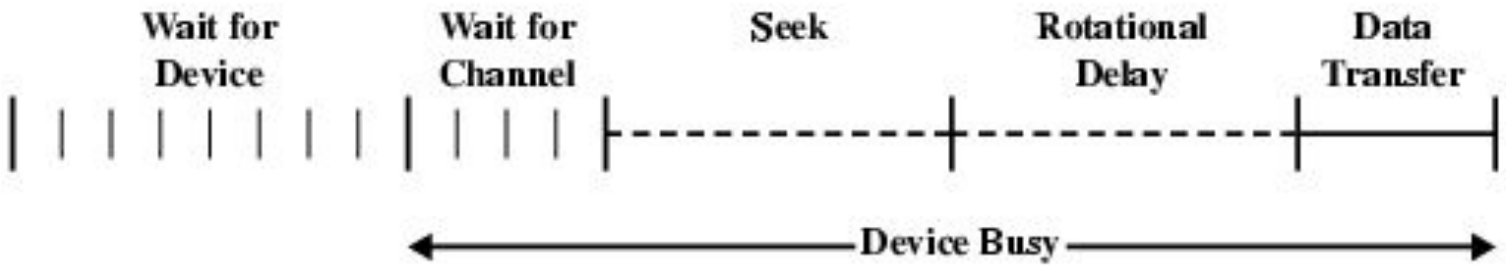
- When the disk drive is operating, the disk is rotating at constant speed. To read or write, the head must be positioned at the desired track and at the beginning of the desired sector on that track.
- **Seek time**
  - On a movable-head system, the time it takes to position the head at the track is known as **seek time**
- **(Rotational) latency**
  - Once the track is selected, the disk controller waits until the appropriate sector rotates to line up with the head. The time it takes for the beginning of the sector to reach the head is known as **rotational delay, or rotation latency**
- **Access time**

The sum of the seek time, if any, and the rotational delay equals the **access time** (Access time = Seek + Latency), which is the time it takes to get into position to read or write.

- **Transfer rate**

Once the head is in position, the read or write operation is then performed as the sector moves under the head; this is the data transfer portion of the operation and the time required for the transfer is the transfer time.

Timing of Disk I/O Transfer



- The actual disk I/O operation depend on the computer system, operating system, and nature of I/O channel and disk controller hardware.
- In addition to access time and transfer time, there are several queuing delays associated with I/O operation.
- When a process issues an I/O request, it must **wait first for the device** to be available.
- At that time, the device is assigned to the process.
- If the device shares a single I/O channel or a set of I/O channels with other disk drivers, there may be an additional **wait for the channel** to be available.
- At that point, the **seek** is performed to begin disk access.

RAID

- Redundant Array of Independent Disks
- **Redundant array of inexpensive disks**
- 7 levels in common use
- **RAID is a set of physical disk drives** viewed by the operating system as a single logical drive.
- **Data are distributed across the physical drives of an array**.
- **Redundant disk capacity is used to store parity information**, **which guarantees data recoverability** in case of a disk failure.
- A **parity bit** is a bit that is added to a group of source bits to ensure that the number of set bits (i.e., bits with value 1) in the outcome is even or odd. **It is a very simple scheme that can be used to detect single or any other odd number (i.e., three, five, etc.) of errors in the output.**

RAID 0

- No redundancy
- Data striped across all disks

- Increase speed
  - Multiple data requests probably not on same disk
  - Disks seek in parallel
  - A set of data is likely to be striped across multiple disks

RAID 1

- **Mirrored Disks**
- **Data is striped across disks**
- **2 copies of each stripe** on separate disks
- **Read from either**
- **Write to both**
- **Recovery is simple**
  - No down time
- **Expensive**

RAID 2

- **Redundant via Hamming code**
- An error-correcting code is calculated across corresponding bits on each data disk
- The bits of the code are stored in the corresponding bit positions on multiple parity disks.
- **Lots of redundancy**
  - **Expensive**
  - Not used

RAID 3

- Similar to RAID 2
- **Bit-interleaved parity**; similar to level 2
- But **instead of an error-correcting code, a simple parity bit is computed** for the set of individual bits **in the same position on all of the data disks**.
- Very high transfer rates

RAID 4

- Each disk operates independently
- Good for high I/O request rate
- **Block-interleaved parity**
- A **bit-by-bit parity strip is calculated across corresponding strips on each data disk**

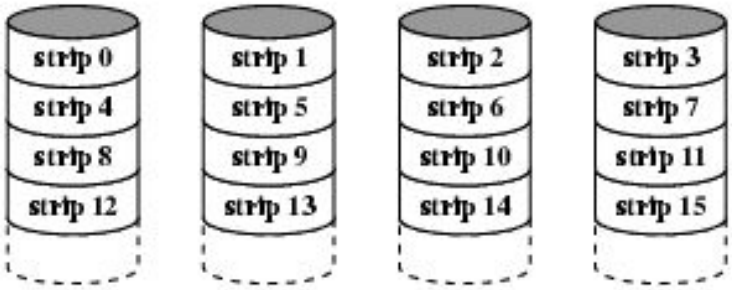
RAID 5

- **Block-interleaved** distributed parity
- **Similar to level 4 but distributes the parity strips across all disks**.
- Commonly used in network servers

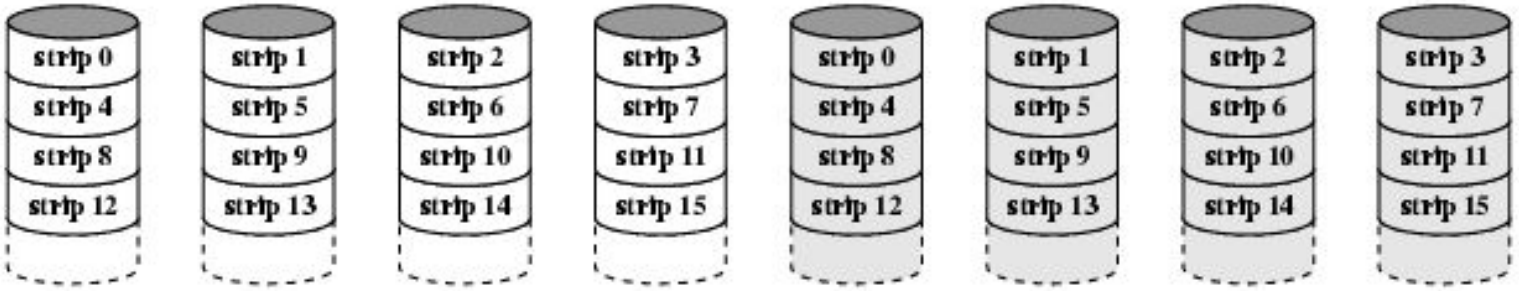
RAID 6

- **Two parity calculations**
- Stored in separate blocks on different disks
- User requirement of N disks needs N+2
- High data availability
  - Three disks need to fail for data loss
  - Significant write penalty

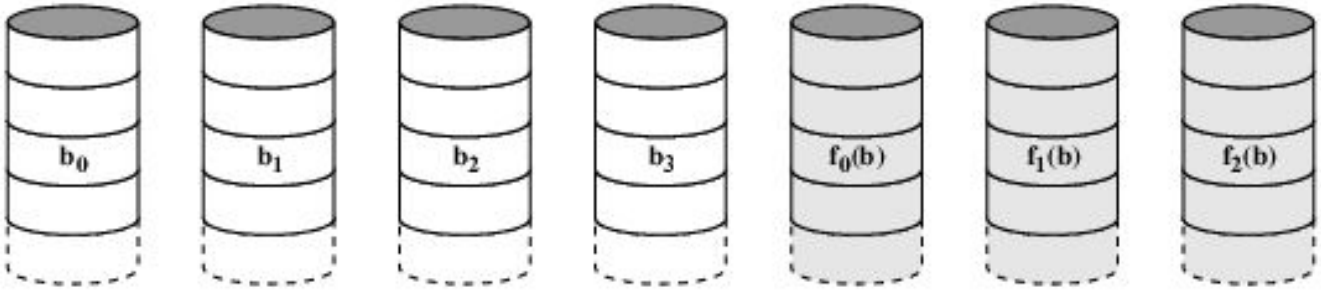
RAID 0, 1, 2



(a) RAID 0 (non-redundant)

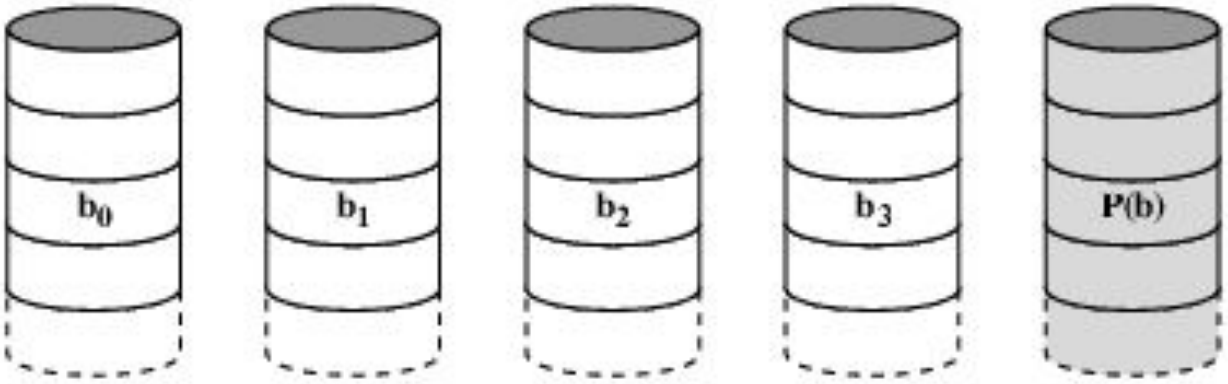


(b) RAID 1 (mirrored)

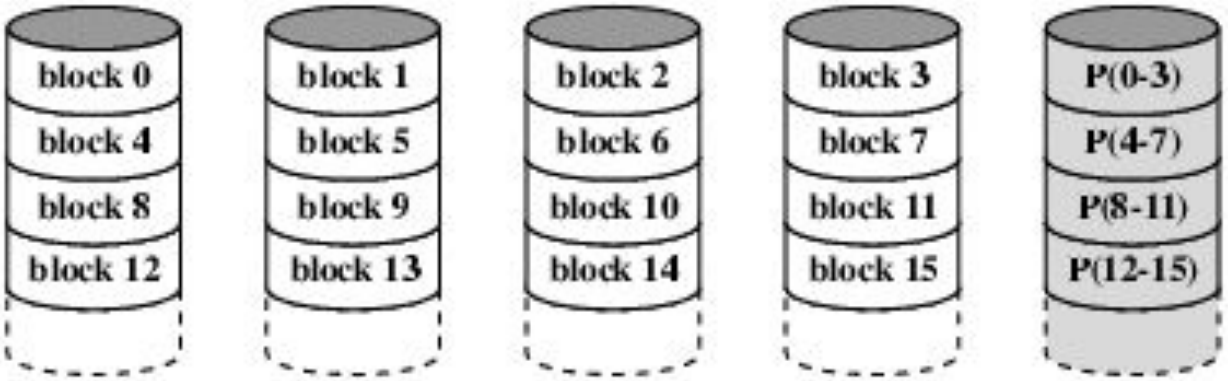


(c) RAID 2 (redundancy through Hamming code)

RAID 3 & 4

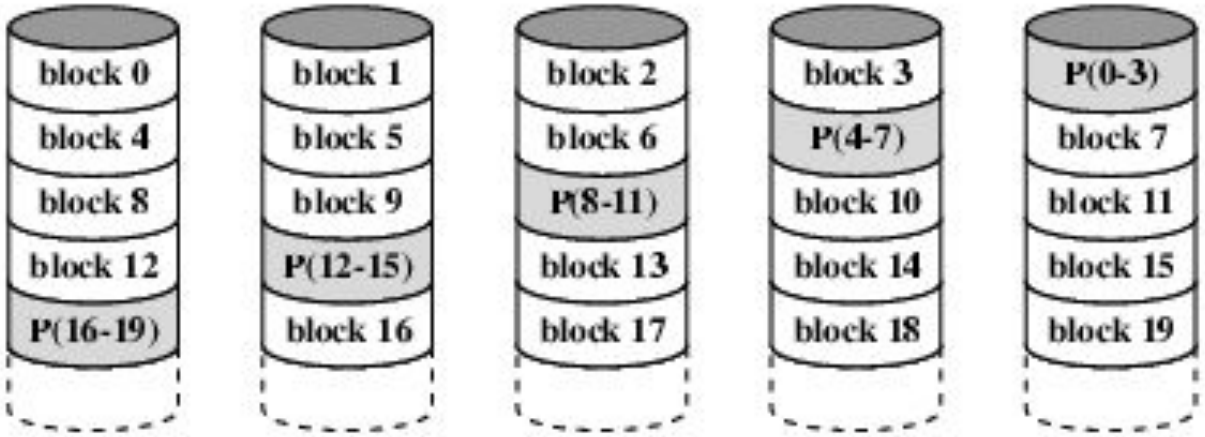


(d) RAID 3 (bit-interleaved parity)

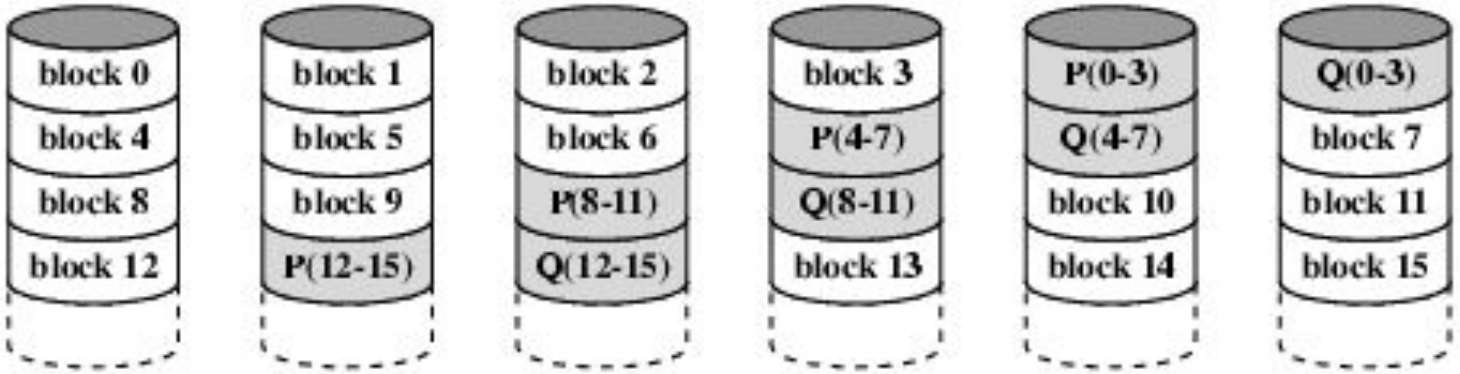


(e) RAID 4 (block-level parity)

RAID 5 & 6

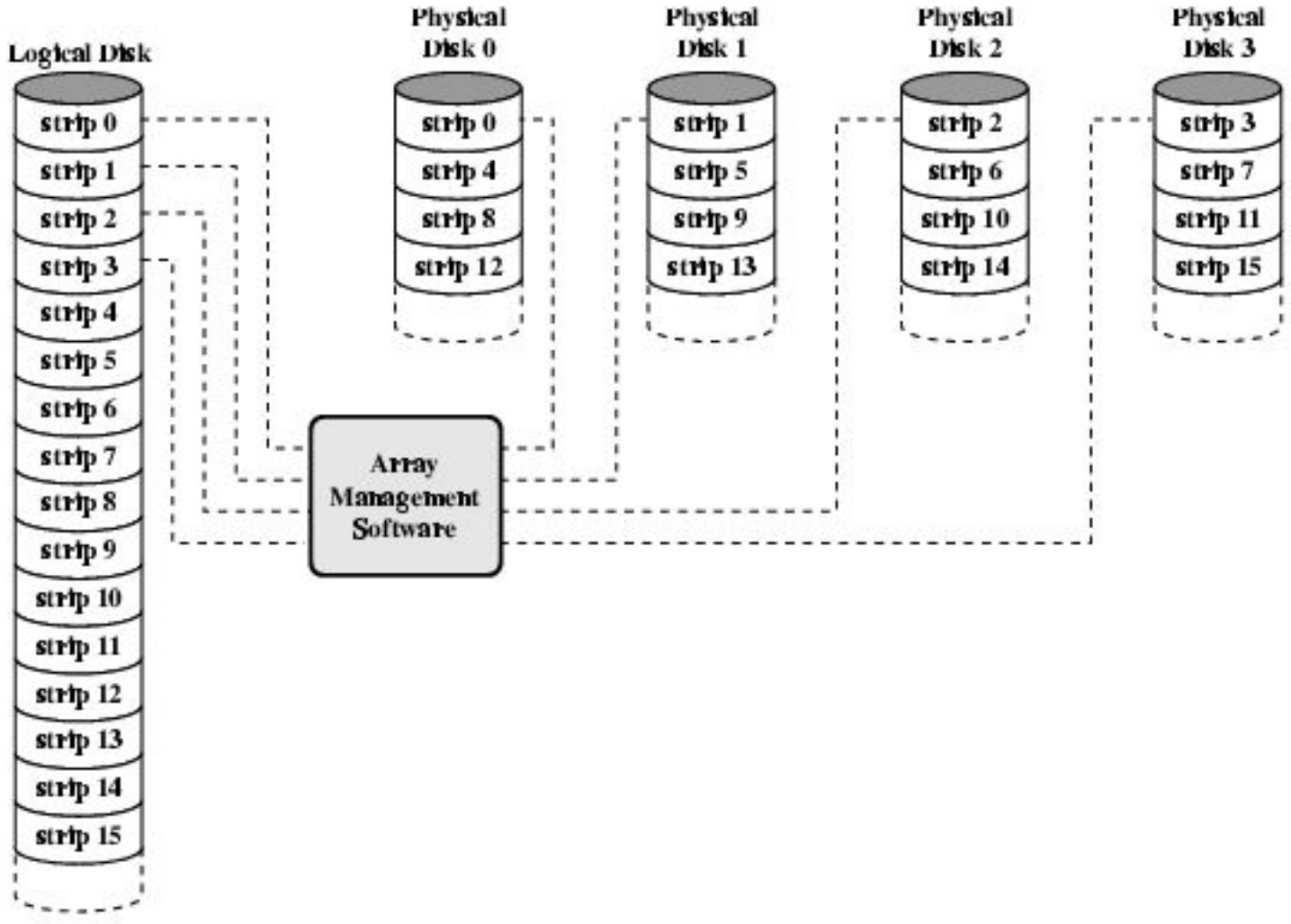


(f) RAID 5 (block-level distributed parity)



(g) RAID 6 (dual redundancy)

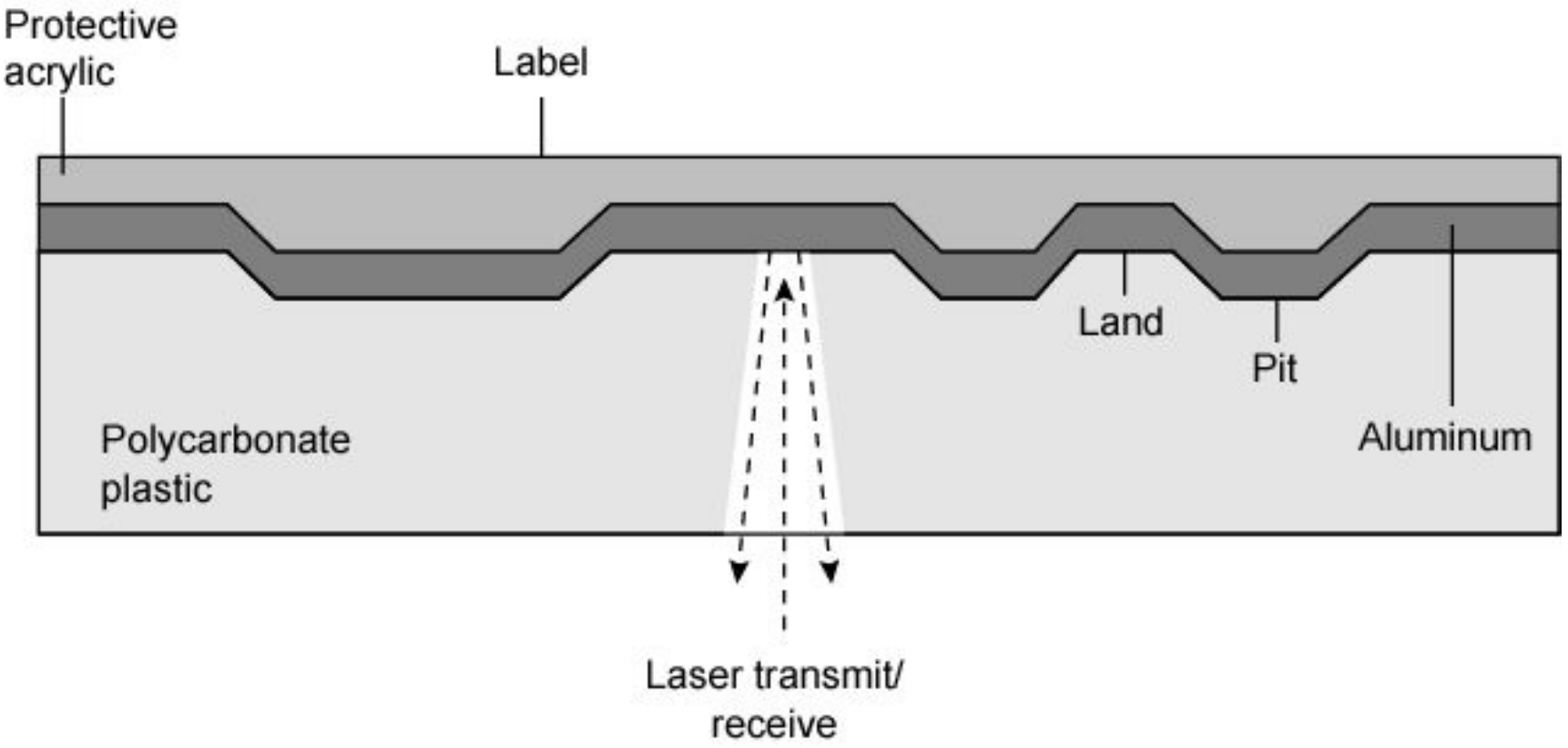
Data Mapping For RAID 0



Optical Storage CD-ROM

- Originally for audio
- 650Mbytes giving over 70 minutes audio
- **Polycarbonate coated with highly reflective coat, usually aluminium**
- Data stored as pits
- **Read by reflecting laser**
- **Constant packing density**
- **Constant linear velocity**
- At a **constant linear velocity (CLV)**, the disk rotates more slowly for accesses near the outer edge than for those near the center. The capacity of a track and the rotational delay both increase.

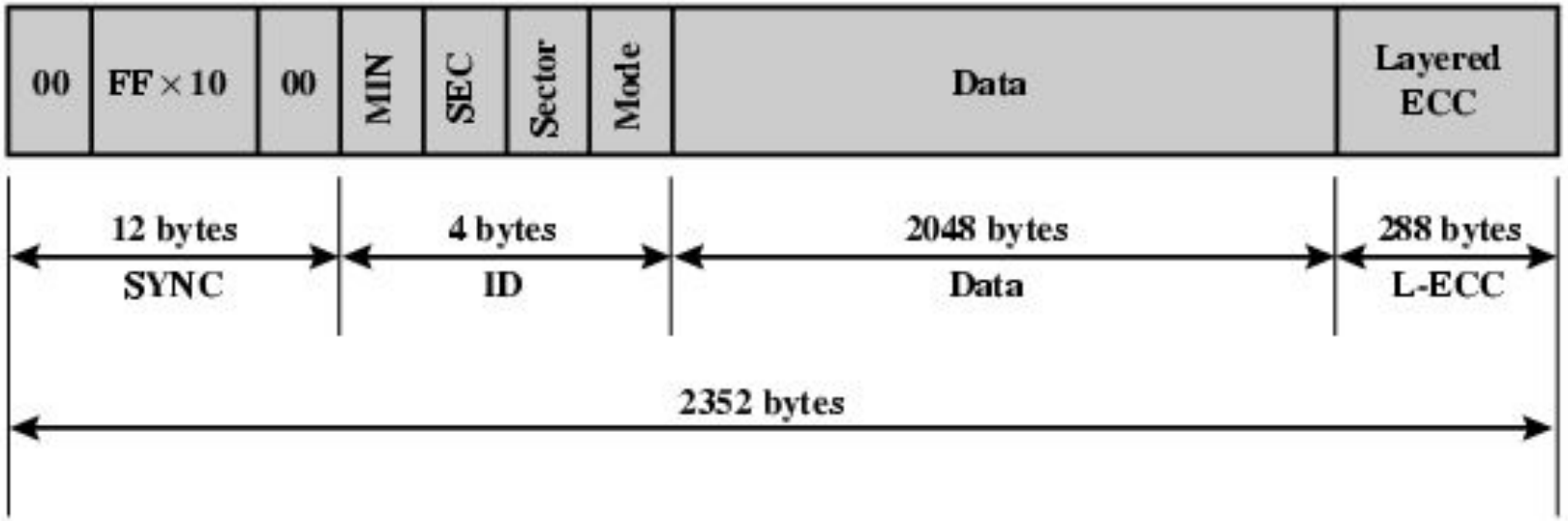
CD Operation



CD-ROM Drive Speeds

- Audio is single speed
  - Constant linear velocity
  - 1.2 ms^{-1}
  - Track (spiral) is 5.27km long
  - Gives 4391 seconds = 73.2 minutes
- Other speeds are quoted as multiples
- e.g. 24x
- Quoted figure is maximum drive can achieve

CD-ROM Format



- Mode 0=blank data field
- Mode 1=2048 byte data+error correction
- Mode 2=2336 byte data with no error-correcting code

Other Optical Storage

- CD-Recordable (CD-R)
  - WORM
  - Now affordable
  - Compatible with CD-ROM drives
- CD-RW
  - Erasable
  - Getting cheaper
  - Mostly CD-ROM drive compatible
  - Phase change
    - Material has two different reflectivities in different phase states

DVD - what's in a name?

- Digital Video Disk
  - Used to indicate a player for movies
    - Only plays video disks
- Digital Versatile Disk
  - Used to indicate a computer drive
    - Will read computer disks and play video disks

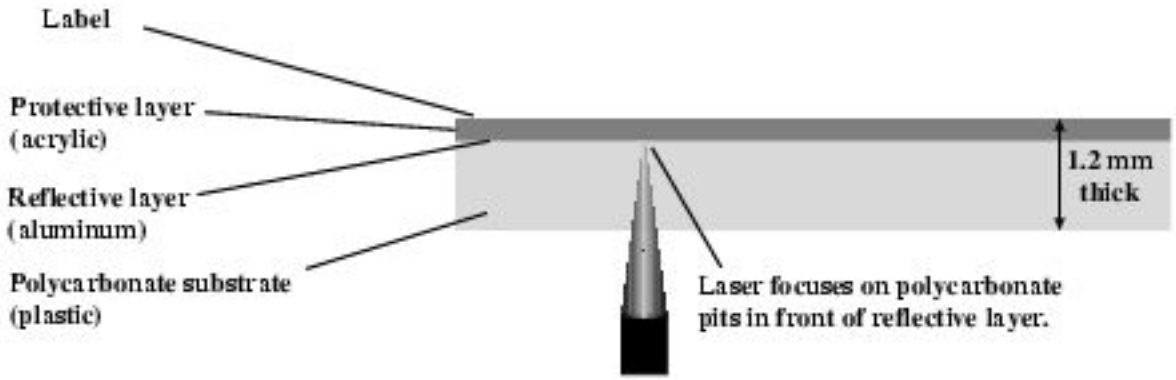
DVD - technology

- Multi-layer
- Very high capacity (4.7G per layer)
- Full length movie on single disk
  - Using MPEG compression
- Finally standardized
- Movies carry regional coding
- Players only play correct region films
- Can be “fixed”

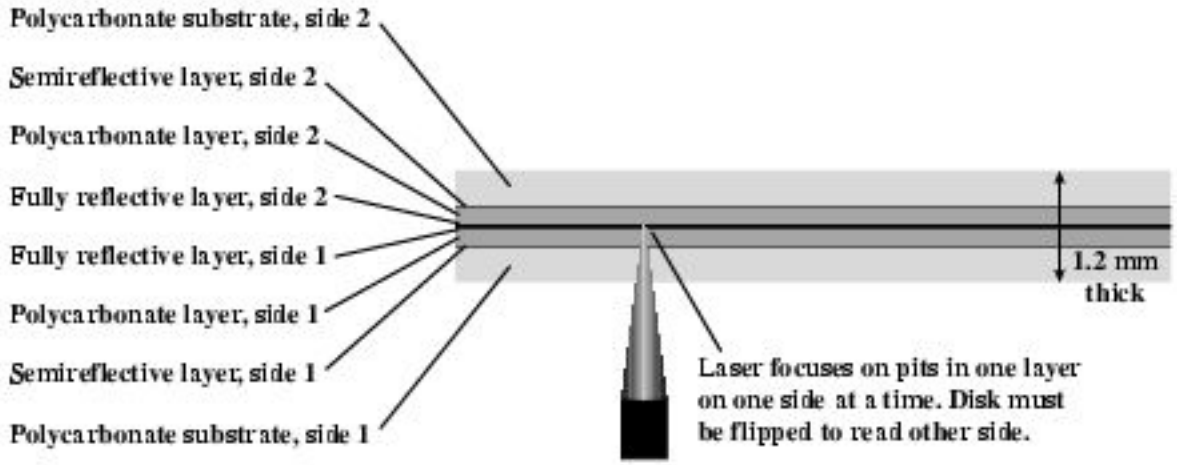
DVD – Writable

- Lots of trouble with standards
- First generation DVD drives may not read first generation DVD-W disks
- First generation DVD drives may not read CD-RW disks
- Wait for it to settle down before buying!

CD and DVD



(a) CD-ROM - Capacity 682 MB



(b) DVD-ROM, double-sided, dual-layer - Capacity 17 GB

Magnetic Tape

- Serial access
- Slow
- Very cheap
- Backup and archive

Magnetic Tape Features

(a) Serpentine reading and writing

- The typical recording technique used in serial tapes is referred to as **serpentine recording**.
- When data are being recorded, the first set of bits is recorded along the **whole length of the tape**.
- When the end of the tape is reached, the heads are repositioned to record a new track, and the tape is again recorded on its whole length, this time in the opposite direction. That process continues, back and forth, until the tape is full.