Secondary Storage

Secondary storage refers to storage of data on a device external to the CPU and main memory (RAM).

Secondary storage devices are pieces of hardware used for secondary storage.

Secondary storage medium is the physical "thing" used by the secondary storage device for storage.

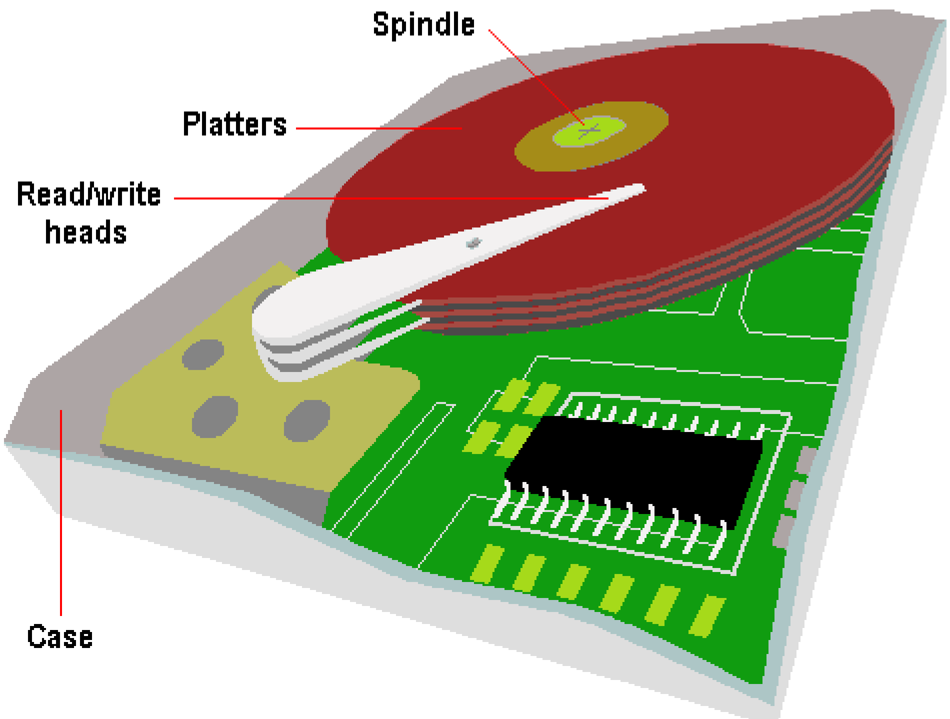
Storage Medium	***Folk & Zoellick***
• Disks	§ 3.1, 3.3
• Tape	§ 3.2, 3.3
• CD-ROM	§ A.1 - A.4
• CD-R and CD-RW	N/A
• DVD	N/A
• Magneto-optical Discs	N/A

Other refs:

- PC Magazine
- The PC Technology Guide (`http://www.dircon.co.uk/pctechguide/`)

Disks: The Physical Level

Nowadays, when we say "disk" (with a 'k') we mean (almost universally) "hard disk".



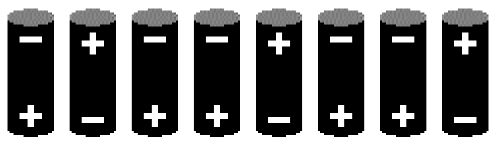
Physically, a "disk" is made up of several individual disks:

- some small number of stacked platters mounted on a spindle
  - platters are aluminum or glass/ceramic, covered with a magnetic coating
- read/write heads move around between each pair of platters
- the platters spin together at several thousand RPMs (as high as 10,000)
- heads fly on cushion of air around the platters created by the spinning
- the case is usually sealed to prevent contamination

Disks: Organization of Data

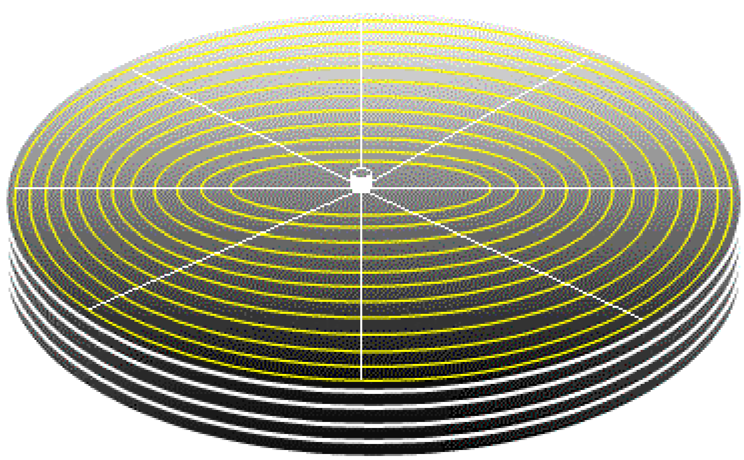
- bits are represented by the orientation (magnetic polarization) of the magnetic particles on the surface of the platters

0 1 0 0 1 0 0 1



  - "reading" detects the polarization, "writing" sets the polarization

- platters consist of concentric rings on each side called *tracks*
- tracks are divided into pieces of pie called *sectors*
- sectors are made up of several bytes



- ***formatting:*** marking a magnetic pattern that specifies the locations of tracks and sectors

Q: Aren’t the sectors wider at the outer edge of the disk?

A:

Disks: Access

Accessing a particular chunk of data on a disk (on a particular surface of a platter on a particular track in a particular sector) consists of several actions:

Action	***Stat***
1. move the read/write arm to the correct track	*seek time*
2. wait for the correct sector to spin under the read/write head	*rotational delay* (aka *latency*)
3. read in/write out the sector containing the desired byte(s)	*transfer time*

Knowing how fast the disk is spinning (RPMs), and the number of bytes on one track...

Q: How would you calculate the average *latency*?

A:

Q: How would you calculate the *transfer time* of N bytes (for N < the number of bytes/track)?

A:

Disks: Improving Access

The bottleneck in the whole process is moving the read/write arm to the correct track.

Solution Move the arm as little as possible.

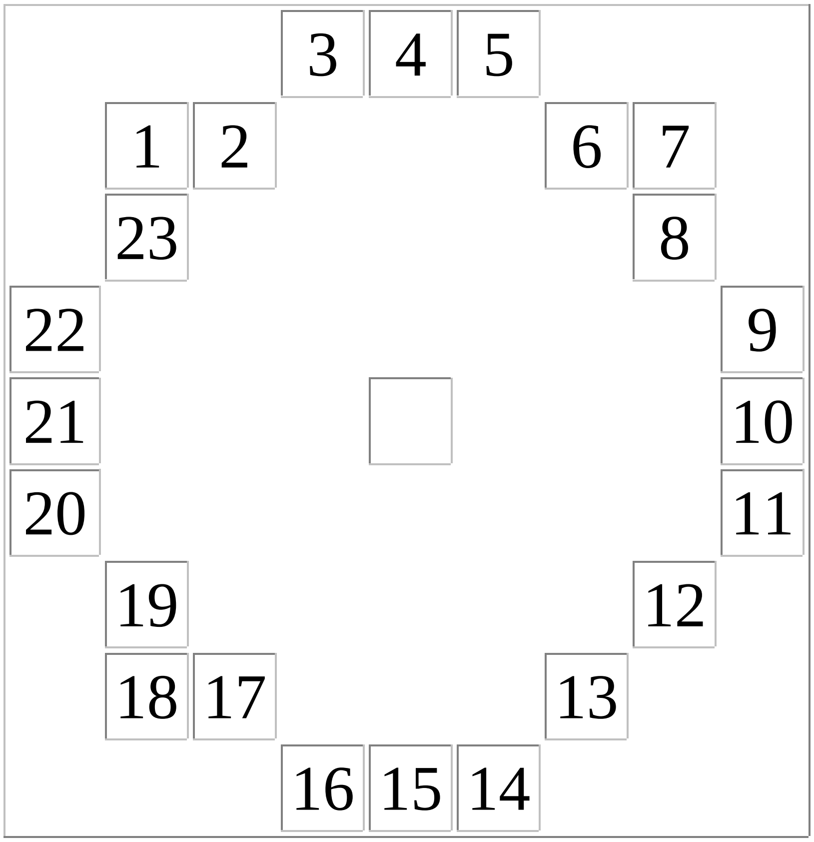
How? Read/write as much as possible before moving to the next track.

For example, when the track being written to becomes full, start writing to the *same track* on the *next platter*.

It makes sense to consider the same track on all platters as one abstract unit: a *cylinder*.

Disks: A Closer Look at Sectors

Have a look at the sector arrangement on the following (admittedly misshapen) disk with 23 sectors:



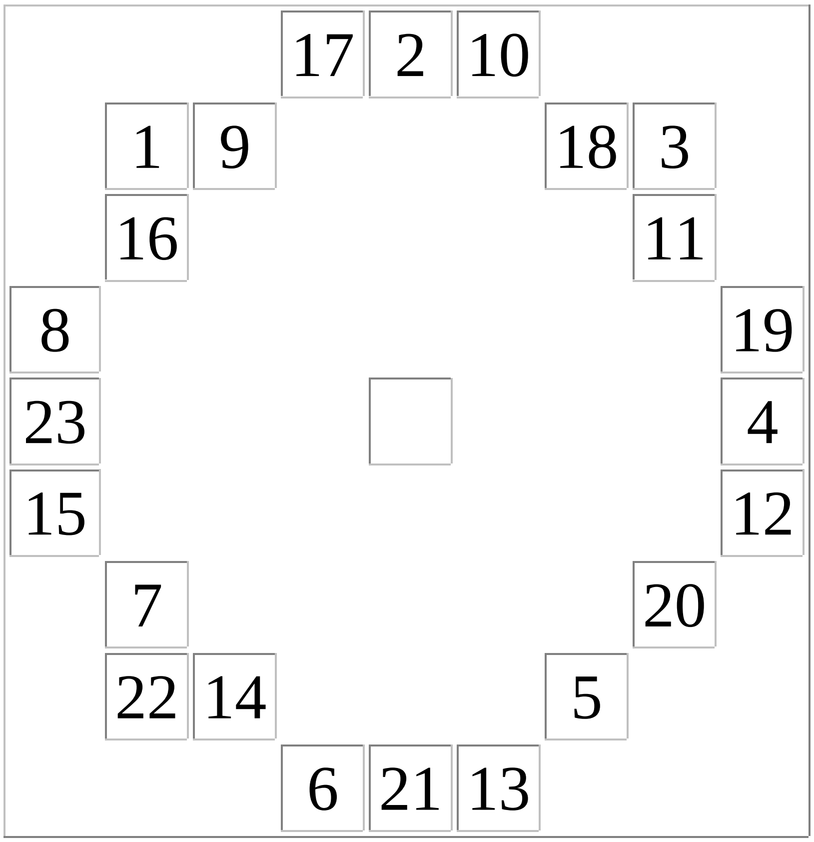
If a file were stored contiguously (as files often are), you'd have to read sector 1 into memory, then sector 2, etc. Unfortunately, in between reading sectors, it takes some time to get ready to read the next sector. Since the disk keeps spinning, by the time the system is ready to read the next sector, it's just passed.

This is known as the *Transferring at Baseline Station* problem.

:^7

Disks: Interleaving

Solution to the *TBS* problem: don’t place consecutive sectors contiguously (side-by-each like a pair of toasts)!



Interspersing sectors in this way is called *interleaving* (specifically, this example is 3:1 interleaving).

N.B. Most disk controllers are fast enough nowadays that disks are no longer interleaved.

Disks: Clusters, Extents, Fragmentation

Software (in particular the *operating system*) sees the disk somewhat more abstractly:

Cluster

- A group of some fixed number of contiguous sectors.
- Usually the smallest chunk of disk accessed by the OS.
- A file consists of one or more clusters.

Extent

- A group of contiguous clusters that make up part of a file.
- A file consists of one or more extents.

If a file consists of one extent, all its data is physically together on disk.

If a file consists of more than one extent, its data is scattered in different places on the disk, kept track of by the OS in the *File Allocation Table* (FAT for short).

A file consisting of more than one extent is *fragmented*.

Tape

Magnetic tape, once used for active data and even programs (!), is now almost exclusively for backups (except in huge processing houses with huge computers).

The Good News:

- high capacity (still the only medium that can backup a whole multi-gig hard drive without swapping media in and out)
- super cheap

The Bad News:

- sequential access (pretty much useless for most applications other than backing up)
- low access rate (due to physical constraints and sequential access)

The Inside Scoop:

- `http://www.dircon.co.uk/pctechguide/15tape.htm`

Tape: Common Formats

Tape backup systems for the most common machines come in several flavours:

Format	***Max Storage***	***Transfer Rate***
QIC (Quarter-Inch-tape Cartridge): *looks like an audio cassette tape*	4GB	1MBps
DAT (Digital Audio Tape): *4mm tape cartridge*	24GB	~2MBps
8mm: *like camcorder tapes*	50GB	6MBps

CD-ROM

CD-ROM (Compact Disc-Read Only Memory) is a storage medium based on technology designed for digital audio (CD-DA: or Compact Disc-Digital Audio).

A CD-ROM:

- uses a 4.75-inch plastic disc
- data is encoded (and read) optically with a laser
- can store about 650MB

Compact Discs are used for many things (other than just audio or even computer storage). For each use there is a set of format specification books named for the colour of their covers.

Red Book	physical properties of CDs; CD-audio specs
Yellow Book	computer data storage
Orange Book	CD-I, CD-R, CD-RW
White Book	video CDs
Blue Book	enhanced CD-audio specs

CD-ROM: The Juicy Details

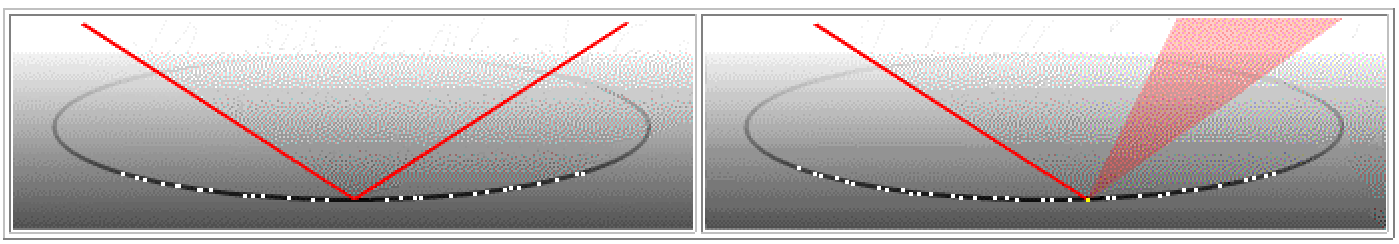
The disc is a sandwich of plastic coated with aluminum coated with laquer.

Data (computer data, audio, video, whatever) is represented as series of *pits* and *lands* in the aluminum layer of the sandwich.

Pit: a little gouge (0.5 µmeters wide).

Land: the flat part between pits.

Reading a CD consists of shining a laser at the disc and detecting changing reflection patterns:



- `1` = change in reflection due to a transition from land to pit to land
- `0` = a "fixed" amount of time between `1`'s

Q: So how can you have two `1`'s in a row?

A:

CLV and CAV

CLV

- Constant Linear Velocity
- the speed at which the single spiral track travels under the read head is constant

Q: If the disk is round and spinning, how can the speed of the spiral track stay constant from the inner part of the disc to the outer edge?

A:

CAV

- Constant Angular Velocity
- the speed at which the disc is spinning is constant

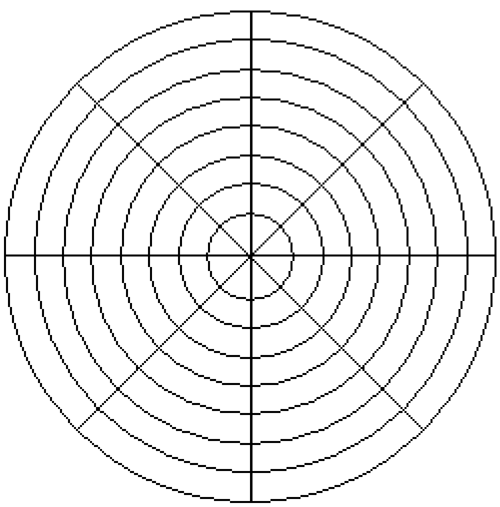
Trick Q: If disc rotation speed is constant, what happens as the spiral track winds its way toward the outer edge of the disc?

A:

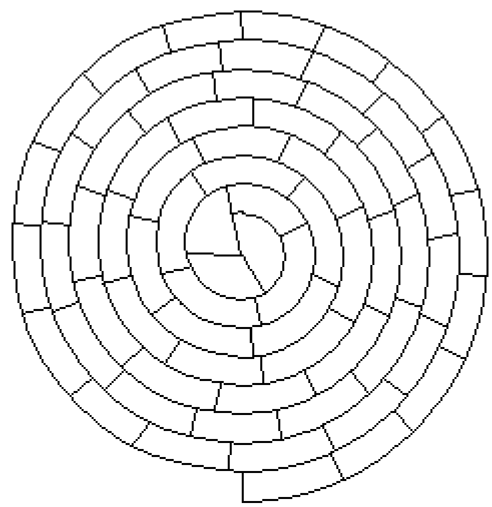
That’s Not What They Say in the Book

Appendix A of Folk & Zoellick implies that transfer rate must be constant. That means that Constant Angular Velocity requires density to decrease (physical size of sectors increase) toward the outer edge.

Although that is how hard disks are laid out, CDs maintain fixed density (and sector size), meaning that transfer rate increases toward the outer edge with CAV.



hard disk layout:
concentric track rings, variable sector size, variable density, fixed transfer rate, CAV



CD layout:
single spiral track, fixed sector size, fixed density, variable transfer rate, CLV <u>or</u> CAV

CLV vs. CAV

Orginally CD-ROM drives were all CLV to maintain constant transfer rate required by CD-audio.

- drives must slow down toward the outer edge of the disc
- spindle motor is constantly changing speed, causing spindle motor stress

Most drives now use CAV (or a combination of CAV and CLV)

- higher transfer rates are possible
- some drives use CAV on inner sectors and switch to CLV toward the edge
    - if the edge is spinning too fast, reliable reading is not possible
    - may reach maximum transfer rate (imposed by other parts of the system
- CAV drives must still be able to operate in single-speed CLV mode for audio CDs

CD-R

CD-R

- Compact Disc-Recordable
- no pits!
- disc is a sandwich of:
    - plastic coated with...
    - cyan-coloured, temperature-sensitive dye coated with...
    - semi-translucent reflective layer of gold coated with...
    - laquer

How does it work?

- a high-powered "writing laser" heats a spot on the disc causing the dye layer of the sandwich to change colour (changing its reflective properties to mimic a pit)
- once a spot has changed colour, it can’t be changed back

Where does it work?

- in a CD-R drive (obviously!)
- a CD-R disc can usually be read in a standard CD-ROM drive, and sometimes in a DVD drive.

CD-RW

CD-RW

- Compact Disc-ReWritable
- sometimes called CD-E (CD-Erasable)
- discs are backward compatible with CD-ROM
- forward compatible with DVD-ROM drives
- disc is (mostly) a sandwich of:
  - plastic coated with...
  - crystalline material coated with...
  - semi-translucent reflective material coated with...
  - laquer

CD-RW (cont.)

How does it work?

- a high-powered laser heats a spot on the crystalline layer to its melting point (500-700°C)
- when the crystalline material melts, it loses its crystalline structure (becomes *amorphous*)
- the crystalline layer is cooled quickly and the amorphous spot hardens, but stays amorphous
- amorphous spots are less reflective than crystalline areas
  - amorphous spot = pit
  - crystalline area = land

But here's the real trick

- a medium-powered laser can heat amorphous spots to crystallization temperature (200°C)
- the spot doesn't melt, but it crystallizes again!

DVD

DVD

- first it meant "Digital Video Disc", then it meant "Digital Versatile Disc", now it means ?

DVD-ROM

- DVD-Read-Only-Memory
- DVD-ROM drives are backward compatible with CD-ROM, CD-R, CD-RW
- the DVD is very much like a CD:
    - a single spiral track but narrower than CD-ROM’s track
    - smaller pits
    - allows capacity of 4.75GB

But Wait, That's Not All!

- smaller track and pits allow two sides on a disc no thicker than a CD-ROM
- size reduction also allows two layers on each side
  - layer of silver coated with...
  - semi-translucent layer of gold
  - use laser at weaker power to read the gold reflective layer
  - increase laser power to read the silver layer below
- 2 sides × 2 layers/side = 4 × 4.75GB = 17GB!

Q: Cool. So why hasn't DVD taken over the (CD) world?

A:

DVD-R, DVD-RAM, +RW

DVD-R

- DVD-Recordable
- uses organic dye that changes colour (like CD-R)

DVD-RAM

- DVD-Random Access Memory
- rewritable DVD approved by the *DVD Forum*
- uses phase-change technology (like CD-RW)
- records in grooves and ridges between grooves of a pre-grooved DVD
- 2.6GB/side

+RW

- formerly DVD+RW (DVD+ReWritable) but the DVD Forum made HP, Phillips and Sony change the name
- +RW drives may be able to write CD-R compatible discs
- records in the grooves only, but at much higher density than DVD-RAM
- claimed to be more compatible and more practical than DVD-RAM
- 3.0GB/side

Magneto-Optical

Magneto-optical technology, born in the 1980’s, combines the magnetic technology of disks with the optical technology of lasers.

- a 3½" cartridge stores up to 640MB
- a 5¼" cartridge stores up to 2.6GB, 4.6GB, (5.2GB this year?)

How does it work?

- like magnetic media, bits are stored by changing the polarity of magnetic particles on the surface of a disc coated with magnetic material
- the difference: on a MO disc, the polarization of its special magnetic material can't be changed at room temperature
- a tightly-focused laser heats a tiny spot of magnetic particles to 300°C (the *Curie point*)
- magnetic particles heated to the Curie point can be repolarized with a magnetic write head

Magneto-Optical (cont.)

So you read it with a magnetic read head, right?

- wrong!
- lasers can read at higher resolution than magnetic heads, allowing tighter packing of data
- luckily, when you bounce a laser off magnetic particles, their polarity causes the reflection of the laser to be rotated!

Q: If data is packed too tightly to read with a magnetic head, how can the data be written with a magnetic head?

A: