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Computer Organization and Architecture
7th Edition

Chapter 6

External Memory

Types of External Memory

- Magnetic Disk
  - RAID
  - Removable
- Optical
  - CD-ROM
  - CD-Recordable (CD-R)
  - CD-R/W
  - DVD
- Magnetic Tape

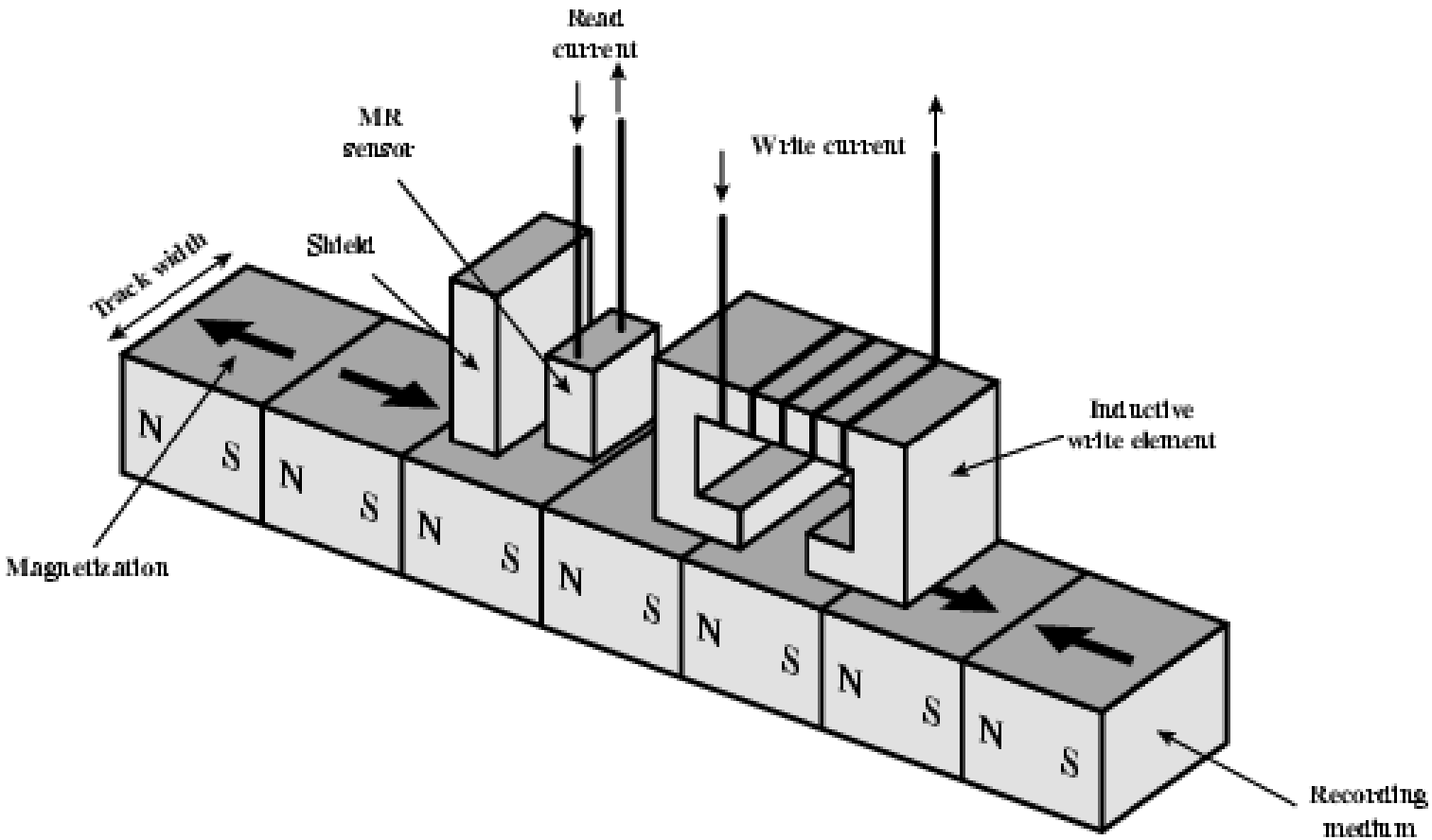
Magnetic Disk

- Disk substrate coated with magnetizable material (iron oxide...rust)
- Substrate used to be aluminium
- Now glass
  - Improved surface uniformity
    - Increases reliability
  - Reduction in surface defects
    - Reduced read/write errors
  - Lower flight heights (See later)
  - Better stiffness
  - Better shock/damage resistance

Read and Write Mechanisms

- Recording & retrieval via conductive coil called a head
- May be single read/write head or separate ones
- During read/write, head is stationary, platter rotates
- Write
  - Current through coil produces magnetic field
  - Pulses sent to head
  - Magnetic pattern recorded on surface below
- Read (traditional)
  - Magnetic field moving relative to coil produces current
  - Coil is the same for read and write
- Read (contemporary)
  - Separate read head, close to write head
  - Partially shielded magneto resistive (MR) sensor
  - Electrical resistance depends on direction of magnetic field
  - MR design allows higher frequency operation
    - Higher storage density and speed

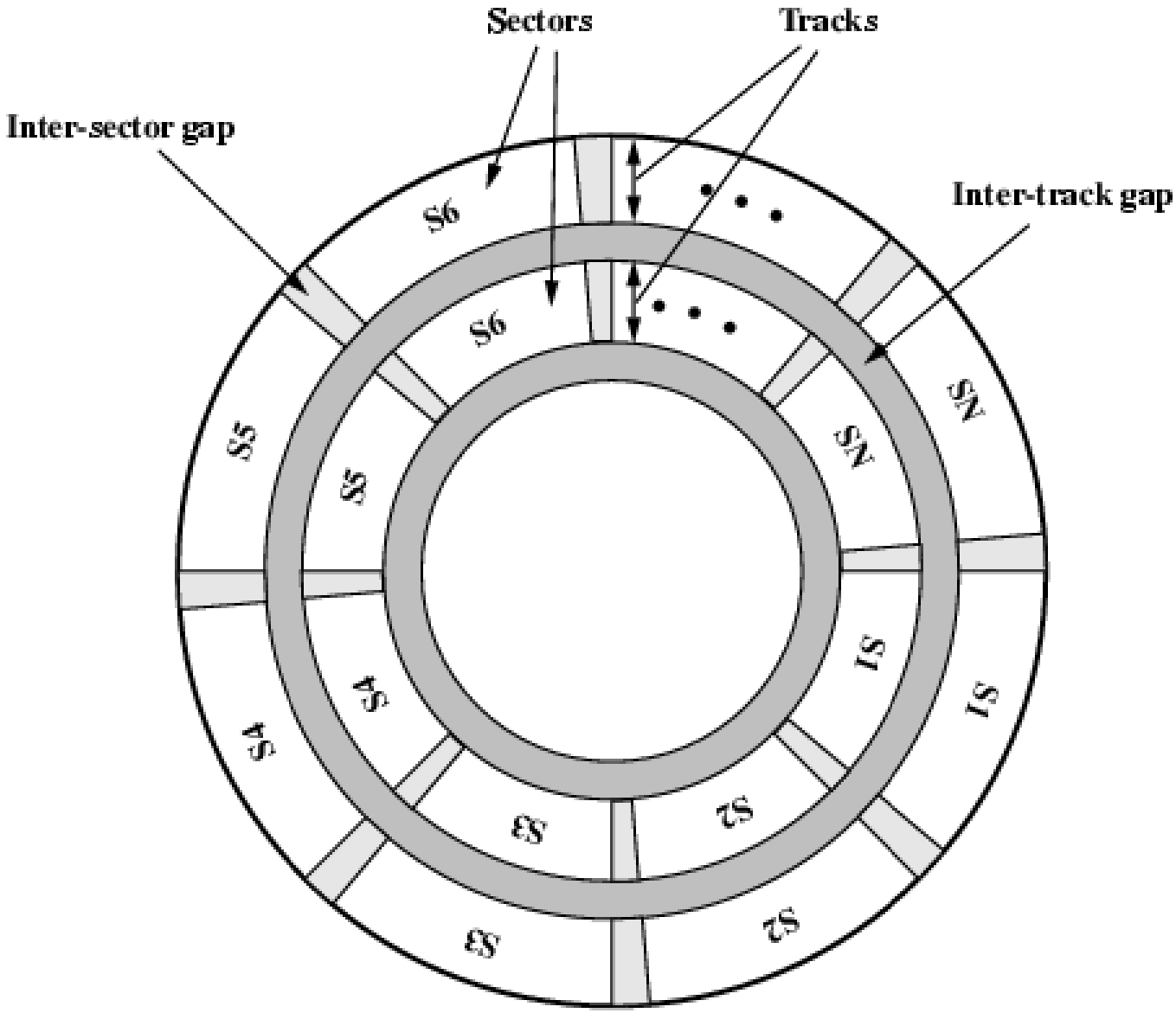
Inductive Write MR Read



Data Organization and Formatting

- Concentric rings or tracks
  - Gaps between tracks
  - Reduce gap to increase capacity
  - Same number of bits per track (variable packing density)
  - Constant angular velocity
- Tracks divided into sectors (~512 bytes)
- Minimum block size is one sector
- May have more than one sector per block

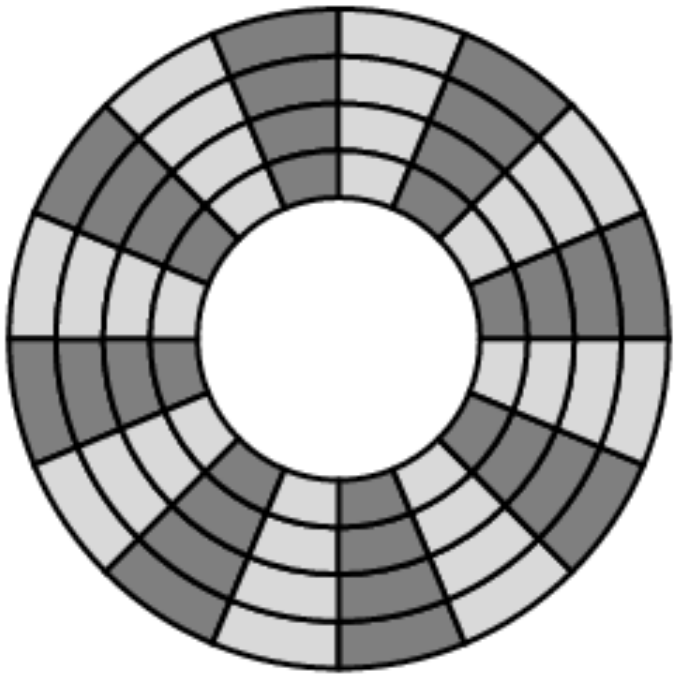
Disk Data Layout



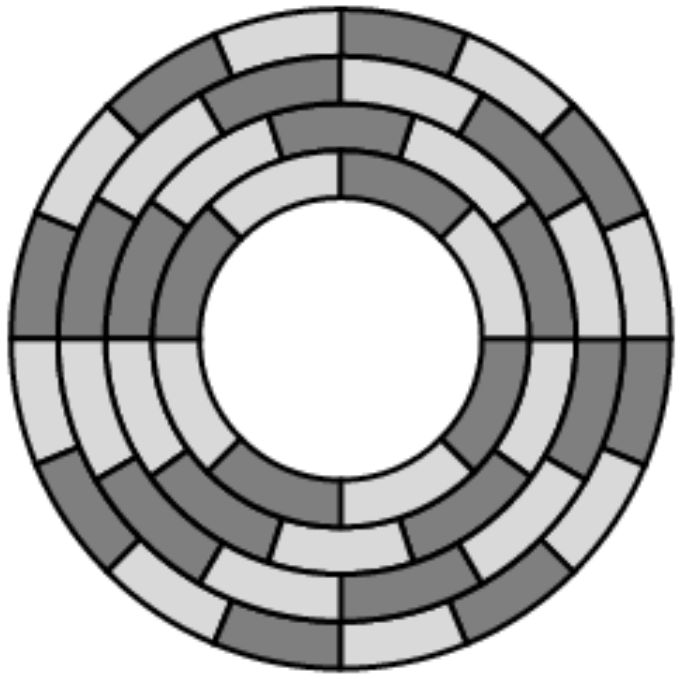
Disk Velocity

- Bit near centre of rotating disk passes fixed point slower than bit on outside of disk
- Increase spacing between bits in different tracks
- Rotate disk at constant angular velocity (CAV)
  - Gives pie shaped sectors and concentric tracks
  - Individual tracks and sectors addressable
  - Move head to given track and wait for given sector
  - Waste of space on outer tracks
    - Lower data density
- Can use zones to increase capacity
  - Each zone has fixed bits per track
  - More complex circuitry

Disk Layout Methods Diagram

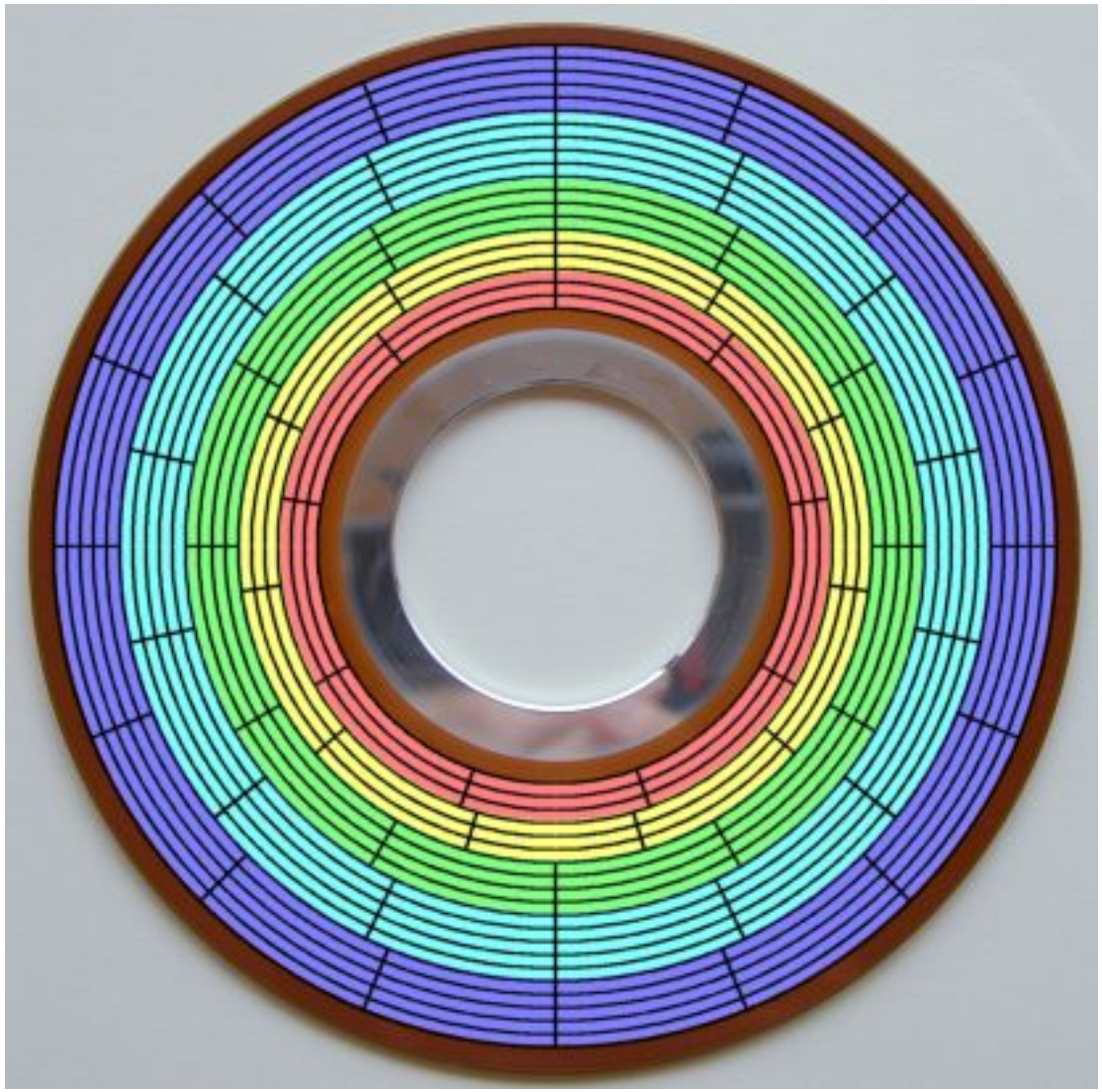


(a) Constant angular velocity



(b) Multiple zoned recording

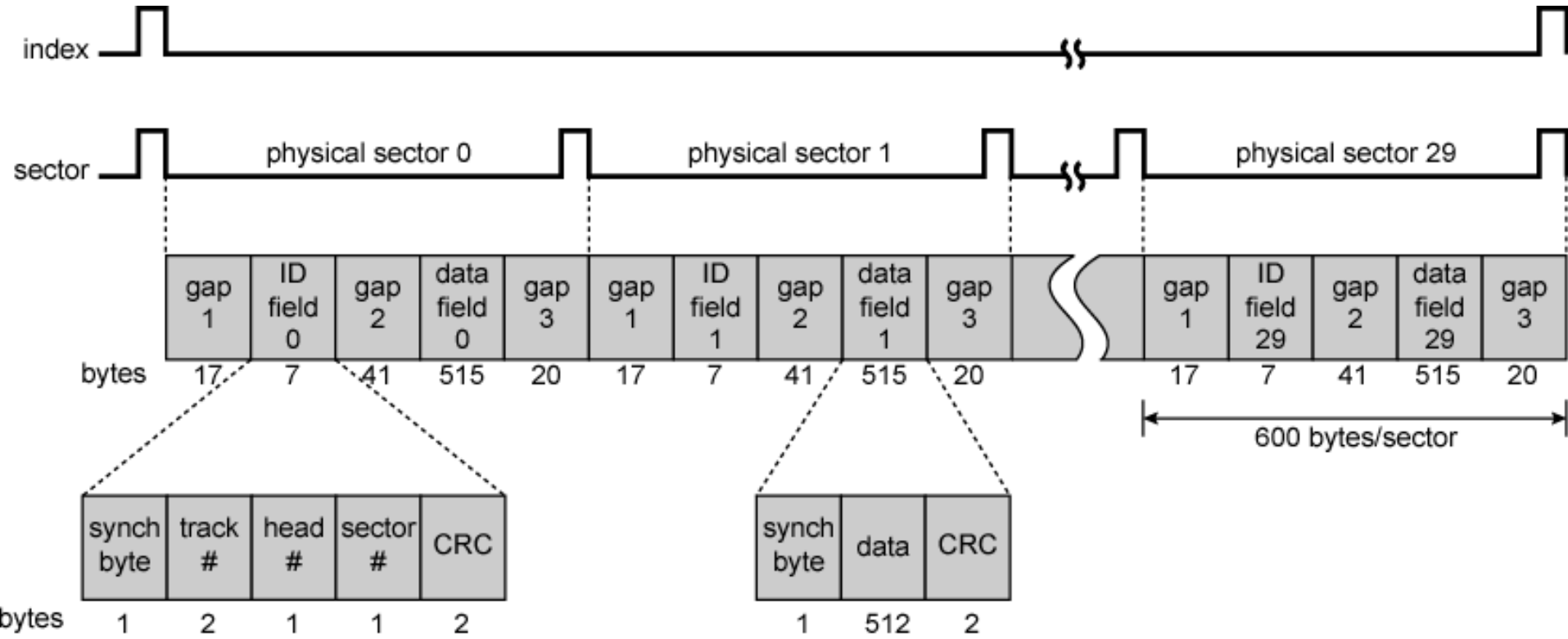
Multiple Zone Recording



Finding Sectors

- Must be able to identify start of track and sector
- Format disk
  - Additional information not available to user
  - Marks tracks and sectors

Winchester Disk Format
Seagate ST506



Characteristics

- Fixed (rare) or movable head
- Removable or fixed
- Single or double (usually) sided
- Single or multiple platter
- Head mechanism
  - Contact (Floppy)
  - Fixed gap
  - Flying (Winchester)

Fixed/Movable Head Disk

- Fixed head
  - One read write head per track
  - Heads mounted on fixed ridged arm
- Movable head
  - One read write head per side
  - Mounted on a movable arm

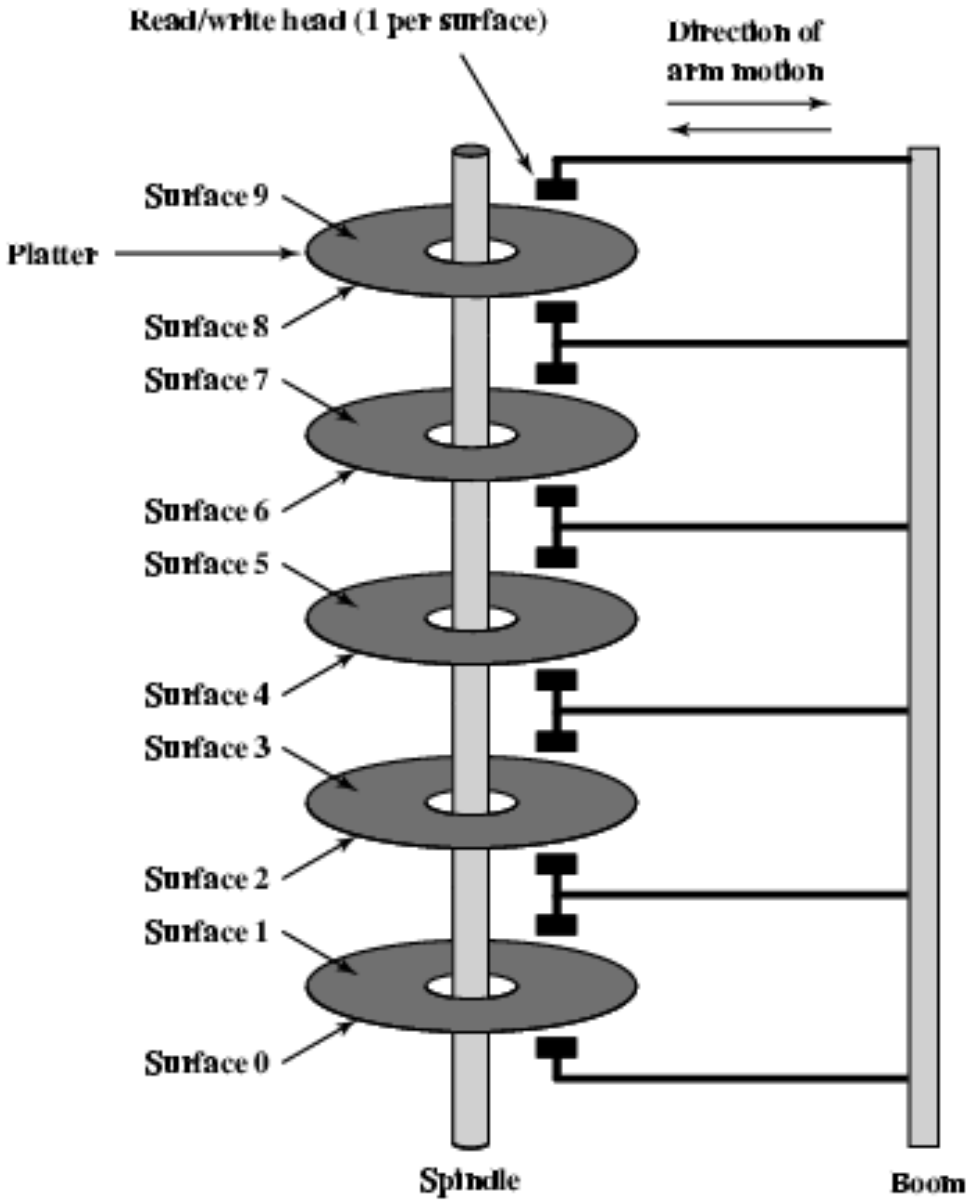
Removable or Not

- Removable disk
  - —Can be removed from drive and replaced with another disk
  - —Provides unlimited storage capacity
  - —Easy data transfer between systems
- Nonremovable disk
  - —Permanently mounted in the drive

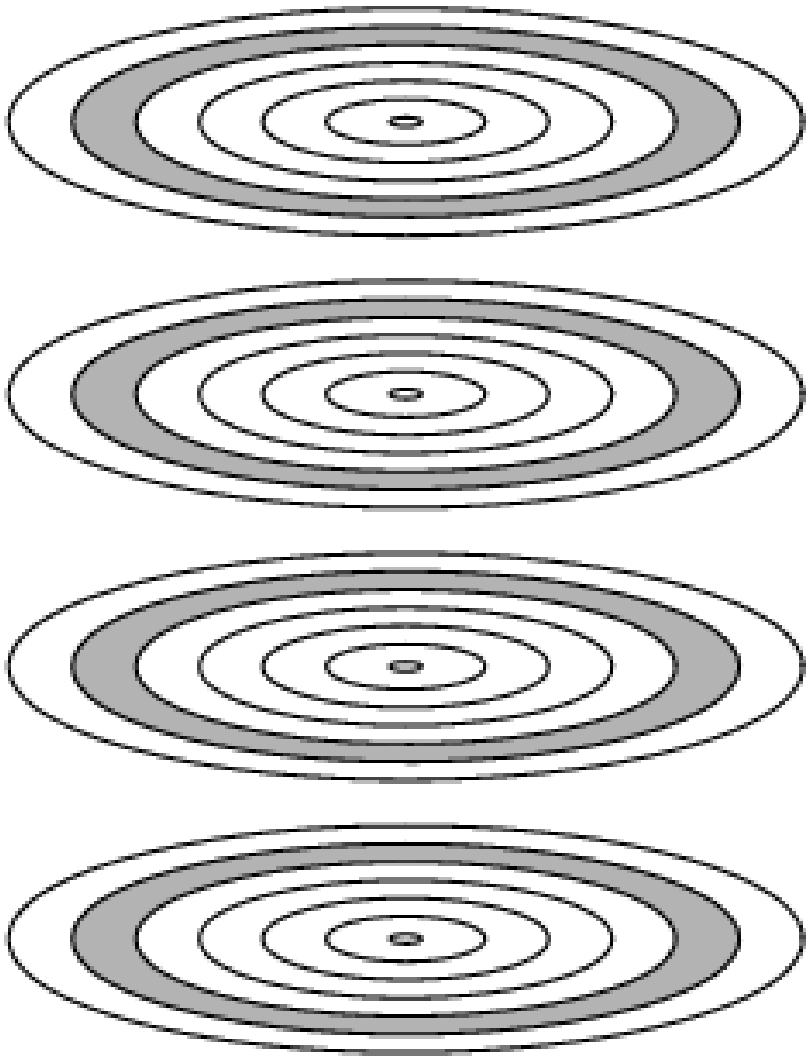
Multiple Platter

- One head per side
- Heads are joined and aligned
- Aligned tracks on each platter form cylinders
- Data is striped by cylinder
  - —reduces head movement
  - —Increases speed (transfer rate)

Multiple Platters



Tracks and Cylinders



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)
- Sealed unit
- One or more platters (disks)
- Heads fly on boundary layer of air as disk spins
- Very small head to disk gap
- Getting more robust

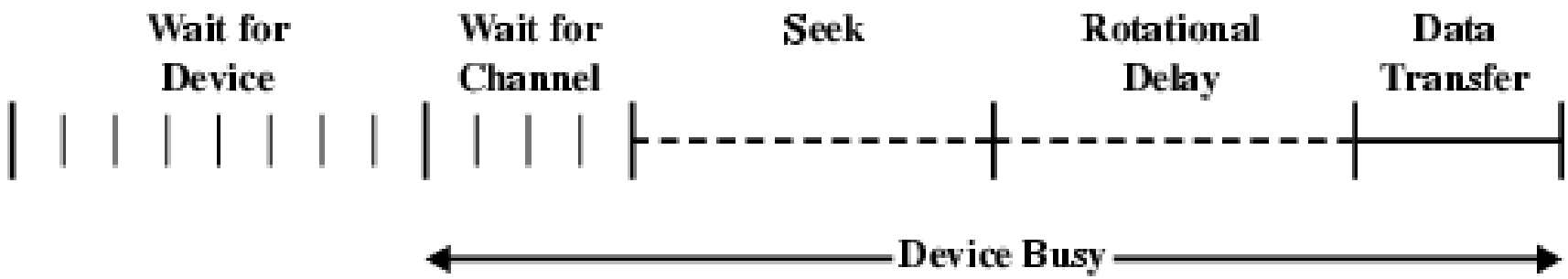
Winchester Hard Disk (2)

- Universal
- Cheap
- Fastest external storage
- Getting larger capacity all the time
  - —250 Gigabyte now easily available

Speed

- Seek time
  - —Moving head to correct track
- (Rotational) latency
  - —Waiting for data to rotate under head
- Access time = Seek + Latency
- Transfer rate

Timing of Disk I/O Transfer



Transfer Time:

$T = b/rN$

T : transfer time

b : number of bytes to be transferred

N : number of bytes on a track

r : rotation speed, in revolution per second

The total average access time:

$T_a = T_s + 1/2r + b/rN$

Where T_s is the average seek time. Second and third terms are average rotational delay and transfer time, respectively.

EXAMPLE:

Assume: T_s = 4ms, r = 15,000rpm (15,000/60 = 250rps), 512 Bytes/sector, 500 sectors/track and we will read a file of 2500 sectors (1.28MB)

a) Assume the file is on 5 adjacent tracks (5 tracks × 500sectors/track = 2500 sectors). For the first track:

Average seek:	4ms
Average rot. Delay:	2ms [1/2r = 1/(2×250) = 0.002]
Read 500 sectors:	4ms [b/rN = (500×512)/(250×500×512)]
Total	10ms

Suppose the remaining tracks can be read with no seek time. Then we have rotational delays and transfer times for the succeeding tracks:

each succeeding track is read in 2+4 = 6ms.

Thus total time becomes : 10 + (4 × 6) = 34ms 0.034 seconds

Now suppose that the sectors are distributed randomly over the disk. For each sector to be accessed we have:

Average seek: 4ms

Average rot. Delay: 2ms [$1/2r = 1/(2\times250) = 0.002$]

Read 1 sector: 0.008ms [$b/rN = (1\times512)/(250\times500\times512)$]

Total 6.008ms

Thus, the total time becomes: $2500\times6.008 = 15.02$ seconds

RAID

- Redundant Array of Independent Disks
- Redundant Array of Inexpensive Disks
- 6 levels in common use
- Not a hierarchy
- Set of physical disks viewed as single logical drive by O/S
- Data distributed across physical drives
- Can use redundant capacity to store parity information

RAID 0

- No redundancy
- Data striped across all disks
- Round Robin striping
- 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
  - Swap faulty disk & re-mirror
  - No down time
- Expensive

RAID 2

- Disks are synchronized
- Very small stripes
  - Often single byte/word
- Error correction calculated across corresponding bits on disks
- Multiple parity disks store Hamming code error correction in corresponding positions
- Lots of redundancy
  - Expensive
  - Not used

RAID 3

- Similar to RAID 2
- Only one redundant disk, no matter how large the array
- Simple parity bit for each set of corresponding bits
- Data on failed drive can be reconstructed from surviving data and parity info
- Very high transfer rates

$$X4(i) = X3(i) \oplus X2(i) \oplus X1(i) \oplus X0(i)$$

$$X1(i) = X4(i) \oplus X3(i) \oplus X2(i) \oplus X0(i)$$

RAID 4

- Each disk operates independently
- Good for high I/O request rate
- Large stripes
- Bit by bit parity calculated across stripes on each disk
- Parity stored on parity disk

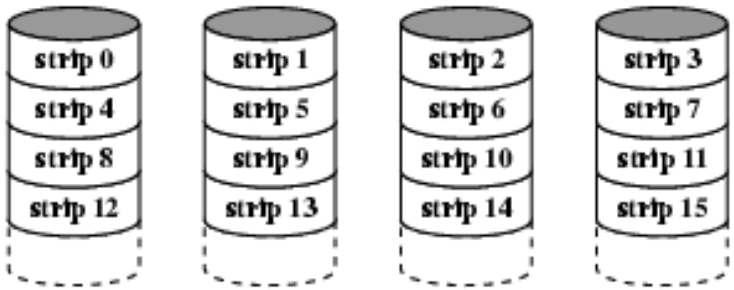
RAID 5

- Like RAID 4
- Parity striped across all disks
- Round robin allocation for parity stripe
- Avoids RAID 4 bottleneck at parity disk
- Commonly used in network servers

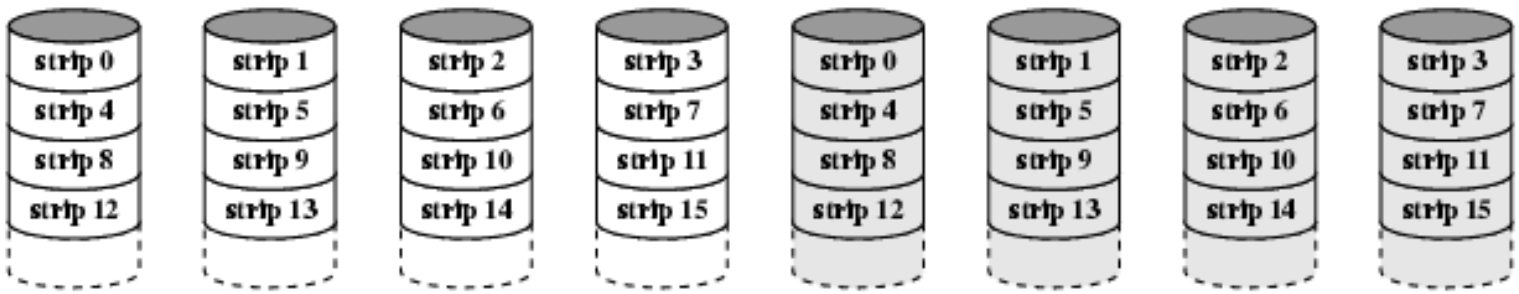
RAID 6

- 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

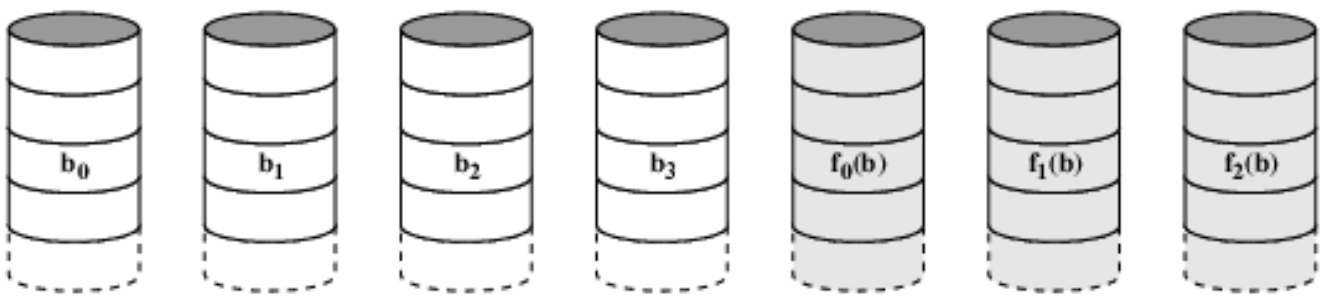
RAID 0, 1, 2



(a) RAID 0 (non-redundant)

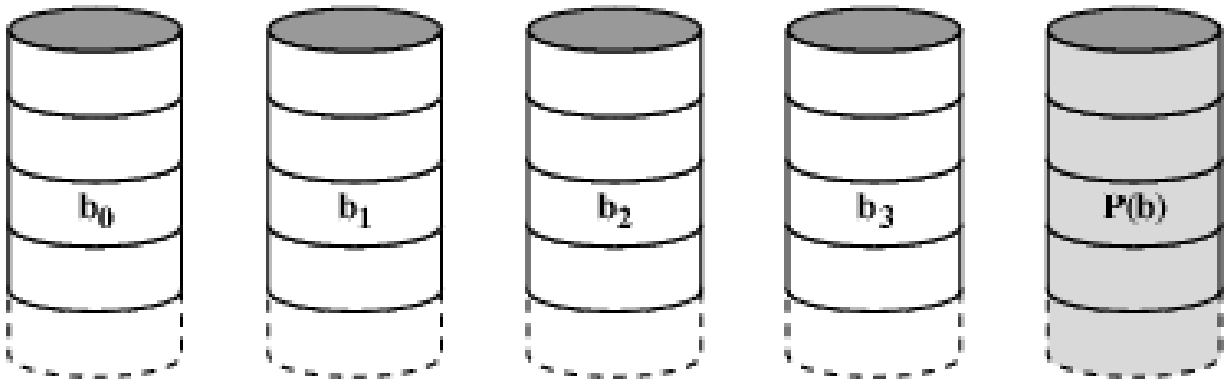


(b) RAID 1 (mirrored)

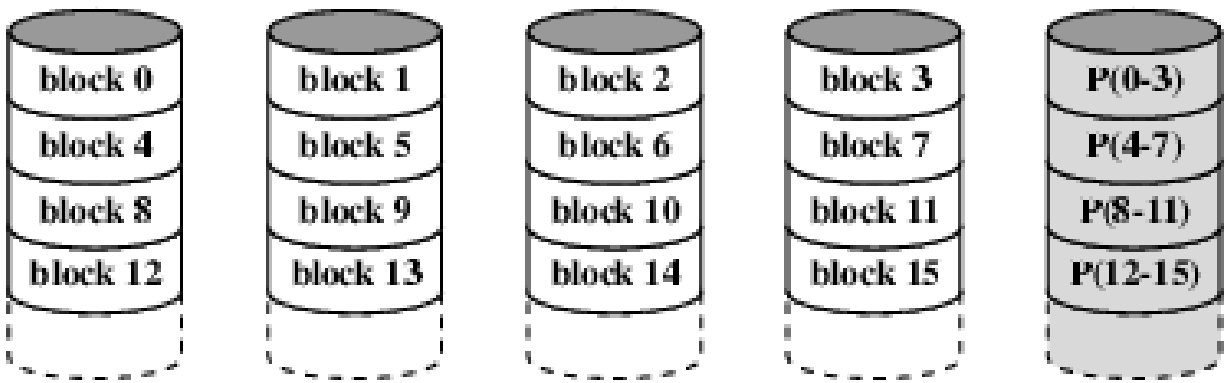


(c) RAID 2 (redundancy through Hamming code)

RAID 3 & 4

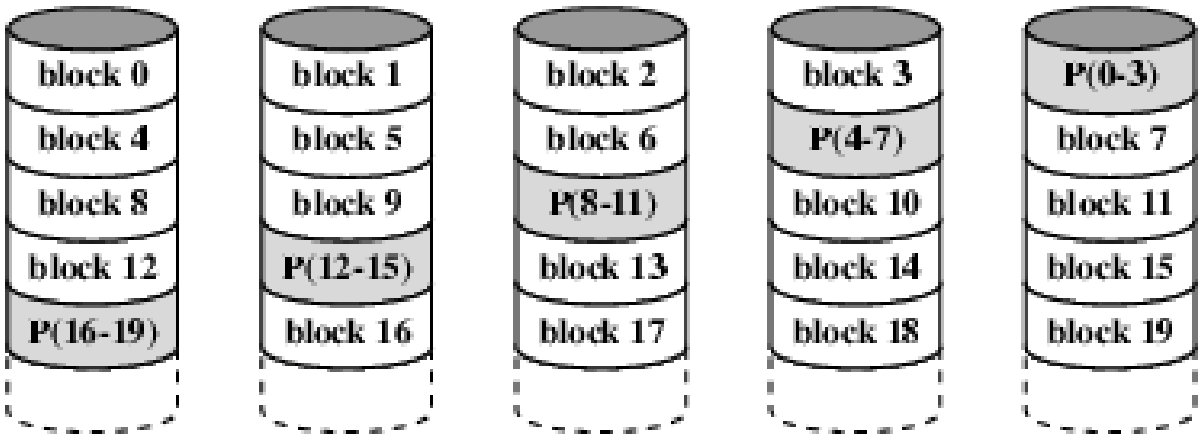


(d) RAID 3 (bit-interleaved parity)

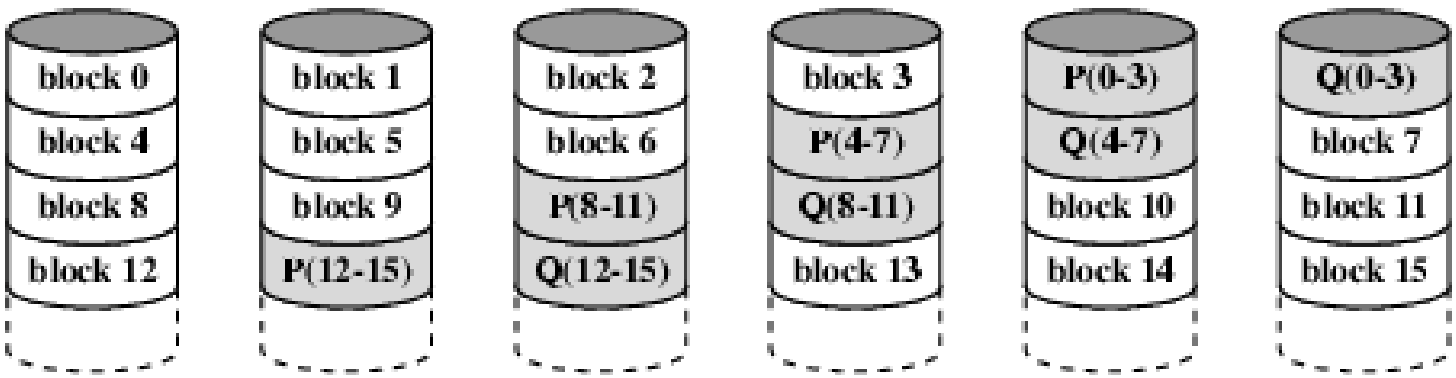


(e) RAID 4 (block-level parity)

RAID 5 & 6

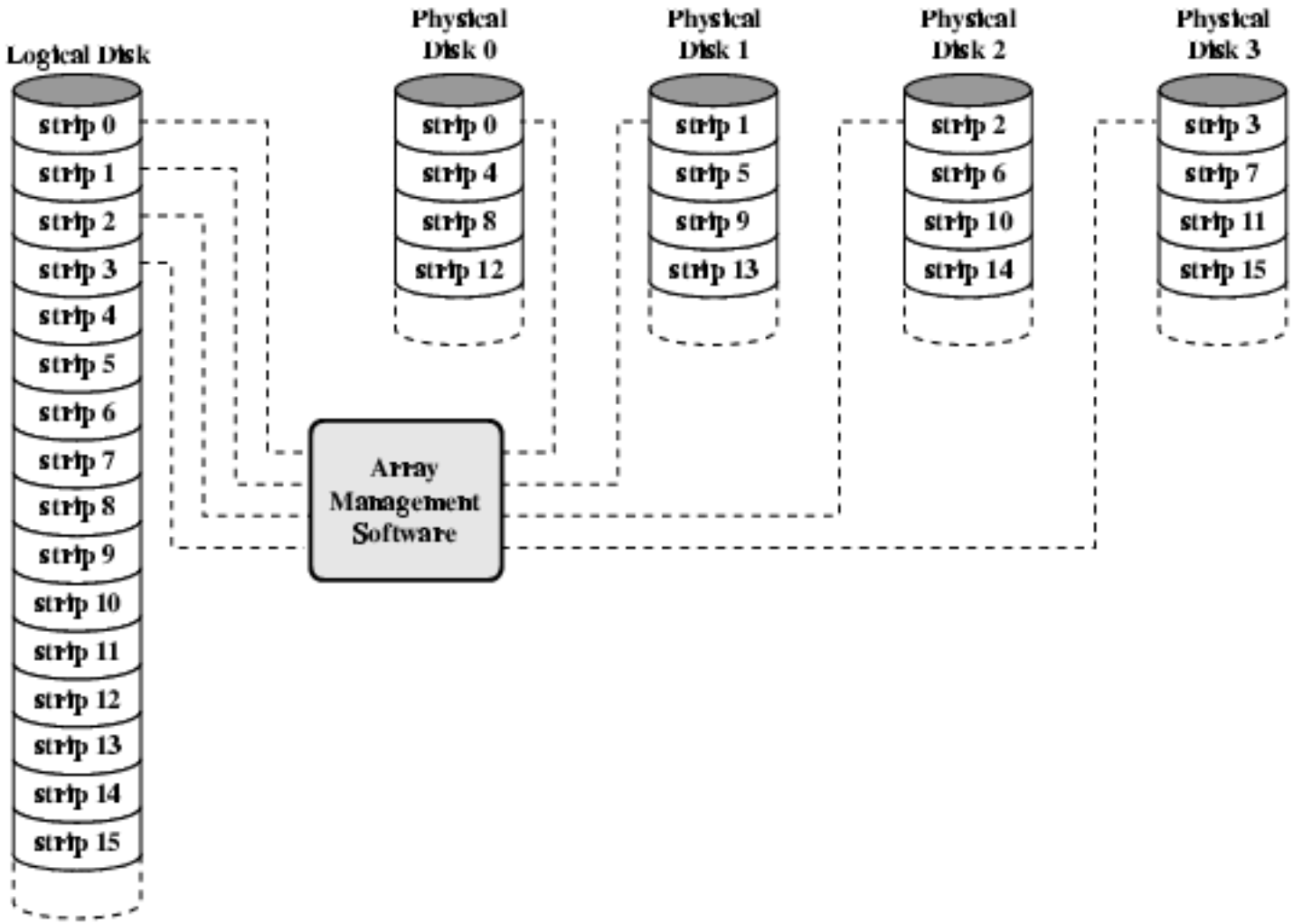


(f) RAID 5 (block-level distributed parity)



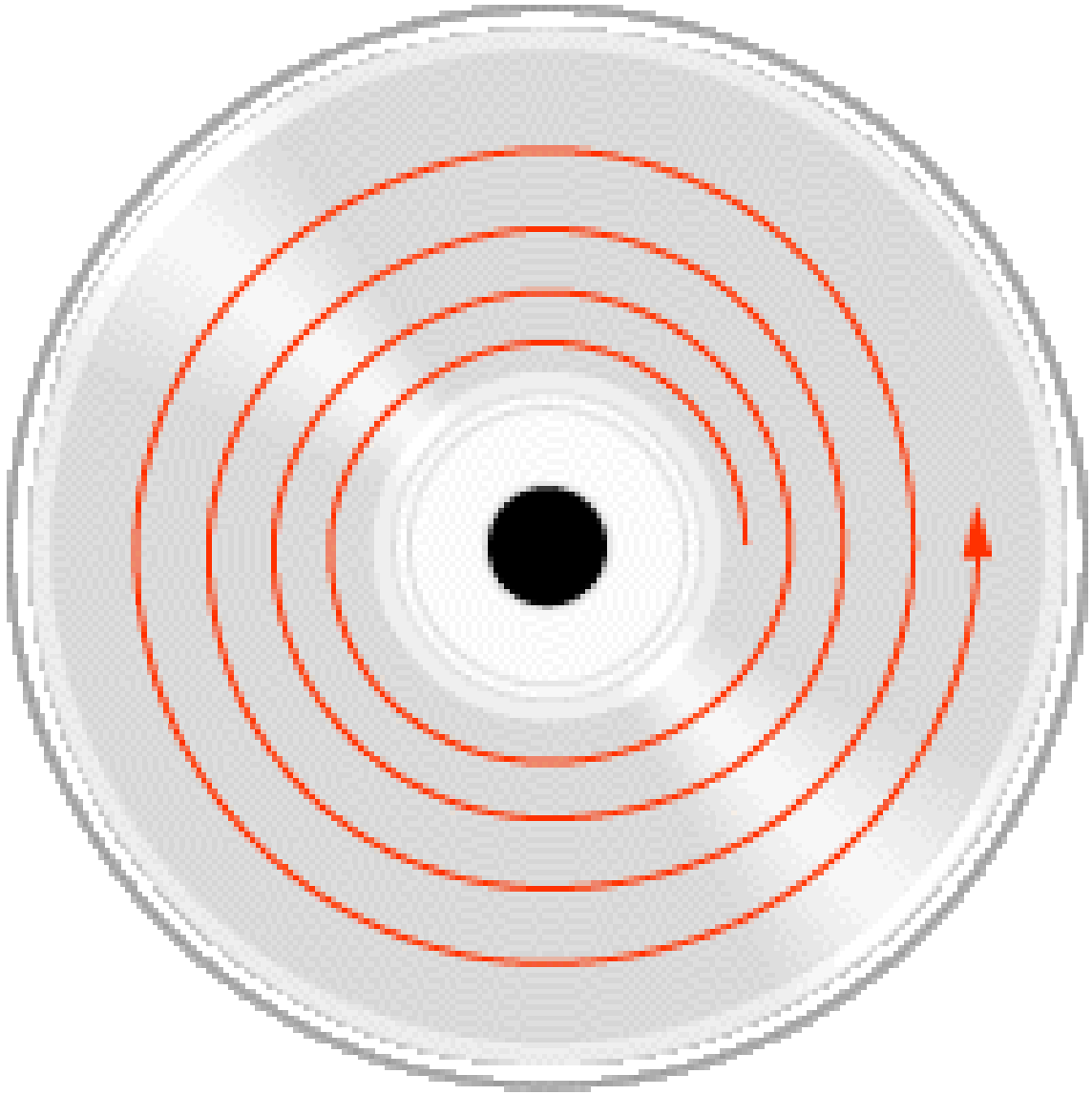
(g) RAID 6 (dual redundancy)

Data Mapping For RAID 0

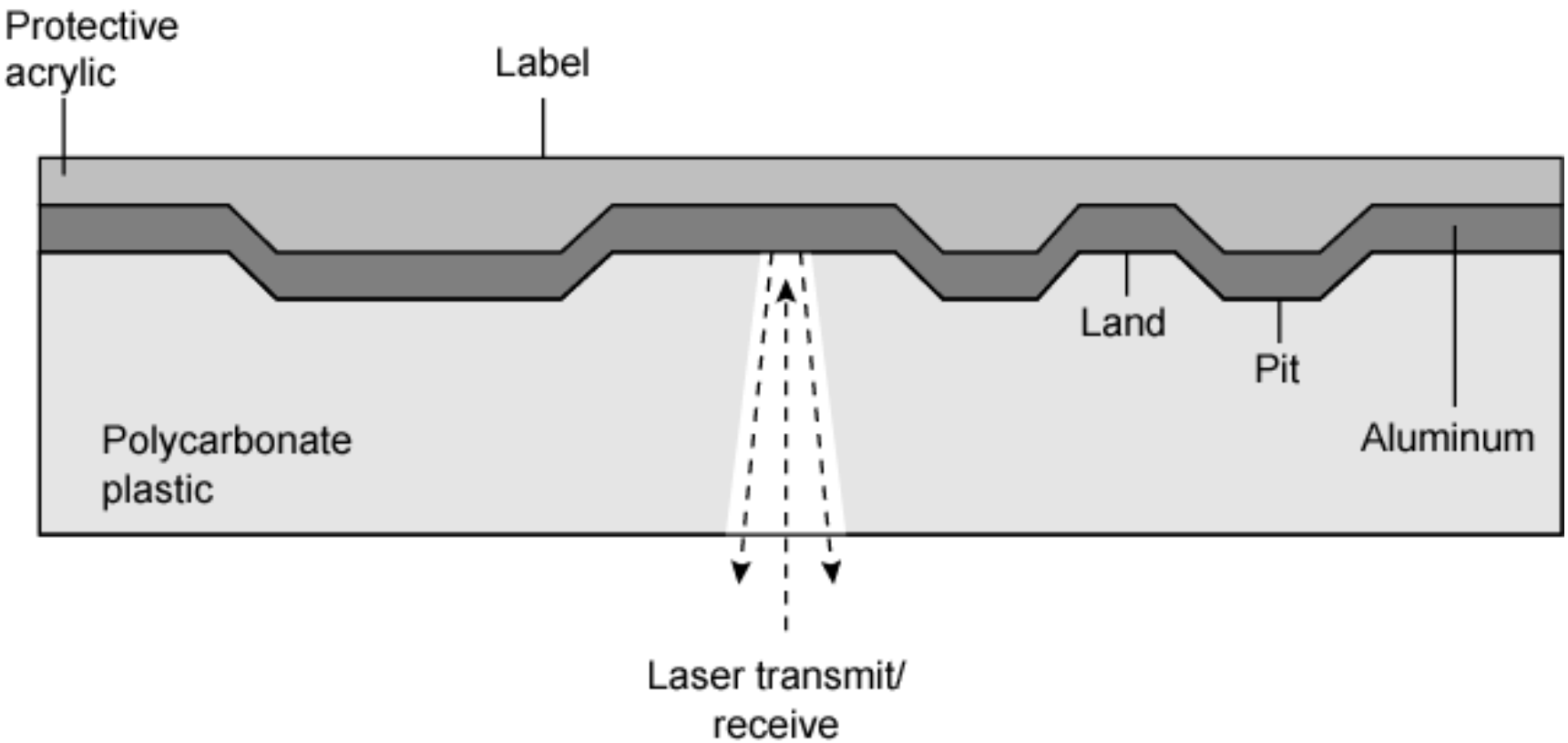


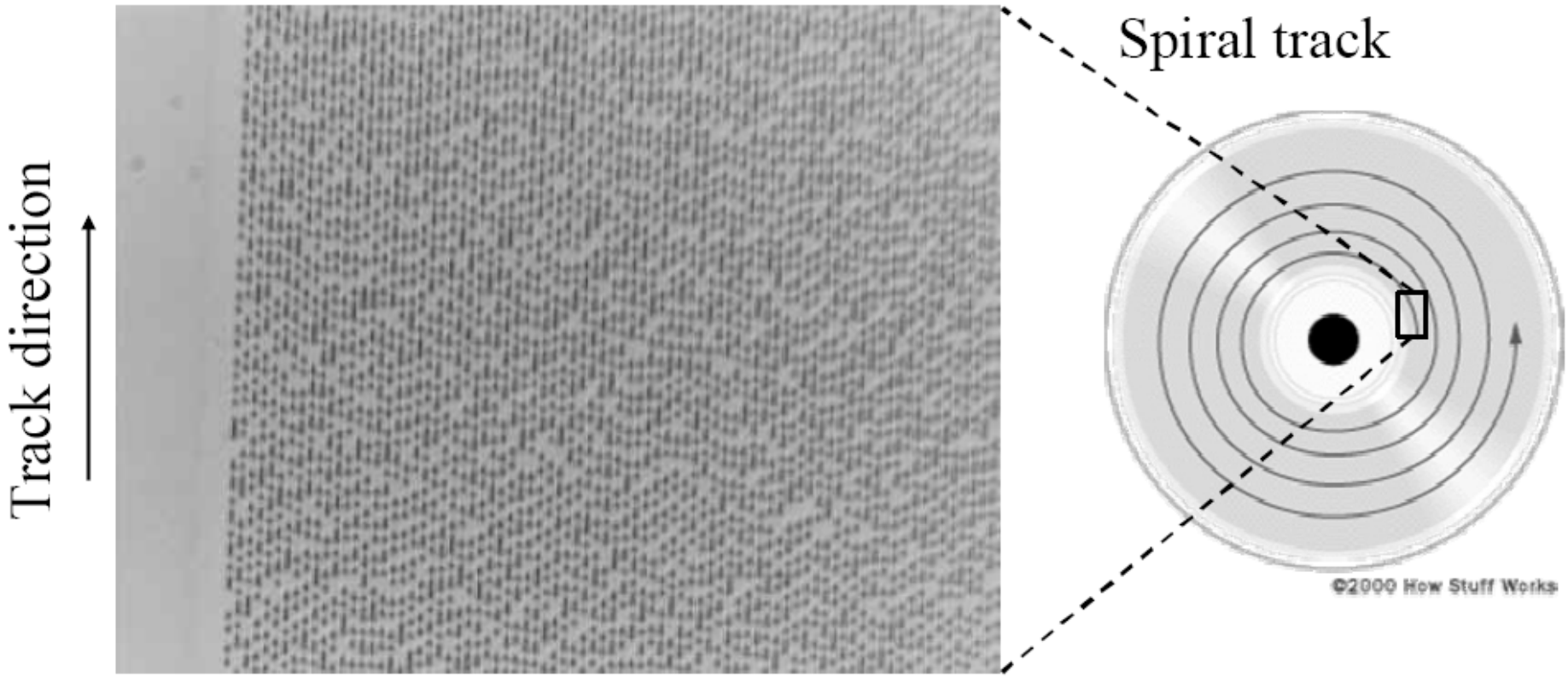
Optical Storage CD-ROM

- 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 (CLV)



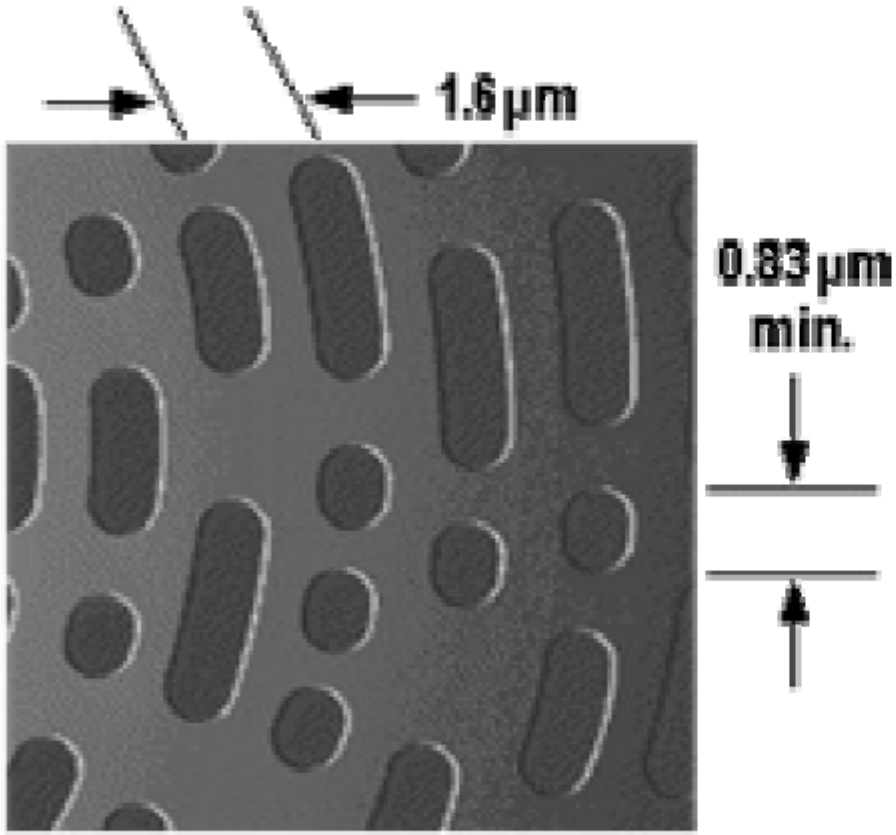
CD Operation



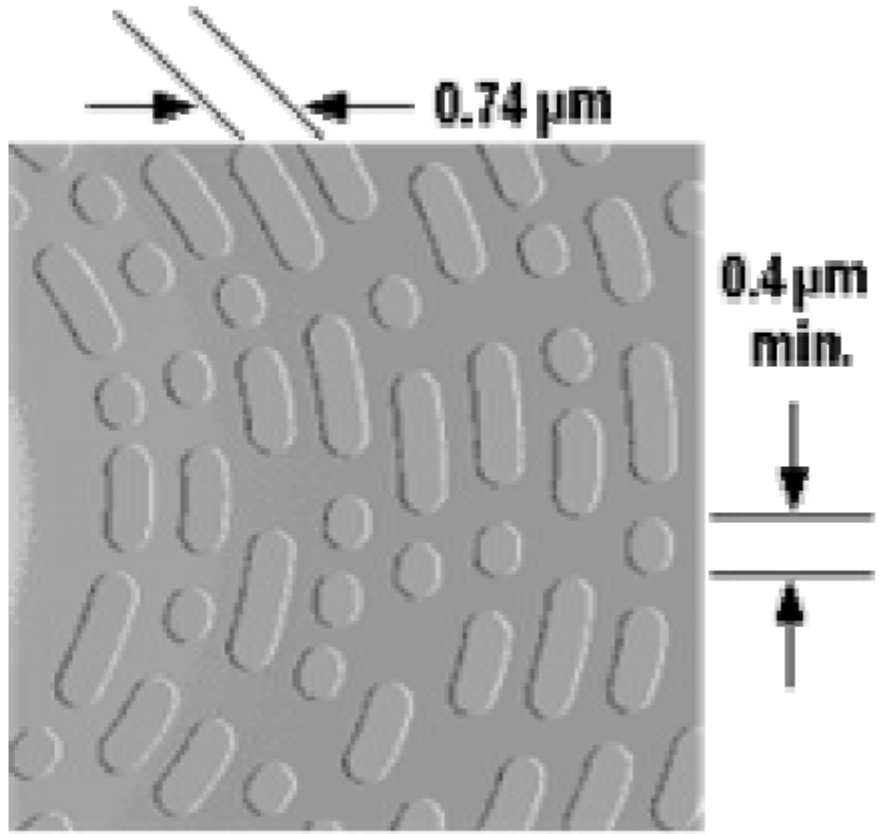


Low-magnification (×32) image of a CD showing an edge of the data zone.

CD Versus DVD

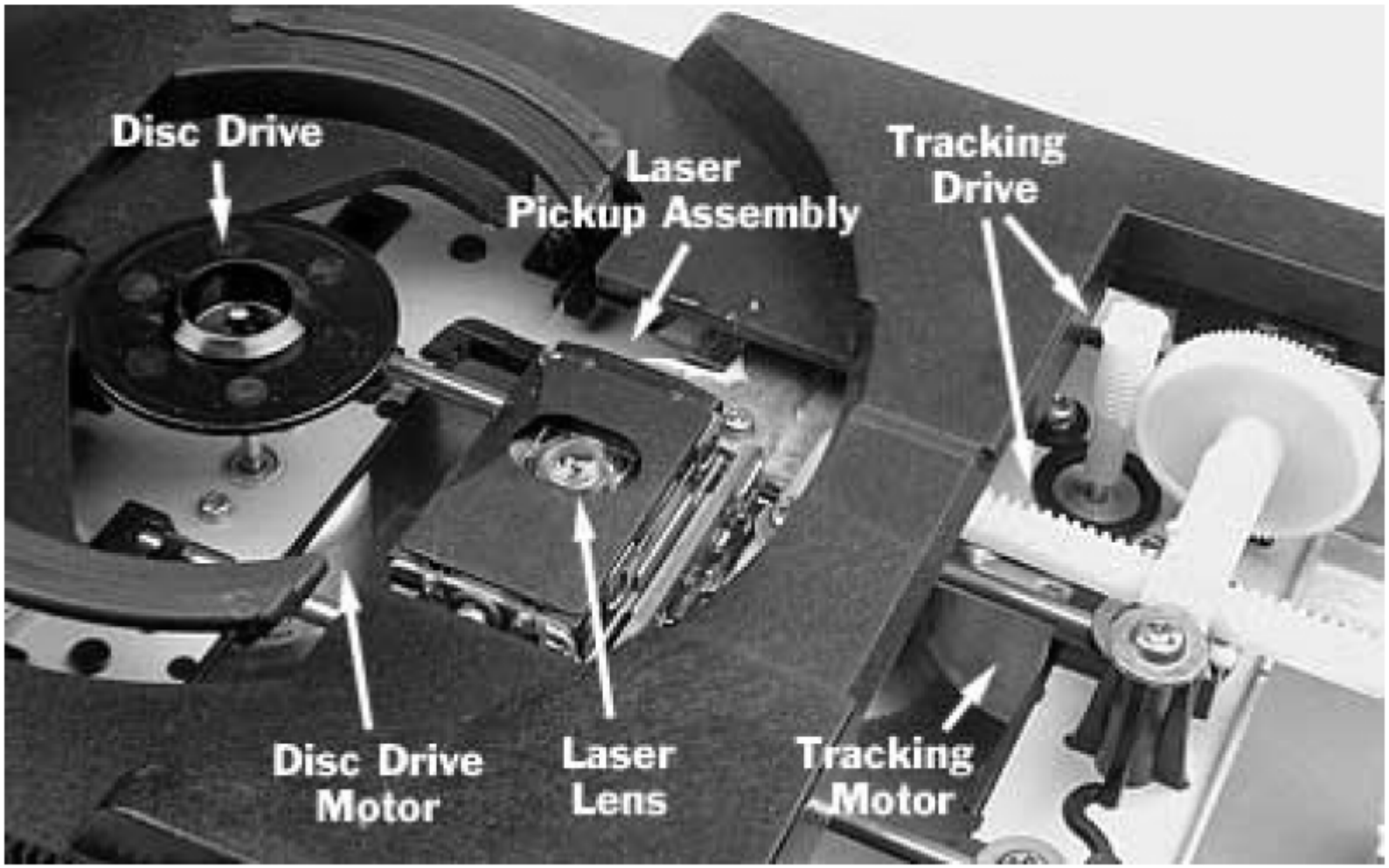


COMPACT disc

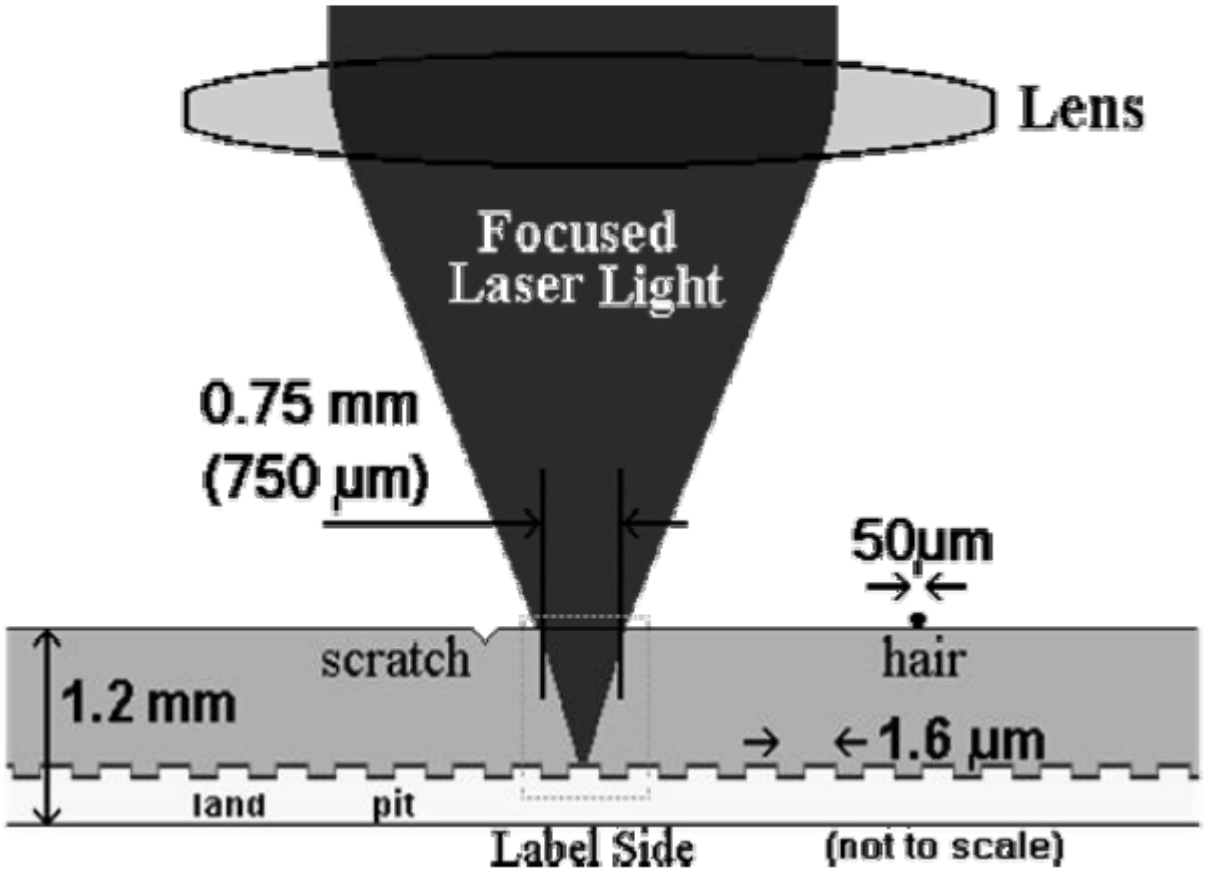


DVD

Inside a CD Player

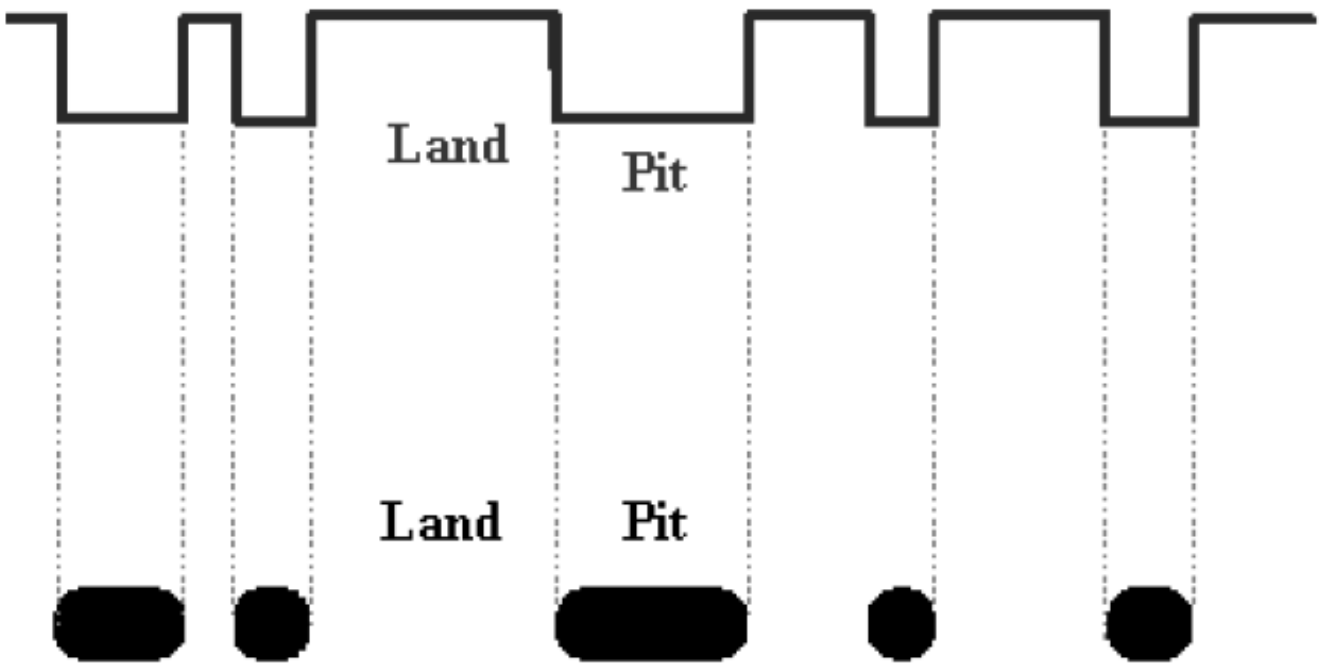


Why Focus the Laser Light through the Substrate?



Translating Binary Digits to Pits

00100100101000000001000001000010100000100100 0



CD

Compact Disk. A nonerasable disk that stores digitized audio information. The standard system uses 12-cm disks and can record more than 60 minutes of uninterrupted playing time.

CD-ROM

Compact Disk Read-Only Memory. A nonerasable disk used for storing computer data. The standard system uses 12-cm disks and can hold more than 650 Mbytes.

CD-R

CD Recordable. Similar to a CD-ROM. The user can write to the disk only once.

CD-RW

CD Rewritable. Similar to a CD-ROM. The user can erase and rewrite to the disk multiple times.

DVD

Digital Versatile Disk. A technology for producing digitized, compressed representation of video information, as well as large volumes of other digital data. Both 8 and 12 cm diameters are used, with a double-sided capacity of up to 17 Gbytes. The basic DVD is read-only (DVD-ROM).

DVD-R

DVD Recordable. Similar to a DVD-ROM. The user can write to the disk only once. Only one-sided disks can be used.

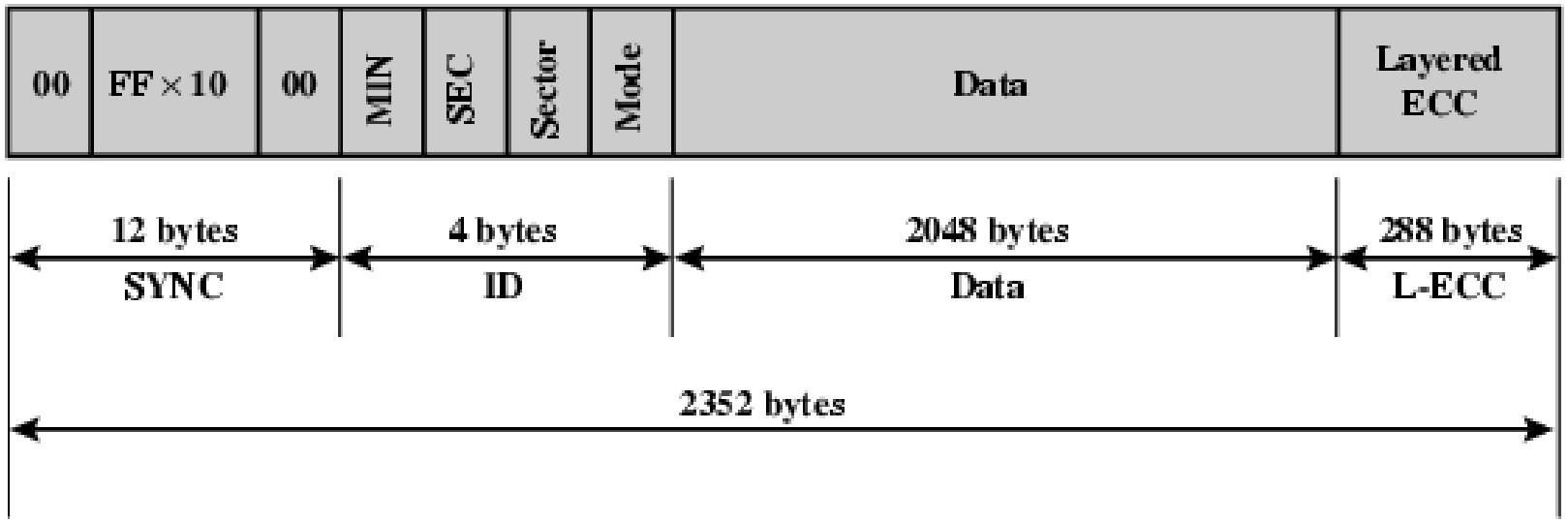
DVD-RW

DVD Rewritable. Similar to a DVD-ROM. The user can erase and rewrite to the disk multiple times. Only one-sided disks can be used.

CD-ROM Drive Speeds

- Audio is single speed
  - —Constant linier 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 Block Format



- Mode 0=blank data field
- Mode 1=2048 byte data+error correction
- Mode 2=2336 byte data

Random Access on CD-ROM

- Difficult
- Move head to rough position
- Set correct speed
- Read address
- Adjust to required location

CD-ROM for & against

- Large capacity (?)
- Easy to mass produce
- Removable
- Robust

- Expensive for small runs
- Slow
- Read only

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
- ~x7 capacity of a CD for ordinary DVD (4.7GB)
- 8.5GB and 17 GB for dual layer & double side

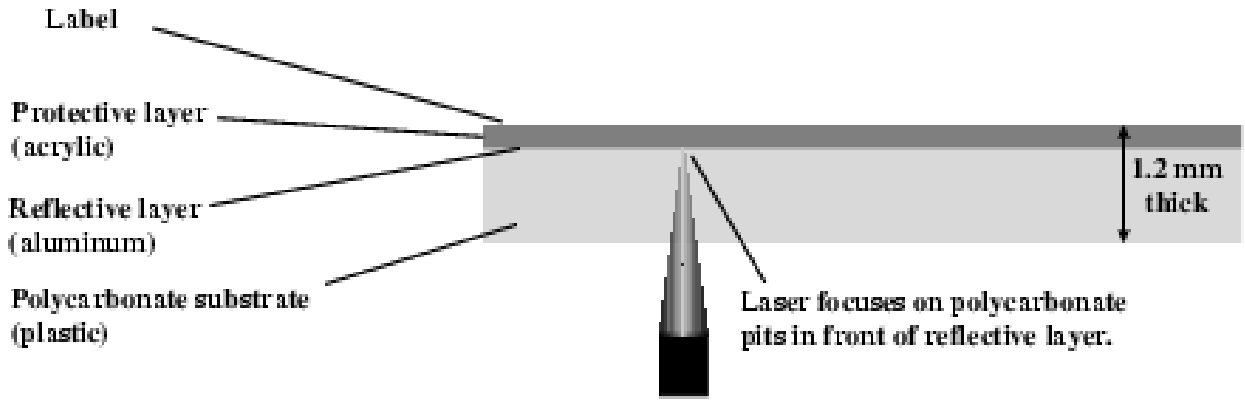
DVD - technology

- Multi-layer
- Very high capacity (4.7G per layer)
- Full length movie on single disk
  - Using MPEG compression
- Finally standardized (honest!)
- Movies carry regional coding
- Players only play correct region films
- Can be “fixed”
- 0.74μm loop, 0.4μm pit spacing (1.6μm and 0.834μm for CD), shorter wavelength laser

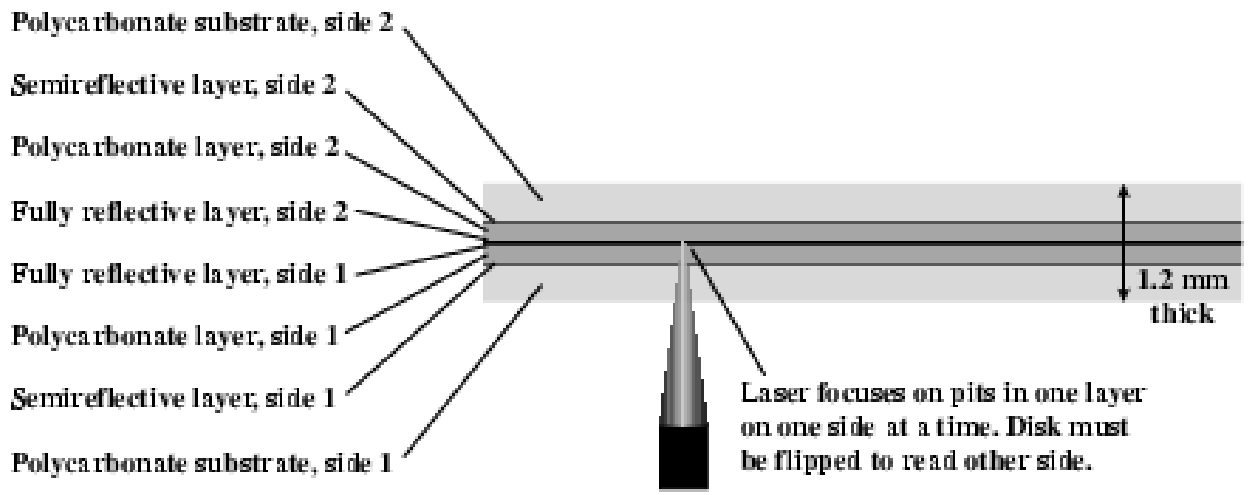
DVD – Writable

- Loads 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

Internet Resources

- Optical Storage Technology Association
  - —Good source of information about optical storage technology and vendors
  - —Extensive list of relevant links
- DLTtape
  - —Good collection of technical information and links to vendors
- Search on RAID