File system

Goal of the file system

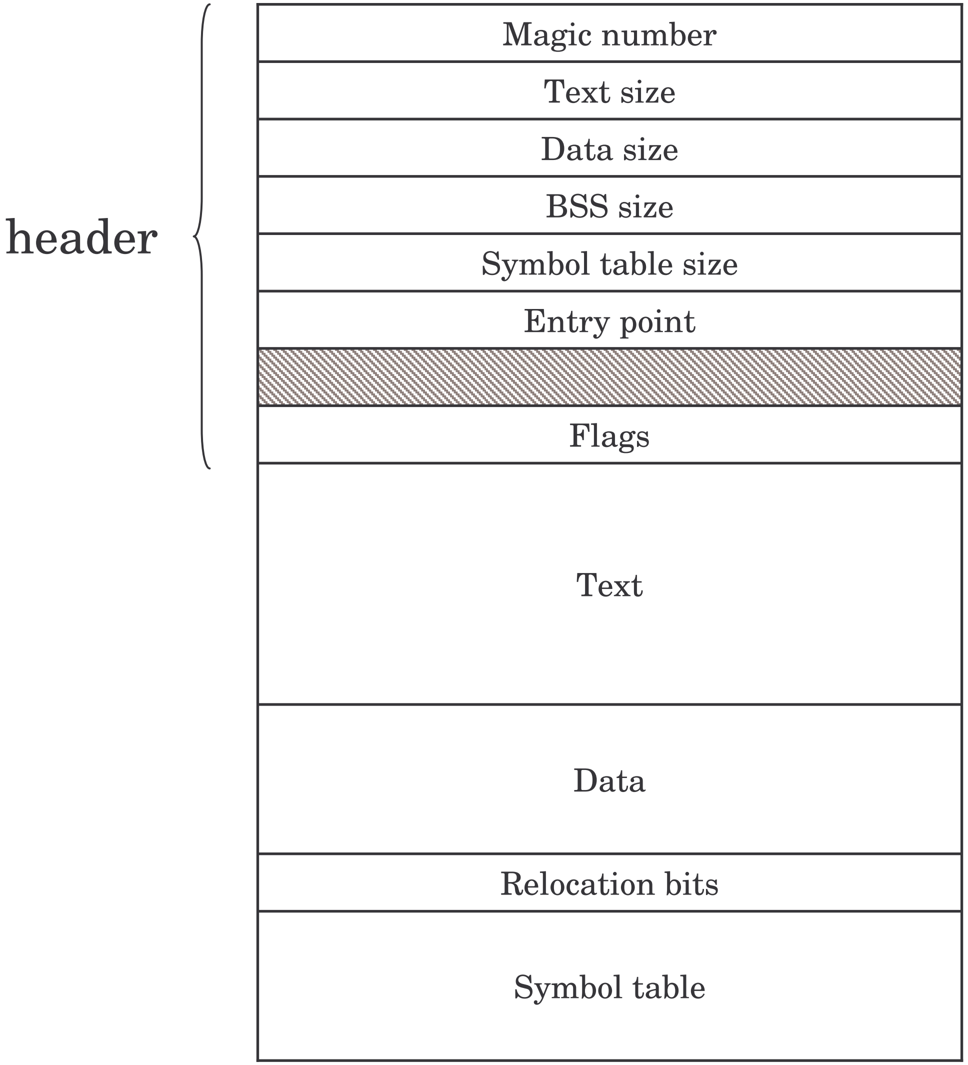
- Uniform naming
- Directories (containing files)
- File extension (e.g. .c, .h, .cpp) logically enforcing file using
  - Windows is aware of extension creating associations between applications and extensions
- File structure
  - Blocks:
    - 1 byte (sequence of bytes, not blocks for real)
    - Records (blocks for real)
    - Sometimes, tree-like organization of records

Types

- Regular files
  - Our data
- Directories
  - System files for maintaining group of files
- Character/block special files
- Pipes
  - Special files

- ASCII/binary differences

Example (Unix executable)



About files

- We've already seen this:
  - File access: random, sequential
    - Seek operation
  - Attributes:
    - Read/write permission
    - Owner
    - Time of creation, last access, etc.
    - Archive (for backups)
  - Operations:
    - Read, write, open, close, creation, deletion, get/set attributes, rename (w/out copy)

Memory mapped files

- Map a file into a part of the process address space that opens it
  - Convenient:
    - I/O becomes memory access
    - Paging becomes the read/write mechanism
  - Troubles:
    - How big is the file?
      - How to deal with a file w/ holes (should the OS map all addresses?)
    - Need a mechanism to ask for frequent "real" write to disk, otherwise the file is not written until a page is evicted
      - Imagine that your word processor crashes and the page hasn't been saved in the last couple of hours!

Directories

- Single level directory
  - Usually on embedded systems
- Two-level directory system
  - Old
- Hierarchical directory system
  - The usual thing everyone is familiar with
  - Multiple/single root (Windows/Unix)

Path names

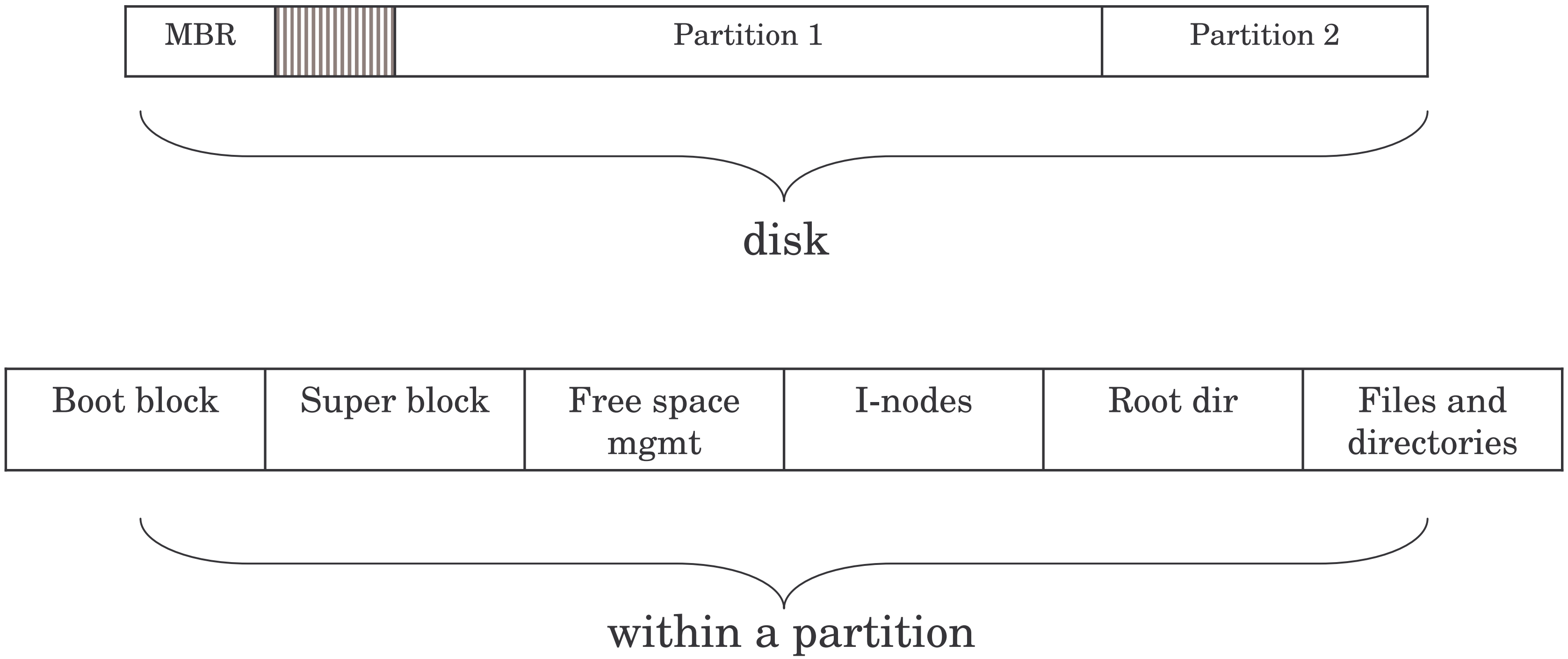
- Already seen:
  - Delimiters / or \ (win)
  - Current directory (relative path names)
- Directory operations
  - Create, delete, opendir/closedir, readdir, rename, link/unlink
    - "Link" as seen earlier
- Mount (Unix)
  - It exists a similar concept in Win2K server

Implementation

Layout

- Stored on disk, how the file system is organized
- Partitions
  - Disks are divided into partitions w/ independent file system in each
- MBR $\rightarrow$Sector 0, where the computer boots from
  - The end of the MBR contains the partition table
- One of the partition is marked as active
- When the computer is booted, the BIOS loads and execute the MBR. The program (MBR) locates the active partition, reads the first block (called *boot block*) and executes it. The program in the boot block is the OS loader, knows where the kernel image is and how to run it appropriately.

Idealized


MBR
Partition 1
Partition 2
disk
Boot block
Super block
Free space mgmt
I-nodes
Root dir
Files and directories
within a partition

Implementing files

- Approximately as tracking and allocating memory
  - Same spatial organization
  - Disk divided in blocks (similar to the concept of pages)
  - Blocks do not need to be the same size as physical sectors (they're the abstraction of the OS)
- As for memory
  - Internal fragmentation (as for memory)
  - External fragmentation (if we try to allocated blocks contiguously)

Contiguous allocation

- Fragmentation
  - Files and holes
- Read time excellent:
  - Single seek operation (beginning of file)
  - Then read contiguously
- Disk compaction is very slow
  - It can be done but it takes ages (in computer terms)

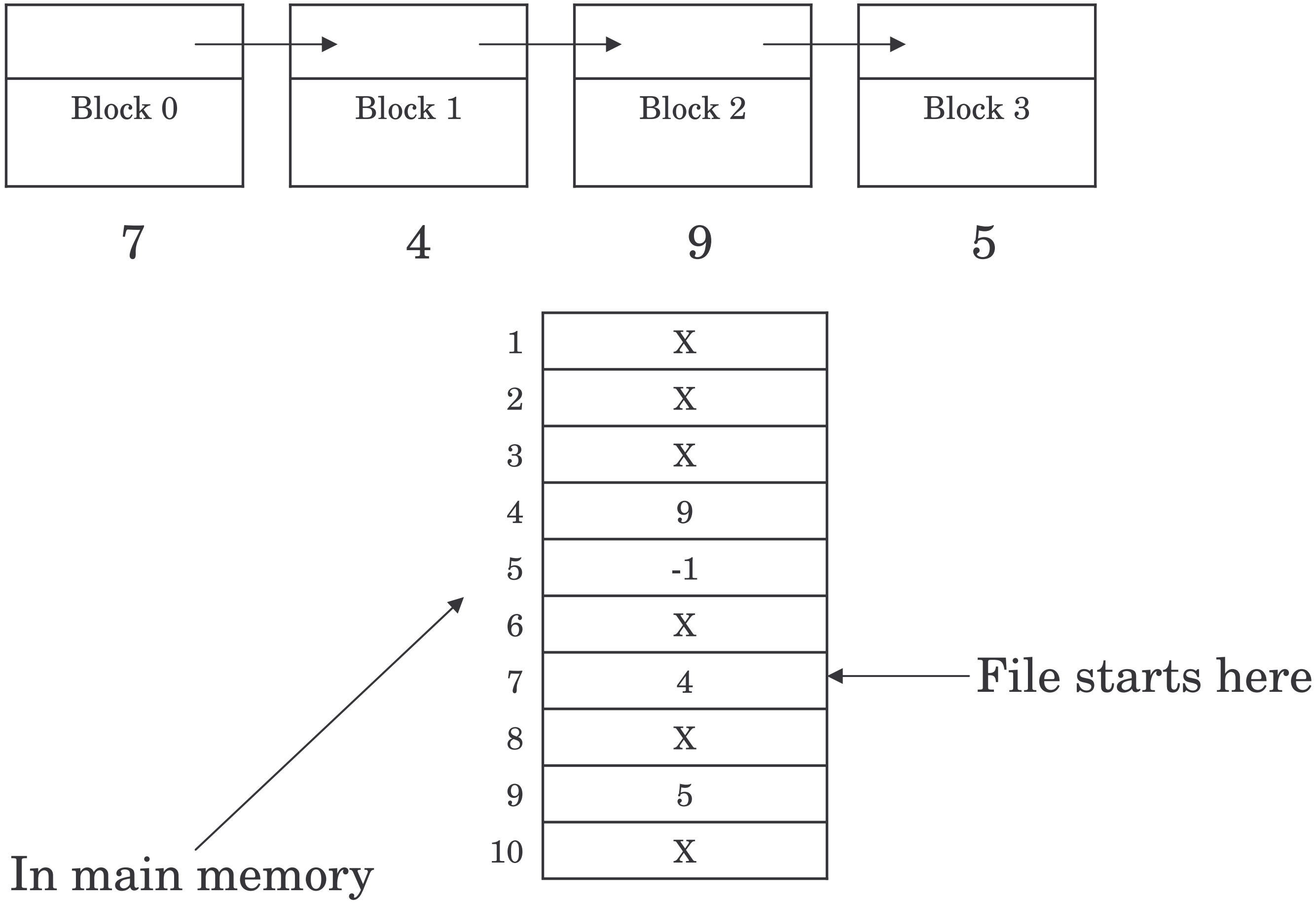
Imagine the consequences…

- You start preparing the file for your thesis and the word processor asks for the final size in bytes!
  - You choose 100Mbytes, maybe there's no such hole in the disk. No thesis
  - You ask for 1Mbyte. You write up to page 10 and "save as…" fails (the hole was too small)
- Contiguous allocation is used though
  - CD-ROMs, because we know the size of files in advance

Linked list allocation

- Linked list:
  - Each block contains also the pointer to the next block (or -1 if last block of file)
  - Sequential read is fine if starting from block 1 of the file
  - Random access painful
  - Also, the room for the pointer changes the size of blocks. The amount of storage is no longer a power of two (can slow down things)

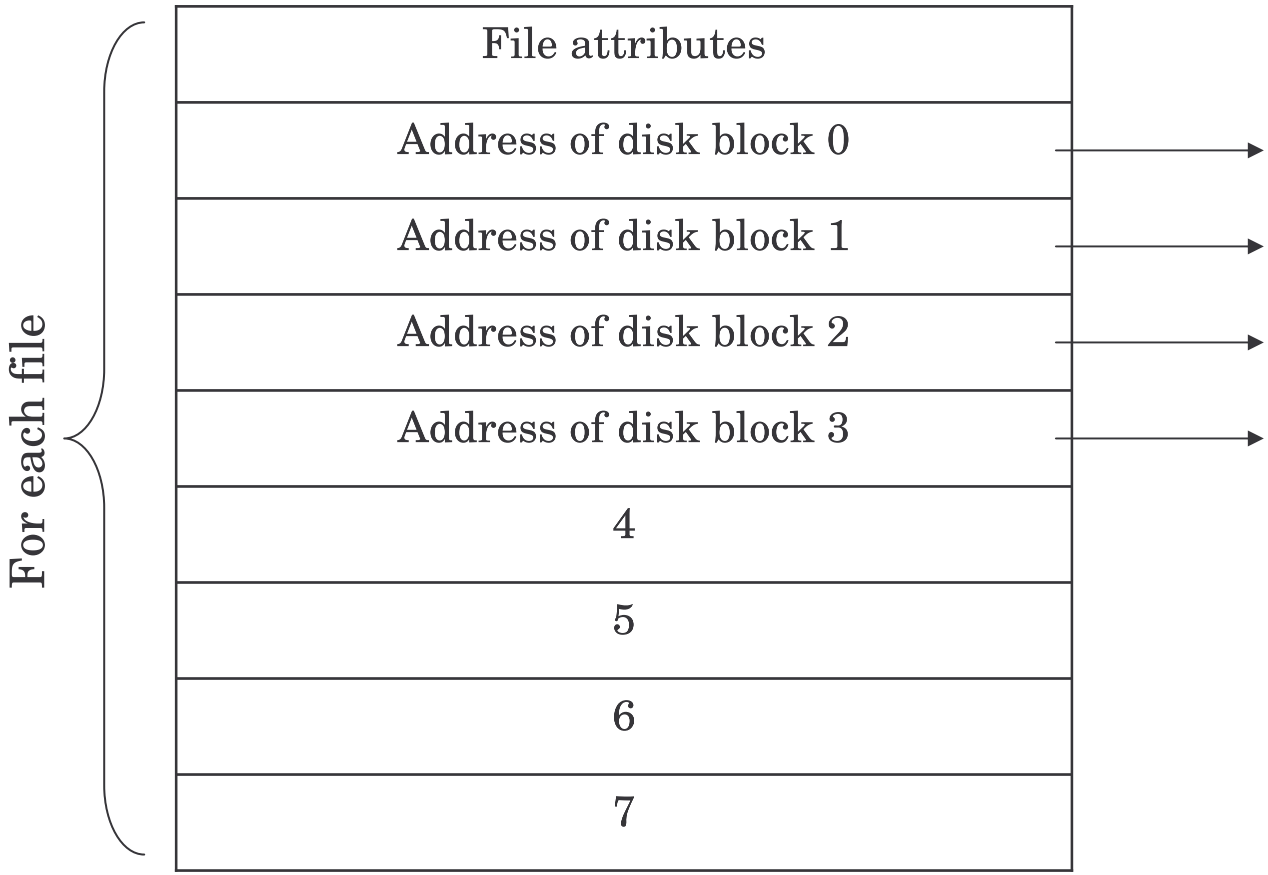
Linked list w/ table in mem



FAT in memory?

- 20GB disk, 1Kbyte block size
- 20M entries
- 3bytes each, 4 for efficiency (32bit processor)
- 80Mbytes of RAM
- If paged, still 80Mbytes of virtual memory + the bus traffic due to paging

I-node solution



I-nodes

- Size of table
  - FAT: proportional to N, if disk has N blocks
  - I-nodes: proportional to the number of files open simultaneously
- Additionally
  - If the I-node is filled the last pointer is reserved for holding the address of the next block of I-nodes (another table similar to the first one)

Directories

- The directory entry contains the information about the files
  - E.g. where I-nodes are stored
- Where are attributes stored (creation times, permission, etc.)
  - In the directory itself (MSDOS)
  - In the I-node (Unix)
- Issues with:
  - Storing long file names
  - Searching large directories (over 1000 of files)
    - Linear search
    - Hash table based search

Shared files

- To show the same file as appearing in multiple directories
  - Note! The same file, not a copy
- If the directory structure contains only the pointer to the I-node (together with the file name)
  - Sharing means setting the pointer to the correct I-node
- Second solution. Having a special file of type LINK (symbolic linking)
  - In practice a redirection of the access to the shared file

Issues with shared files

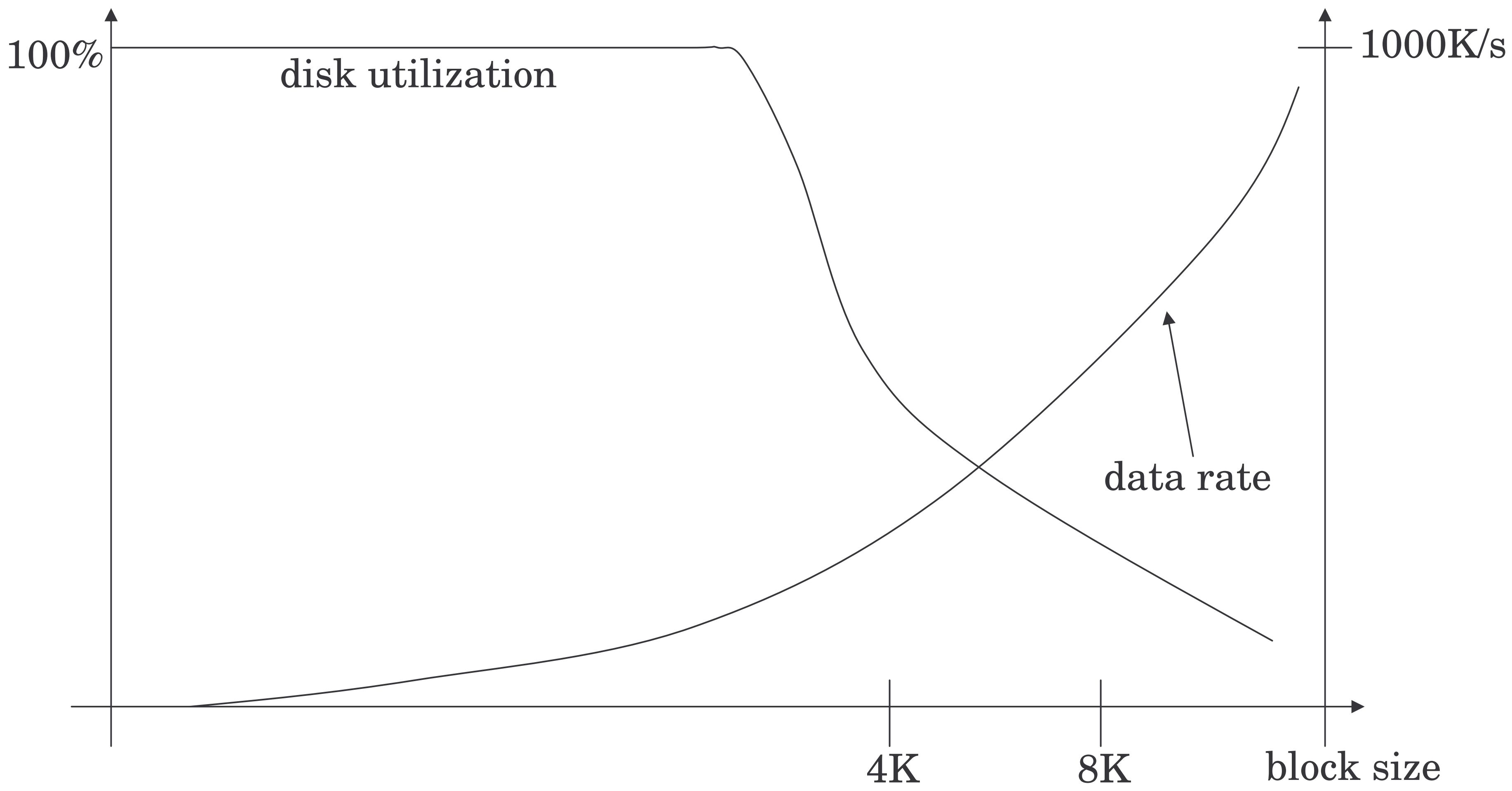
- Accounting appropriately
  - What if the owner of the file deletes it but a link is still active on the file
  - Owner doesn't own a file but he/she's still charged for it
- LINK approach is a bit slower
  - The path must be followed and the correct I-node found

Disk space management

- As for memory
  - External vs. internal fragmentation
- Example:
  - Average seek time 10ms
  - Rotation time 8.33ms
  - Bytes per track 131072
  - Reading k bytes:

$$10 + (8.33/2) + (8.33/131072)*k$$

Choosing block size



Keeping track of free blocks

- As for memory
  - Linked list of free blocks
    - 16Gb disk → 16K pointers for a 1Kb block and 32bit block numbers
      - 16G = 2^34, 1K block size means 2^24 blocks. Each block contains 255 ~2^8 pointers (32bit each). 2^16 blocks are required
  - Bitmap
    - Same disk, 2^24 bits which requires:
      - 2^(24 - 4 – 10) = 2^10
  - The bitmap is much smaller than the linked list
    - Usually the bitmap can be in main memory (at least a page)
    - Also for the linked list, for speeding up access part of it should be in main memory

Quotas

- Limit the disk space used by a single user
- Keep track of what files belong to each user
- …just to know that it exists!

Backups

- Recover from
  - Stupidity
  - Disaster
- Physical dump
  - Sector by sector copy of the disk
- Logical dump
  - Backup software parser the directory tree and copies files (excluding /dev, pipes, etc.)

Backups

- Full or incremental
  - Full: copy everything (directories and files)
  - Incremental: copy only modified files + part of the directory hierarchy containing them
- Costly operations
- People are not aware of the full value of their data until they lose them

File system consistency

- Check whether the list of free blocks and files are mutually consistent
- Reliability
  - RAID (we've seen it)
  - Stable storage (algorithmically safe)
- Safety
  - What, where, and how often to backup files

Performance

- Caching
  - How to choose what to evict from cache
    - Similar to memory: FIFO, second chance, LRU can be used
  - ...but unfortunately, we shouldn't be caching forever. Avoid data not written for long time, just in case of a crash
  - Unix has a daemon saving to disk every 30 seconds or so (update)
  - MSDOS uses a write-through cache, "write" are scheduled as soon as possible (always consistent)
  - Windows started to use the first strategy too (more efficient)

Performance

- Block read ahead
  - Try to guess what's needed next
  - Try to estimate how sequential a file is accessed
  - If sequential, try reading ahead before blocks are needed
- Reducing arm motion
  - Where to put I-nodes
  - Try to do block clustering