Introduction to File Systems

COMP 321

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File Properties

Stores information (a "container")

- Fixed-length or variable-length records
- "Objects" (e.g., a database)
- The type and organization of the data may be
  - Enforced by OS/file system, or
  - Implemented in a library, or
  - Up to the user
- A file is generally stored on disk
  - Traditional rotating magnetic disk or solid state drive (SSD)

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File Properties

Has a lifetime

- Permanent (until explicitly deleted), or
- Temporary (until automatically deleted when no longer in use, or after some period such as nightly)

Usually has a name

- Naming and directories will be covered later

Has permissions/owner

- Protection, also covered later

Types of File Access Patterns

Sequential access

- System remembers an open file's current position (offset) within the file
- Read or write by *N* bytes advances file's current position by *N* bytes
- "Rewind" operation sets file's current position to the beginning of file

Random (or direct) access

- Every individual read or write can specify the file position to use
- Or can explicitly set (e,g., "`lseek()`") to a new position in the file anytime
  - Relative to the beginning of the file
  - Relative to the open file's current position in the file
  - Relative to the end of the file

Hard Disks, Big(ger) and Small(er)

5.25” “full-height” vs. a more modern 2.5” hard disk

Photo: Wikimedia Commons and Ian Wilson

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Really Old Hard Disks

14” disk drives with removable disk packs (sort of like a floppy disk, but way before that time)

The fixed electronics was the most expensive part

Photo: Wikimedia Commons and Deutsche Fotothek

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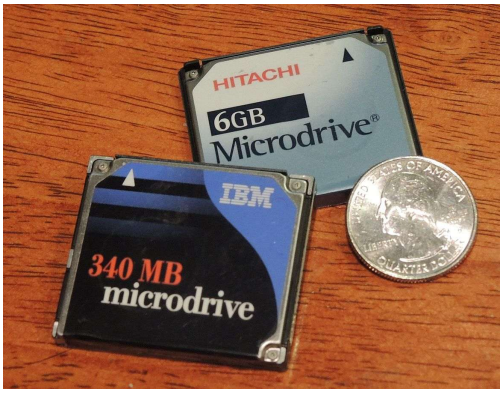
Hard Disk Internals

A modern 3.5” drive

… but they’re all basically the same inside

Photo: Amazon.com and Western Digital (WD Blue WD20EZRZ 2 TB 3.5” SATA Hard Drive)

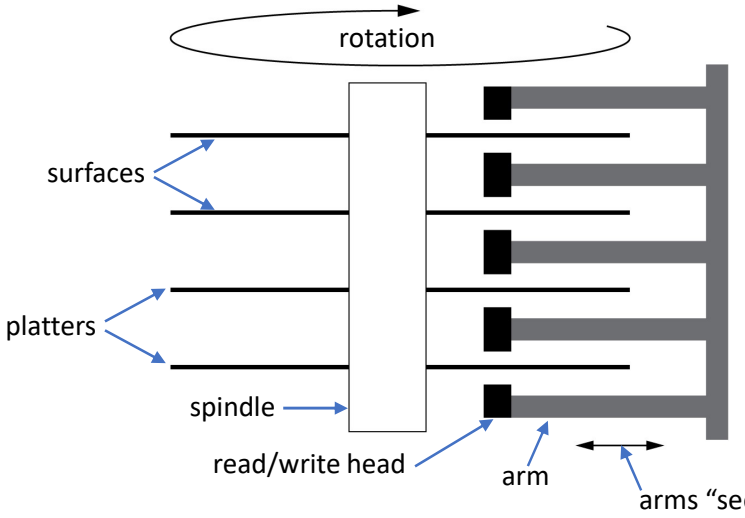
The Same Basic Thing in Many Sizes



Photos: Wikimedia Commons

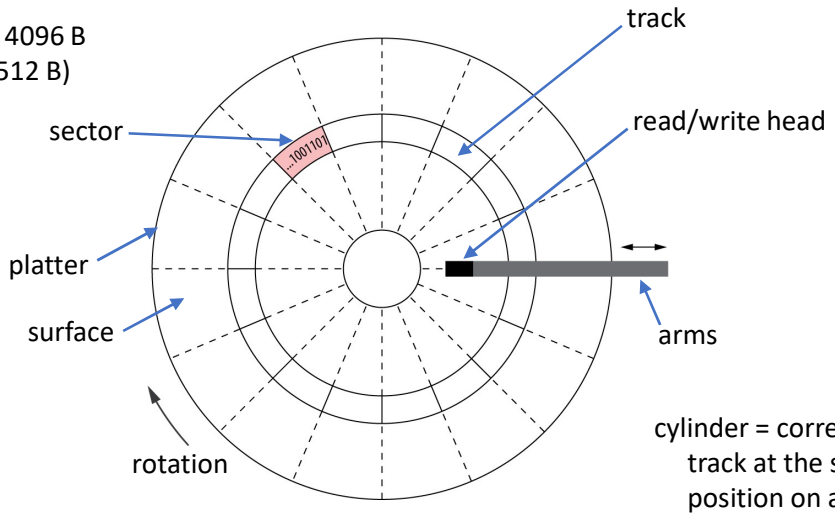
IBM and Hitachi “Microdrive” — 1 inch in diameter, but still the same inside

Hard Disk (Side View)



Hard Disk (Top View)

sector size = 4096 B
(older disks 512 B)



cylinder = corresponding track at the same seek position on all surfaces

Reading or Writing the Disk

Hardware can read or write only in granularity of whole sectors

Steps in reading or writing the disk

- Disk just keeps spinning in same direction at the same speed continuously
  - (Except it can be stopped spinning to save power, but it's very slow to stop and restart spinning and become stable again)
- The disk must seek to the correct cylinder (move set of arms in or out)
- Start paying attention to correct head and thus correct surface (zero time)
- Wait for the beginning of the sector to rotate up to the head
- Transfer the bits of the sector, one by one, off of/onto the surface

Performance of Reading or Writing the Disk

The disk must seek to the correct cylinder (move the set of arms in or out)

- Requires time for arms to start moving and to stop moving
- Requires time to heads based on distance (number of cylinders)

Wait for the beginning of the sector to rotate up to the head

- Depends only on the rotational speed (RPM) of the disk
- On ***average***, this takes ***one half*** of time for a single revolution

Transfer the bits of the sector, one by one, off of/onto the surface

- Also depends on the number of sectors per track (i.e., one full rotation time divided by the number of sectors per track)

Some Example Hard Disk Characteristics

	Old	Common	Fast
Average seek time	30 ms	9 ms	4 ms
Rotational speed	3600 RPM	5400 RPM	10,000 RPM
Full revolution time	16.66 ms	11.11 ms	6 ms
Average rotation delay	8.33 ms	5.55 ms	3 ms

Disk Request Scheduling (the Classical View)

Rotational latency can't really be controlled (disk just keeps spinning)

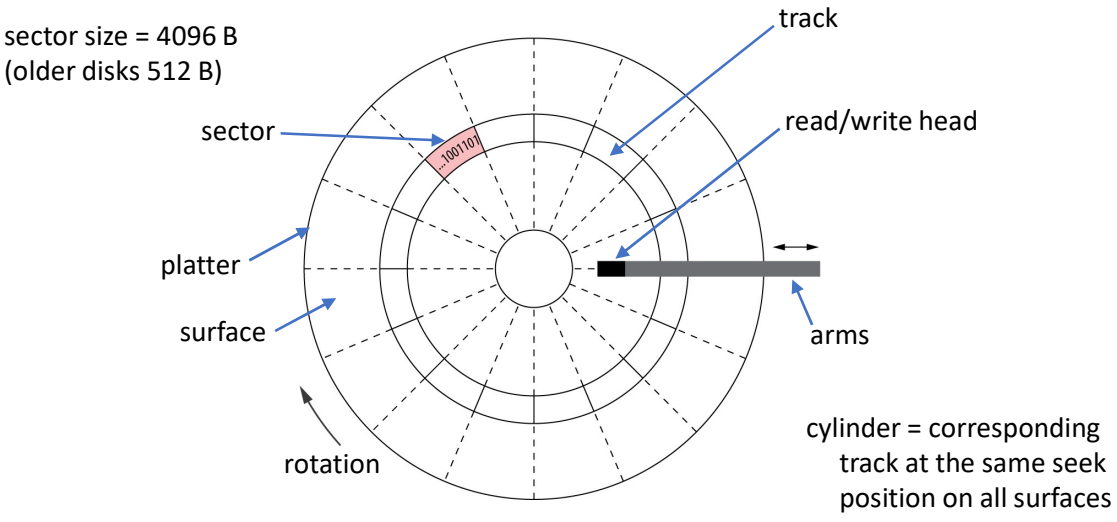
But ordering requests by seek position (cylinder) can be controlled

- Disk commands are in form of **c**ylinder #, **h**ead #, **s**ector # (CHS addressing)
- First-Come-First-Served (FCFS or FIFO) ordering
- Shortest-Seek-Time-First (SSTF) ordering
  - Fastest for this next request, but this can lead to disk request ***starvation***!
- SCAN and C-SCAN ordering (attempt to minimize total seek time)
  - Always goes out to last and in to first cylinder, regardless of requests
- LOOK and C-LOOK ordering (attempt to minimize total seek time)
  - Goes only to pending requests' outermost and innermost cylinders
- SCAN, C-SCAN, LOOK, C-LOOK each commonly called the ***elevator algorithm***

Problems with Classical Disk Request Scheduling

- Automatic bad sector forwarding
  - Disk drive internally reserves some sectors to use if a sector goes bad
  - Replacement sector could be in a different cylinder
- Variable number of sectors per track
  - Can fit more sectors in outer tracks since they have larger circumference

Hard Disk (Top View)



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- "Secret" disk ***geometry*** (# of cylinders, # of heads, # sectors/track)
  - A natural extension of variable number of sectors per track
  - Disk industry is very competitive (despite companies buying each other)
- Interface now uses "***logical block" addressing*** (LBA), not CHS addressing
  - But block numbers numerically near each other are generally still "near" each other physically (e.g., in the same or nearby cylinders)

Disk Request Scheduling (the Modern View)

OS still generally tries to do disk request scheduling (course grain)

- Orders pending queue of disk requests as usual (minimize total seek time)
- OS can give requests to disk drive without waiting for completion
- Disk drive internally can hold a limited-length queue of pending requests

Disk drive does the real scheduling internal to the disk drive (fine grain)

- Disk drive manufacturer knows real geometry and location of every sector (every "logical block")
- Drive can schedule on the internal queue of requests optimally
- Completes requests from the internal queue "out of order"

Solid State Drives (SSDs)

No moving parts (not mechanical, all electronic)

Two example 1 TB SSDs:

Photos: Amazon.com and Samsung (860 EVO 2.5" SATA interface and 970 EVO M.2 NVMe interface)

Solid State Drives (SSDs)

- Many attach to the computer with same interface as a "traditional" disk drive
- Based on "flash memory" non-volatile storage
- Very different performance characteristics than with traditional hard disks
- Internally, storage is still organized in sectors (usually there called "pages")
- Pages are grouped into "blocks" of, e.g., 32 to 128 pages
- Reading is easy, but writing requires the entire block to be erased first (slow)
- Blocks can only be erased a limited (but large) number of times
- Internal drive algorithms for block wear leveling, page remapping

Now common, but file systems still generally designed around traditional disks

Types of File Access Patterns

Sequential access to data within a file

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Random (or direct) access to data within a file

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On-Disk File System Data Structures

The file system certainly keeps some data in memory as it runs

But hard disks (and thus file systems) can be very, very large

- A hard disk can store orders of magnitude more data than physical memory
- And there can be many (many!) individual files on the disk
- Impossible in general to store everything in memory

And data structures are also needed on-disk so they are permanent

- Don't want to lose all data on a crash or power failure
- Also don't want to lose even some kinds of data (such as keeping the data of all files on disk but losing the ***names*** of the files on a crash or power failure)

Guidelines for On-Disk File System Data Structures

- On-disk file system data structures are "permanent" (good and bad)
  - With memory, crash and reboot gives you fresh new data structures
  - But data structures on disk are still there after a crash and reboot
- A tradeoff between simplicity and performance
  - Want good performance, but be careful not to mess things up
- Put "related" things "near" each other on disk
  - Classical disk scheduling no longer fully works, but it still helps
- ***Can't use memory pointers (memory addresses) on disk***
  - Pointers recorded on disk no longer mean the same thing when read back
  - Must link things together on disk some other way

File System "Blocks" vs. Hardware Disk Sectors

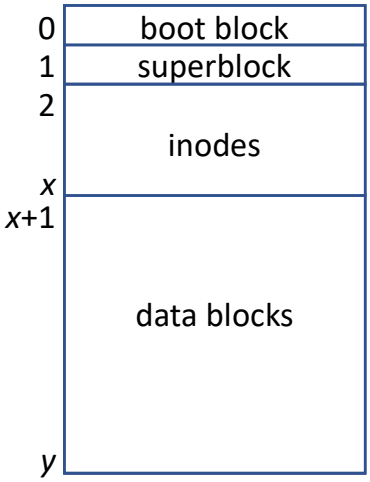
- Disk sectors are relatively small (512 bytes or 4096 bytes)
- File systems generally treat multiple sectors together as a file system "block"
- Power of 2 multiple, e.g., 2 consecutive sectors, 8 consecutive sectors, …
- ***Advantages***
  - Lowers bookkeeping overhead: keeping track of individual free blocks, keeping track of the blocks that belong to each file
  - Better performance, since keeps sectors of a file's data more "together"
  - Larger total file size possible for a given number of bits representing block numbers (e.g., 16-bit block number means only 65,535 ***blocks*** can be used)
- ***Disadvantage***
  - Slight increase in internal fragmentation within each file

Overall Types of On-Disk Data Structures

Two general types of on-disk file system data structures

- ***Per-file*** information
  - Information about what blocks store the data of that file
  - The file's owner and protection information
  - Information such as the creation time and last modified time
  - The name of the file?
- ***Global*** information
  - Total size of the file system (number of blocks)
  - Information necessary for finding per-file information for a given file
  - The list of free blocks

Simple Example: Classical Unix Format



File System Contents

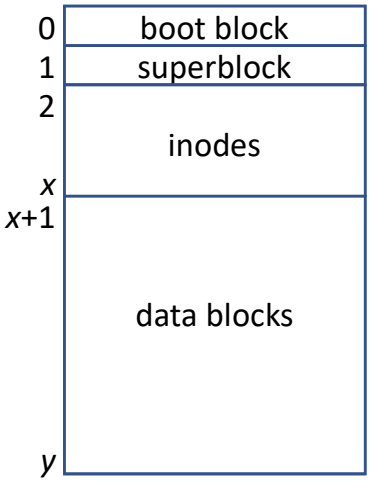
contains code to boot the computer

global information (or beginning of global information)

per-file information (short for "index node")

all other storage within the file system

Consequences of this Format

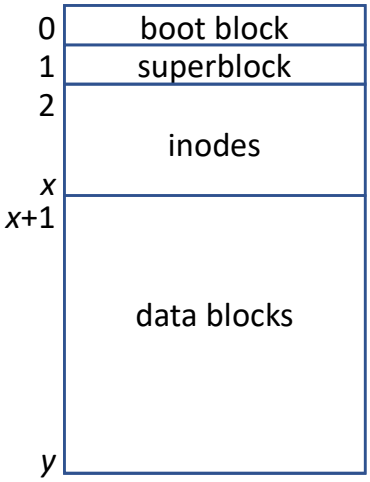


File System Contents

Advantages

- Can identify any block by its block number
- Block 0 is not really part of the file system, so 0 can be used in the file system as a special value (e.g., like NULL)
- Can identify any inode by its inode number
  - Example with 4096 blocksize, 256 inode size
  - Exactly 16 inodes per block of inodes
  - Easy to calculate where any inode is, given its inode number

Consequences of this Format



File System Contents

Disadvantages

- All inodes must be preallocated when the file system is "formatted"
  - Must decide in advance how many inodes
  - Wastes space if too many are preallocated
  - Or can't make a new file if not enough inodes are preallocated, even if free data blocks are available
- The inode for a file can be a long seek away from the data blocks of the file's contents
- ***These disadvantages can all be fixed, but don't worry about them now***