Computer Organization and Architecture

9 External Memory

Tongwei Ren

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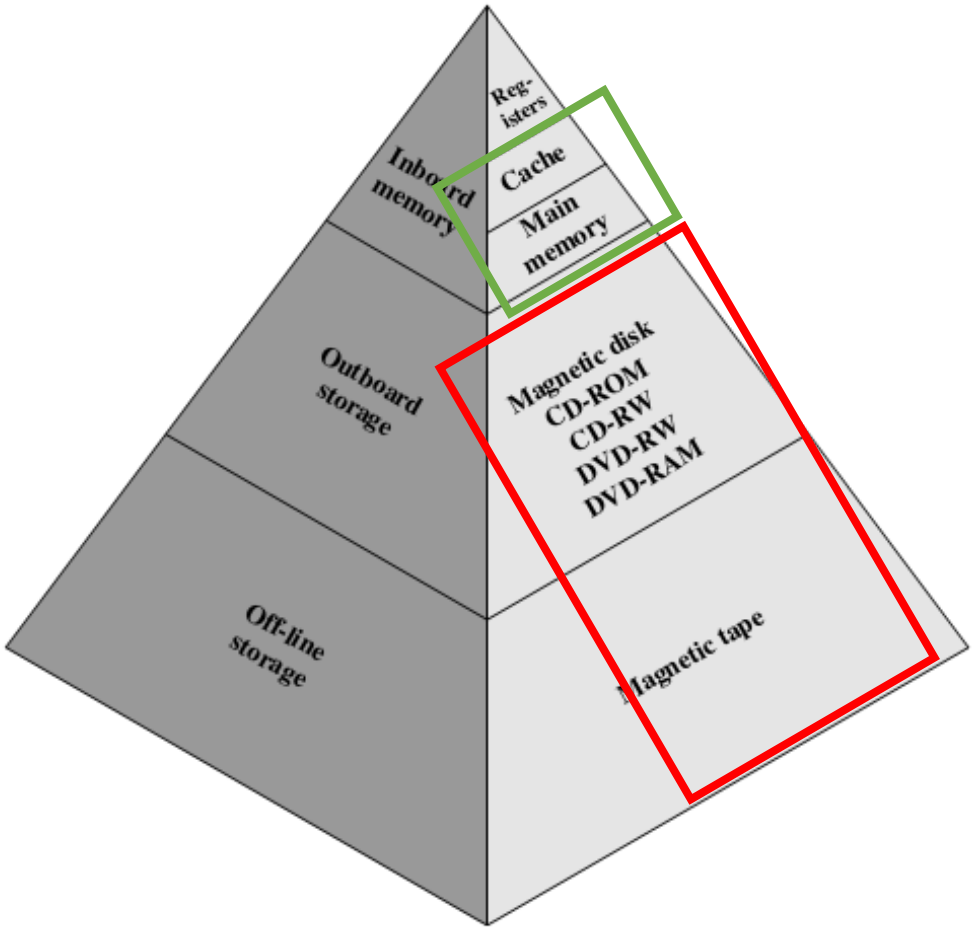
南京大學
NANJING UNIVERSITY

Review

- Memory hierarchy
- Cache
  - Basic idea, work procedure
- Some questions
- Elements of cache design
  - Cache size, mapping function, replacement algorithm, write policy, line size, number of caches

Memory Hierarchy



External Memory

- Characteristics
  - Store large scale data, which may be not always used
  - Not volatile

- Types
  - Magnetic disk
  - Optical memory
  - Magnetic tape
  - USB flash disk, solid state disk (SSD): flash

Magnetic Disk

- A disk is a circular platter constructed of nonmagnetic material (substrate) coated with a magnetizable material
  - Substrate: aluminum, aluminum alloy material, glass, …
  - Benefit of glass substrate
    - Improvement in the uniformity of the magnetic film surface to increase disk reliability
    - A significant reduction in overall surface defects to help reduce read-write errors
    - Ability to support lower fly heights
    - Better stiffness to reduce disk dynamics
    - Greater ability to withstand shock and damage

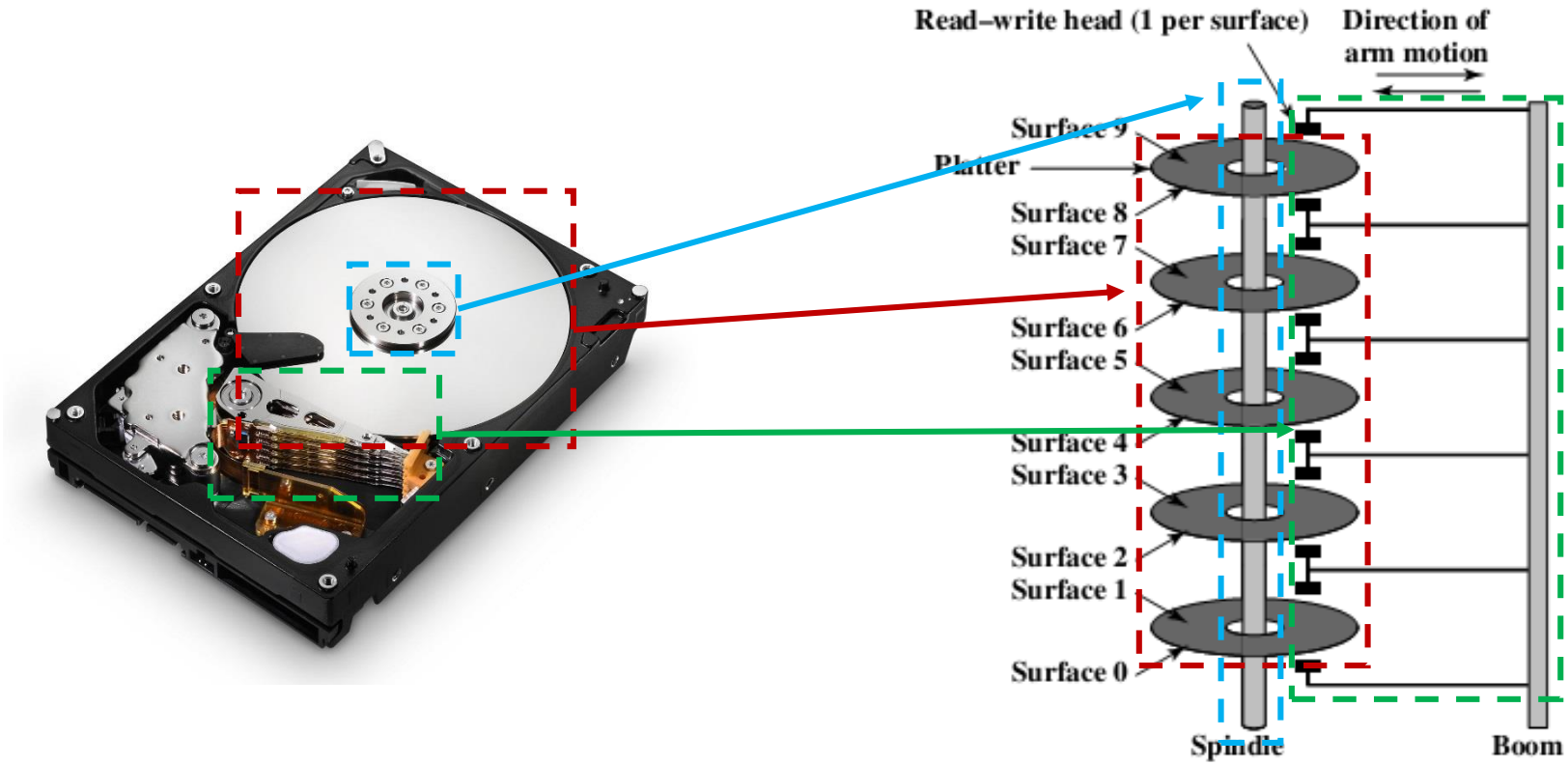
Magnetic Disk (cont.)

- Types

floppy disk

hard disk

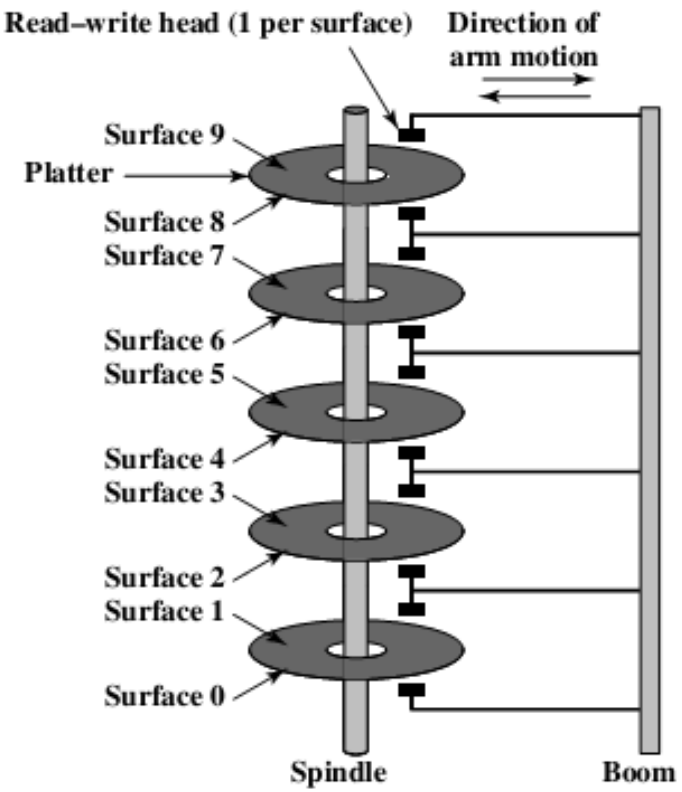
Magnetic Disk (cont.)



hard disk

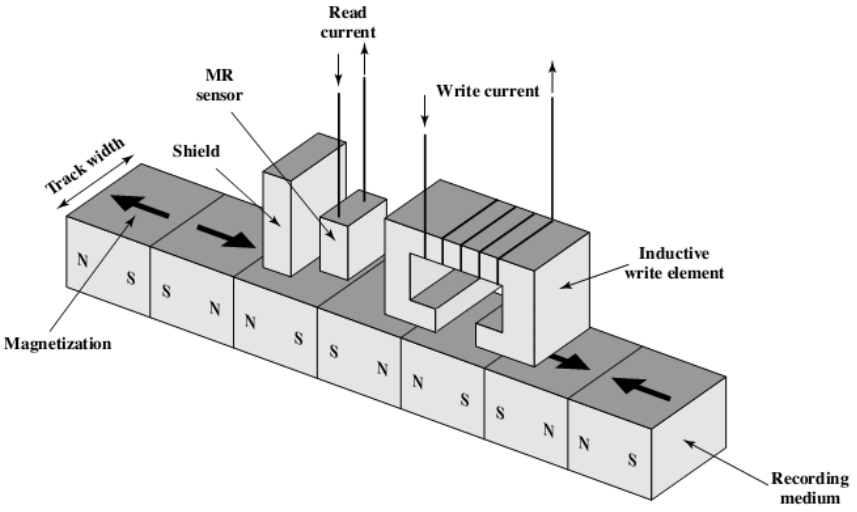
Magnetic Disk (cont.)

- Employ a movable head, with one read-write head per platter surface, in which all of the heads are mechanically fixed and moved together
- At any time, all of the heads are positioned over tracks that are of equal distance from the center of the disk



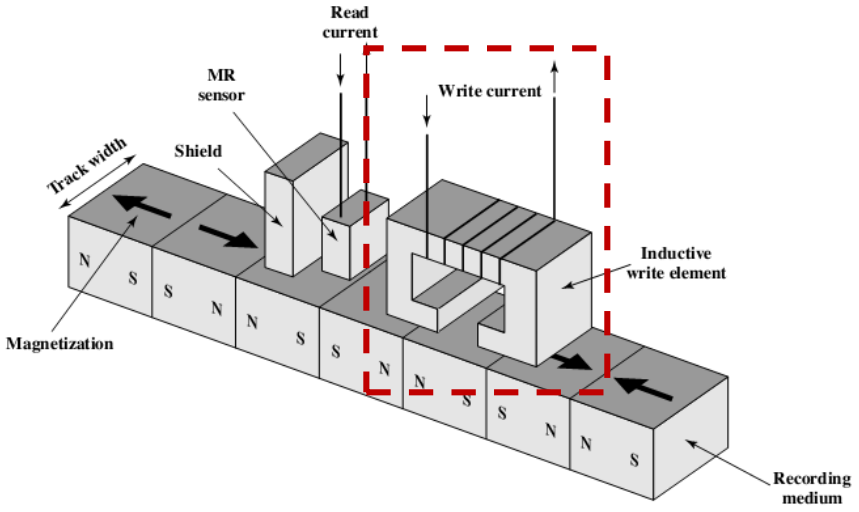
Magnetic Disk (cont.)

- Read and write mechanism
  - Read and write operation conduct coil named the **head**
  - During a read or write operation, the head is stationary while the platter rotates beneath it
  - Number of head
    - Single: read and write share one head (floppy disk, older rigid disk)
    - Two: use a separate read head (contemporary rigid disk)



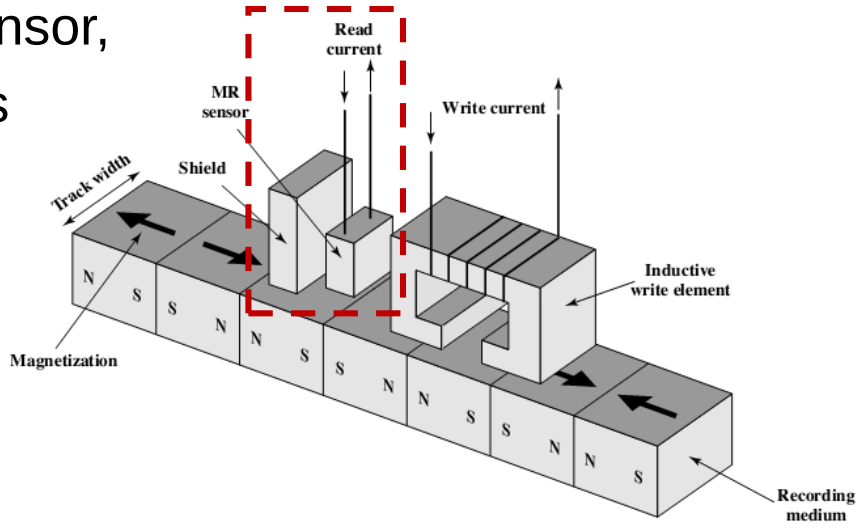
Magnetic Disk (cont.)

- Write mechanism
  - Electric pulses are sent to the write head
  - Electric current induces a magnetic field across the gap
  - The resulting magnetic patterns are recorded on the surface below
  - Reversing the direction of the current reverses the direction of the magnetization on the recording medium



Magnetic Disk (cont.)

- Read mechanism
  - The read head consists of a partially shielded magnetoresistive (MR) sensor, whose electrical resistance depends on the direction of the magnetization of the medium moving under it
  - Pass a current through MR sensor, and detect resistance changes by voltage signals
  - Higher-frequency operation leads to greater storage densities and operating speeds



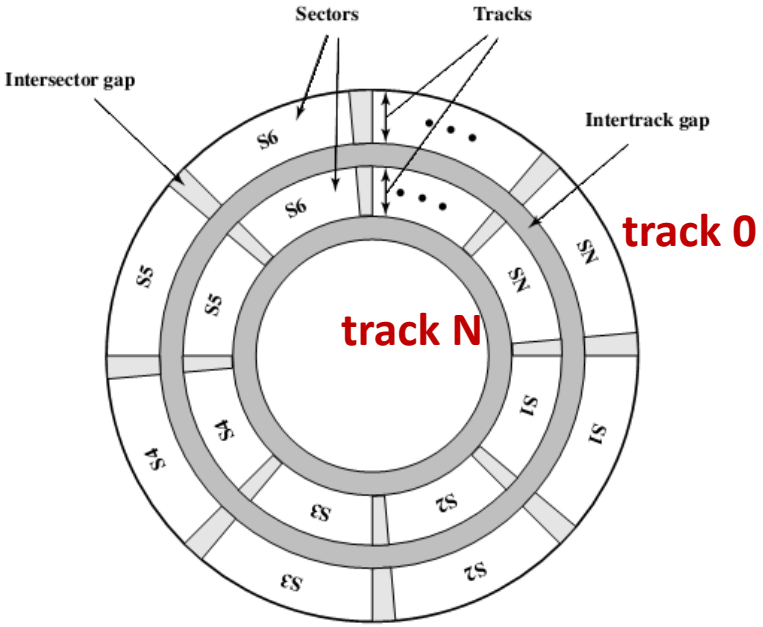
Magnetic Disk (cont.)

- Head mechanism
  - The head must generate or sense an electromagnetic field of sufficient magnitude to write and read properly
  - The narrower head requires the closer distance to the platter
  - Greater data density requires a narrower head and narrower tracks, which will lead to the greater risk of error
  - Winchester head
    - The head is actually an aerodynamic foil that rests lightly on the platter's surface when the disk is motionless
    - The air pressure generated by a spinning disk is enough to make the foil rise above the surface

[沈佳楠, 121250118]

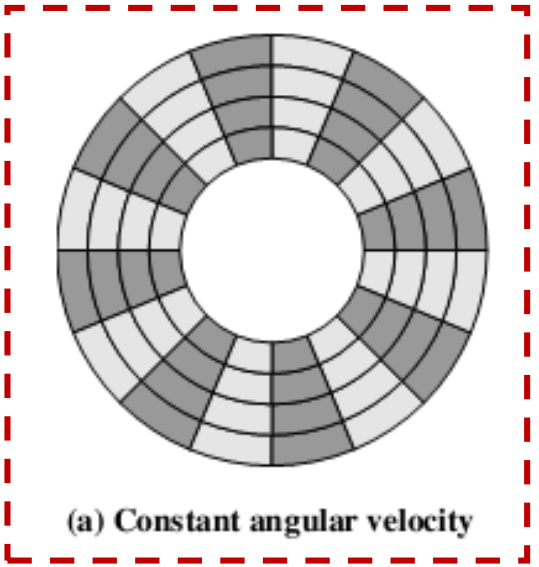
Magnetic Disk (cont.)

- Data organization
  - The organization of data on the platter in a concentric set of rings, called **track**s
  - Data are transferred to and from the disk in **sector**s
    - Usually 512B
  - Adjacent tracks are separated by **gap**s, and adjacent sectors are separated by intratrack (intersector) gaps

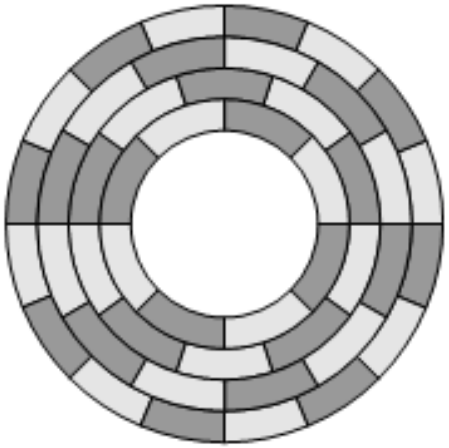


Magnetic Disk (cont.)

- Data organization (cont.)
  - Constant angular velocity (CAV)
    - Increase the space between bits to make the disk be scanned at a fixed speed
    - Advantage: individual blocks of data can be directly addressed by track and sector
    - Disadvantage: disk storage capacity is limited by the maximum recording density achieved on the innermost track



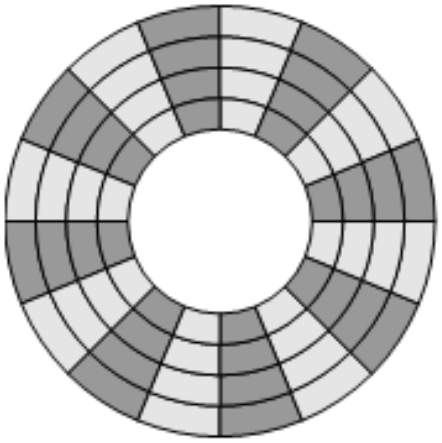
(a) Constant angular velocity



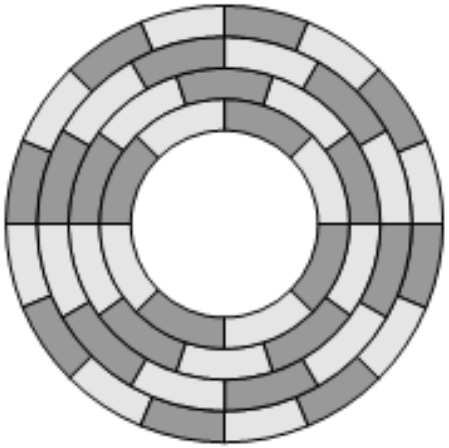
(b) Multiple zoned recording

Magnetic Disk (cont.)

- Data organization (cont.)
  - Multiple zone recording
    - Divide the surface into a number of concentric zones, the number of sectors per track is constant in each zone, and zones farther from the center contain more sectors than zones closer to the center
    - Advantage: increase storage capacity
    - Disadvantage: require more complex circuitry



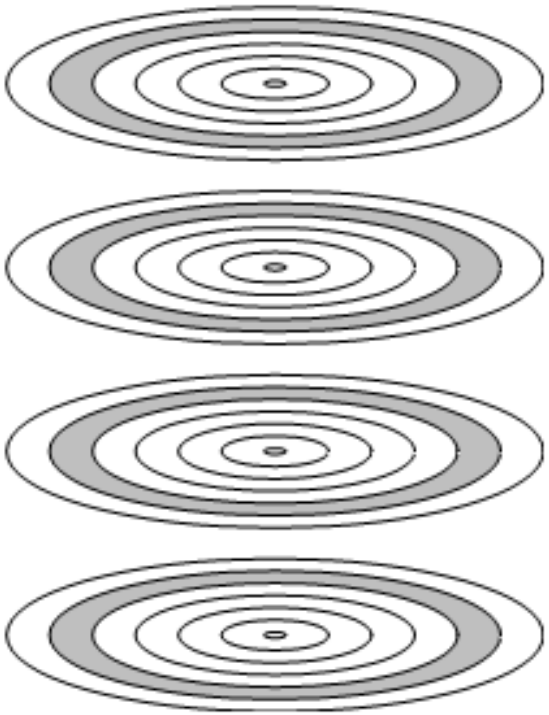
(a) Constant angular velocity



(b) Multiple zoned recording

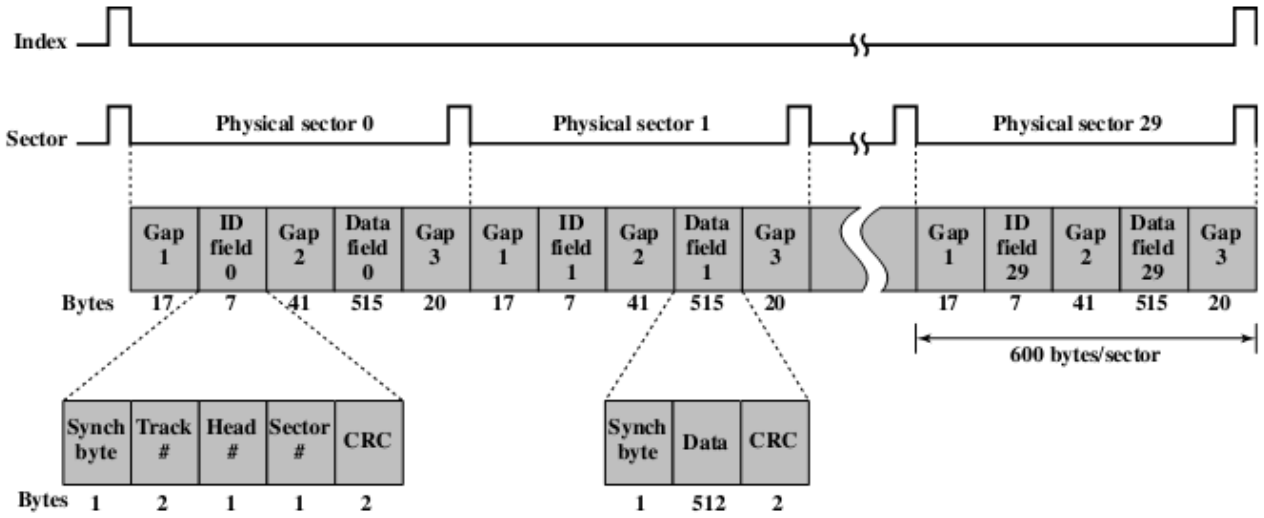
Magnetic Disk (cont.)

- The set of all the tracks in the same relative position on the platter is referred to as a **cylinder**



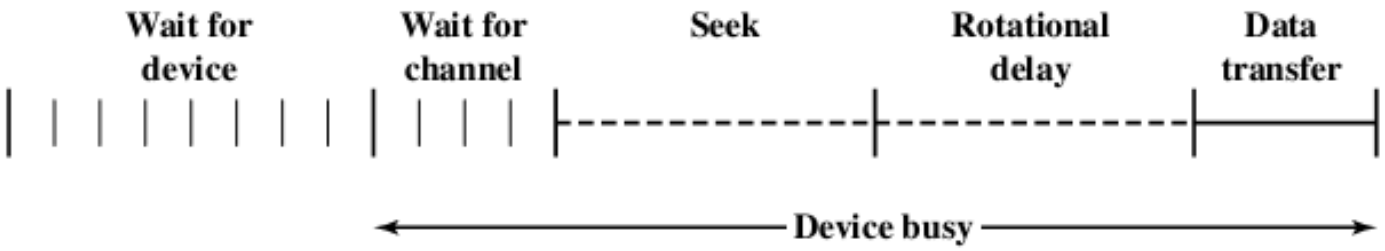
Magnetic Disk (cont.)

- Formatting
  - There must be some starting point on the track and a way of identifying the start and end of each sector
  - Format: add some extra data used only by the disk drive and not accessible to the user



Magnetic Disk (cont.)

- Timing of a disk transfer



  - **Seek time**: the time required to move the disk arm to the required track
    - Initial startup time
    - Time taken to traverse the tracks

Magnetic Disk (cont.)

- Timing of a disk transfer (cont.)
  - **Rotational delay / rotational latency**: The time it takes for the beginning of the sector to reach the head
    - Usually the time of passing half track
  - **Access time**: seek time + rotational delay
  - **Transfer time**: the time required for data transfer

$$T = \frac{b}{rN}$$

T = transfer time

b = number of bytes to be transferred

N = number of bytes on a track

r = rotation speed, in revolutions per second

Magnetic Disk (cont.)

- Timing of a disk transfer (cont.)
  - **Total average access time**

$$T_a = T_s + \frac{1}{2r} + \frac{b}{rN}$$

T_s is the average seek time

Magnetic Disk (cont.)

- Timing of a disk transfer (cont.)
  - Example
    - Consider a disk with an advertised average seek time of 4 ms, rotation speed of 15,000 rpm, and 512-byte sectors with 500 sectors per track.
    - Suppose that we wish to read a file consisting of 2500 sectors for a total of 1.28 Mbytes
    - Condition 1: sequential organization
      The file occupies all of the sectors on 5 adjacent tracks (5 tracks × 500 sectors/track 2500 sectors)
    - Condition 2: random access
      The sectors are distributed randomly over the disk

Magnetic Disk (cont.)

- Timing of a disk transfer (cont.)
  - Example (cont.)
    - Condition 1: sequential organization

Average seek	4 ms
Average rotational delay	2 ms
Read 500 sectors	4 ms
	10 ms

Suppose that the remaining tracks can now be read with no seek time, each successive track is read in 2 + 4 = 6 ms

Total time = 10+ (4 * 6) = 34 ms = 0.034 seconds

Magnetic Disk (cont.)

- Timing of a disk transfer (cont.)
  - Example (cont.)
    - Condition 2: random access

Average seek	4 ms
Average rotational delay	2 ms
Read 1 sector	0.008 ms
	6.008 ms

Total time = 2500* 6.008 = 15020 ms = 15.02 s

Magnetic Disk (cont.)

- Head scan algorithm
  - First come first service (FCFS)
    - Process I/O in sequence
  - Shortest seek time first (SSTF)
    - Move the head to the nearest track required by an I/O
  - SCAN
    - Move the head between track 0 and track N
  - C-SCAN
    - Move the head from track N to track 0
  - LOOK
    - Like SCAN but track 0 and track N are not required

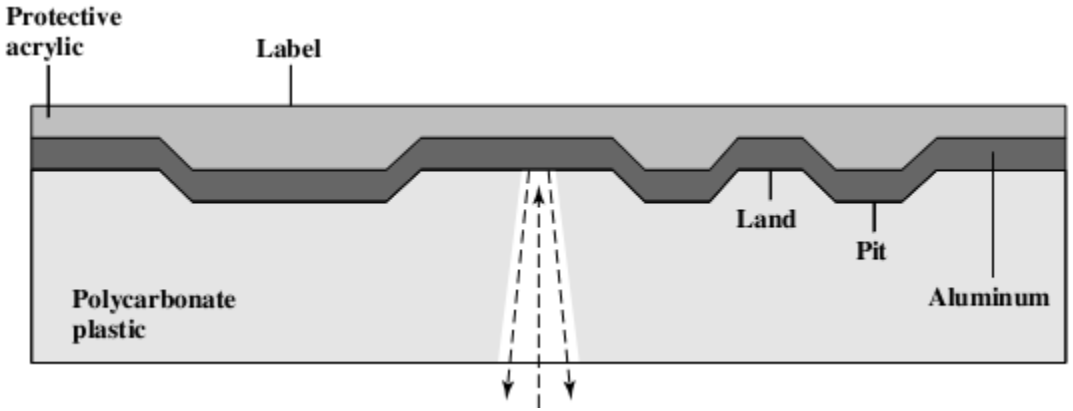
Optical Disk

- Optical disk products
  - CD: Compact Disk
  - CD-ROM: Compact Disk Read-Only Memory
  - CD-R: CD Recordable
  - CD-RW: CD Rewritable
  - DVD: Digital Versatile Disk
  - DVD-R: DVD Recordable
  - DVD-RW: DVD Rewritable
  - Blu-Ray DVD: High definition video disk

Optical Disk (cont.)

CD and CD-ROM

- Production
  - Create a master disk with a finely focused, high-intensity laser
  - Make a die to stamp out copies onto polycarbonate by using the master
  - Coat the pitted surface with a highly reflective surface
  - Protect the shiny surface by a top coat of clear acrylic
  - A label can be silkscreened onto the acrylic



CD and CD-ROM (cont.)

- Read
  - retrieved from a CD or CD-ROM by a low-powered laser housed in an optical-disk player, or drive unit
    - If the laser beam falls on a **pit**, which has a somewhat rough surface, the light scatters and a **low intensity** is reflected back
    - If the laser beam falls on a **land**, which is a smooth surface, a **higher intensity** is reflected back
  - The disk contains a single spiral track, and all sectors are the same length
    - Rotating the disk at a variable speed
    - The pits are then read by the laser at a constant linear velocity

CD and CD-ROM (cont.)

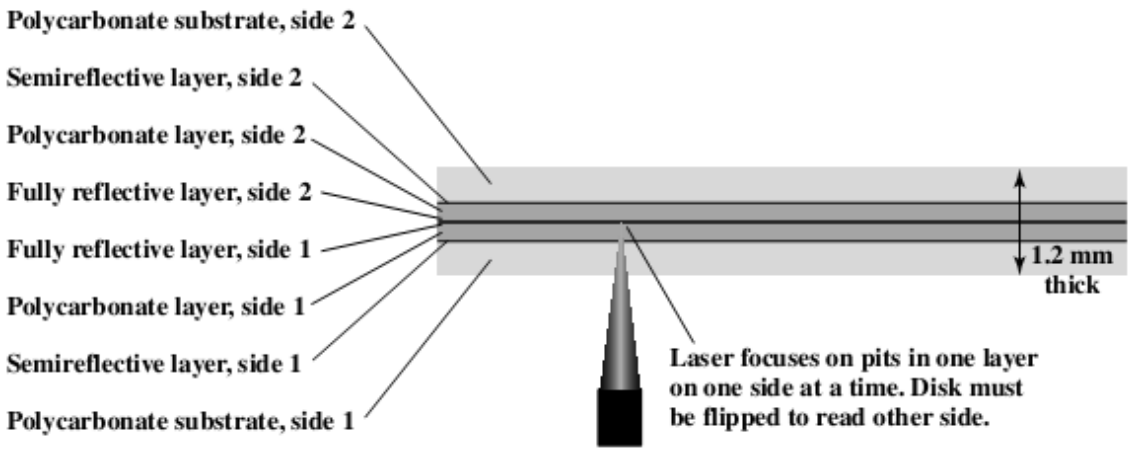
- Difference of CD and CD-ROM
  - CD-ROM players are more rugged and have error correction devices to ensure that data are properly transferred
- Advantage
  - The optical disk together with the information stored on it can be mass replicated inexpensively
  - The optical disk is removable
- Disadvantage
  - It is read-only and cannot be updated
  - It has an access time much longer than that of a magnetic disk drive

CD-R and CD-RW

- CD-R
  - Include a dye layer, which is used to change reflectivity and is activated by a high-intensity laser
  - The resulting disk can be read on a CD-R or CD-ROM drive
- CD-RW
  - Uses a material that has two different reflectivities in two different phase states, which can be changed by laser light
  - The material eventually and permanently loses its desirable properties, usually between 500,000 and 1,000,000 erase cycles

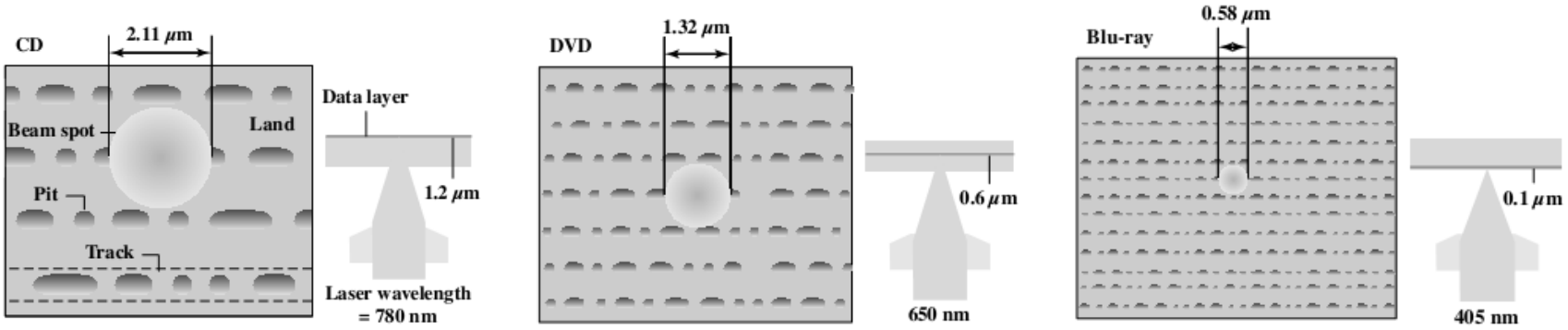
Digital Versatile Disk

- Compared to CD
  - Bits are packed more closely on a DVD
  - The DVD employs a second layer of pits and lands on top of the first layer
  - The DVD-ROM can be two sided, whereas data are recorded on only one side of a CD



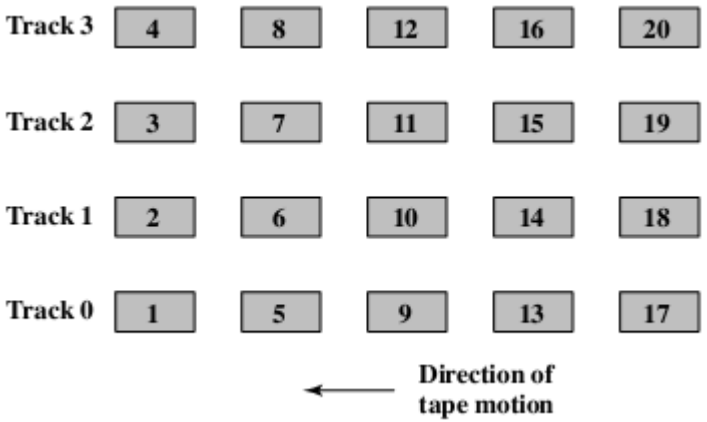
High-Definition Optical Disk

- Provide higher bit density by using a laser with a shorter wavelength, in the blue-violet range
- The data pits are smaller



Magnetic Tape

- Use the same reading and recording techniques as magnetic disk
- The medium is flexible polyester tape coated with magnetizable material
- Parallel recording vs. serial recording (serpentine recording)



Magnetic Tape (cont.)

Summary

- Magnetic disk
  - Data organization, formatting, read and write mechanism, timing of a disk transfer, head scan algorithm
- Optical memory
  - CD, CD-ROM, CD-R, CD-RW, DVD, DVD-R, DVD-RW, blue ray
- Magnetic tape

Thank You

rentw@nju.edu.en

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