File Systems Implementation

Today

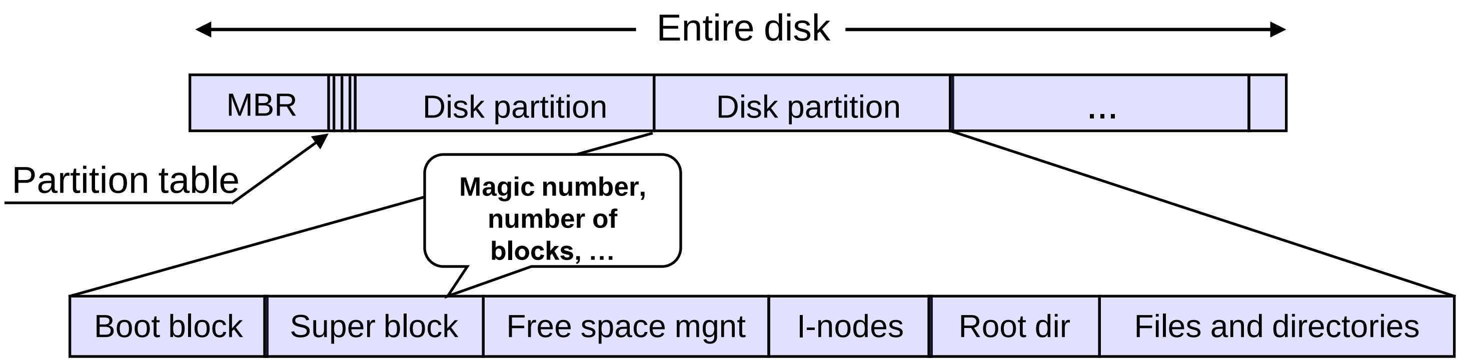
- File & directory implementation
- Efficiency, performance, recovery
- Examples

Next

- Mass storage and I/O

File system layout

- Disk divided into 1+ partitions – one FS per partition
- Sector 0 of disk – MBR (Master Boot Record)
  - Used to boot the machine
- Followed by Partition Table (one marked as active)
  - (start, end) per partition; one of them active
- Booting: BIOS → MBR → Active partition's boot block → OS
- What else in a partition?

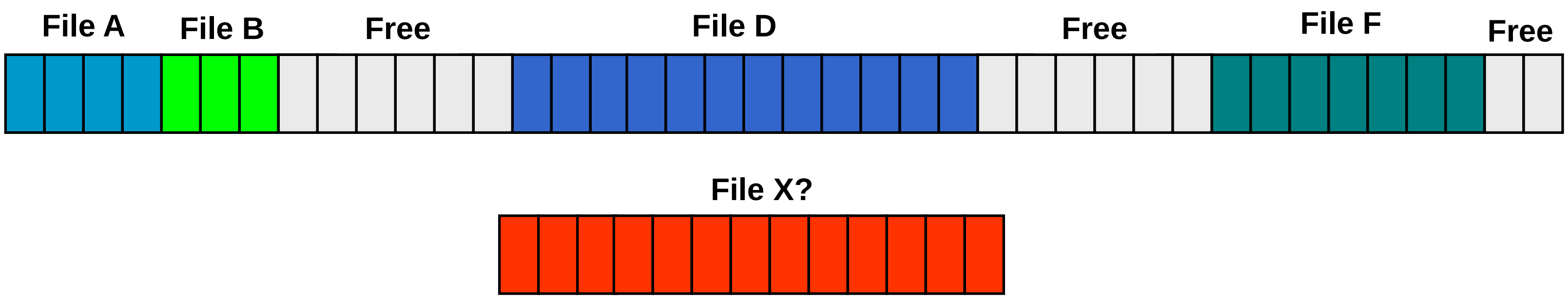


Implementing files

Keeping track of what blocks go with which file

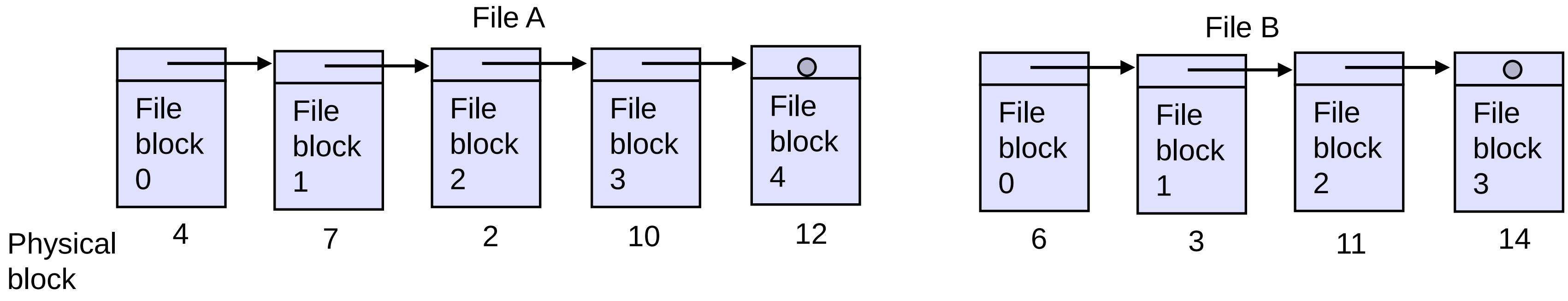
- Contiguous allocation
  - Each file is a contiguous run of disk blocks
  - e.g. IBM VM/CMS
  - Pros:
    - Simple to implement
    - Excellent read performance
  - Cons:
    - Fragmentation

Where would it make sense?



Implementing files

- Linked list
  - Files as a linked list of blocks
  - Pros:
    - Every block gets used
    - Simple directory entry per file
  - Cons:
    - Random access is a pain
    - List info in block → block data size not a power of 2
    - Reliability (file kept together by pointers scattered throughout the disk)



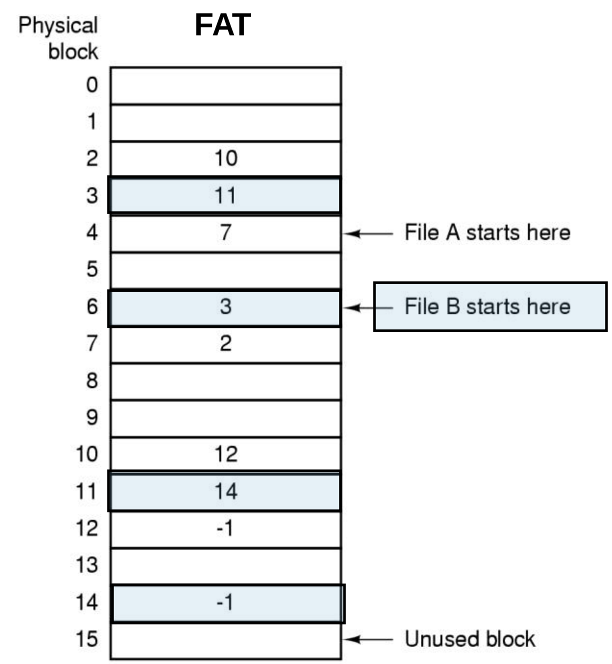
Implementing files

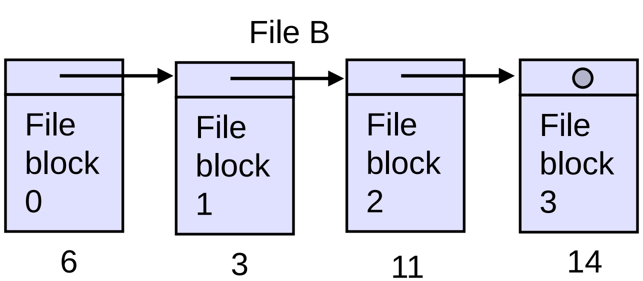
- Linked list with a table in memory
  - Files as a linked list of blocks
  - Pointers kept in FAT (File Allocation Table)
  - Pros:
    - Whole block free for data
    - Random access is easy
  - Cons:
    - Overhead on seeks or
    - Keep the entire table in memory

      20GB disk & 1KB block size →

      20 million entries in table →

      4 bytes per entry ~ 80MB of memory

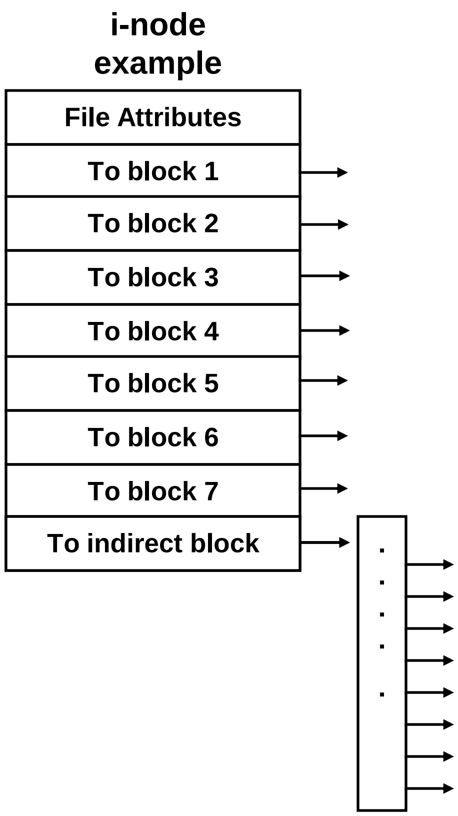




Implementing files

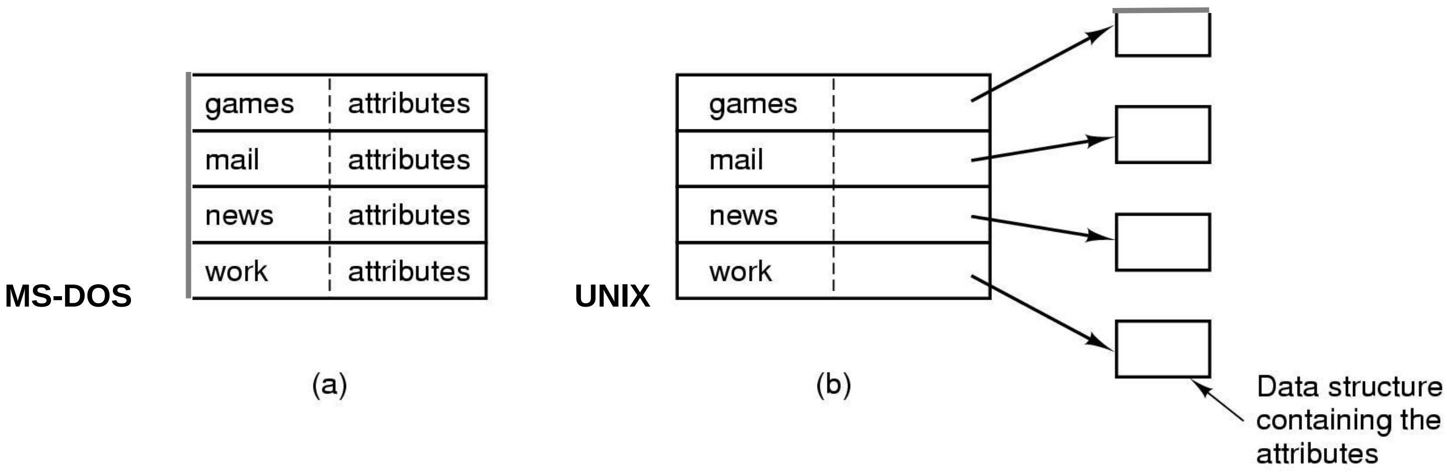
- I-nodes - index-nodes
  - Files as linked lists of blocks, all pointers in one location: i-node
  - Each file has its own i-node
  - Pros:
    - Support direct access
    - No external fragmentation
    - Only a file i-node needed in memory (proportional to # of open files instead of to disk size)
  - Cons:
    - Wasted space (how many entries?)
  - More entries – what if you need more than 7 blocks?

Save entry to point to address of block of addresses



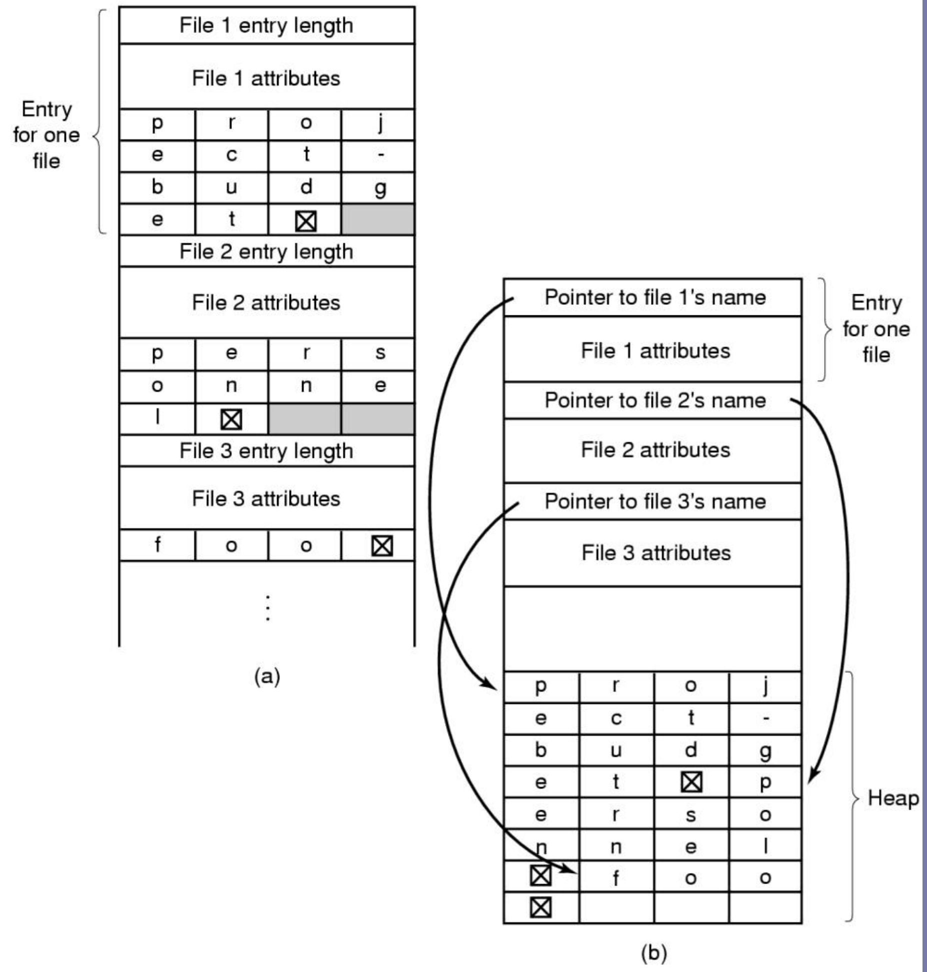
Implementing directories

- Directory system function: map ASCII name onto what's needed to locate the data
- Related: where do we store files' attributes?
  - A simple directory: fixed size entries, attributes in entry (a)
  - With i-nodes, use the i-node for attributes as well (b)
- As a side note, you find a file based on the path name; this mixes what your data is with where it is – *what's wrong with this picture?*



Implementing directories

- So far we've assumed short file names (8 or 14 char)
- Handling long file names in directory
  - In-line (a)
    - Fragmentation
    - Entry can span multiple pages (page fault reading a file name)
  - In a heap (b)
    - Easy to +/- files
- Searching large directories
  - Hash
  - Cash



Shared files

- Links and directories implementation
  - Leave file's list of disk blocks out of directory entry (i-node)
    - Each entry in the directory points to the i-node
  - Use symbolic links
    - Link is a file w/ the path to shared file
    - Good for linking files from another machine
- Problem with first solution
  - Accounting
    - C creates file, B links to file, C removes it
    - B is the only user of a file owned by C!
- Problem with symbolic links
  - Performance (extra disk accesses)

Disk space management

- Once decided to store a file as sequence of blocks
  - What's the size of the block?
    - Good candidates: Sector, track, cylinder, page
    - Pros and cons of large/small blocks
    - Decide base on median file size (instead of mean)
- Keeping track of free blocks
  - Storing the free list on a linked list
    - Use a free block for the linked list
  - A bit map
- And if you tend to run out of free space, control usage
  - Quotas for user's disk use
  - Open file entry includes pointer to owner's quota rec.
  - Soft limit may be exceeded (warning)
  - Hard limit may not (log in blocked)

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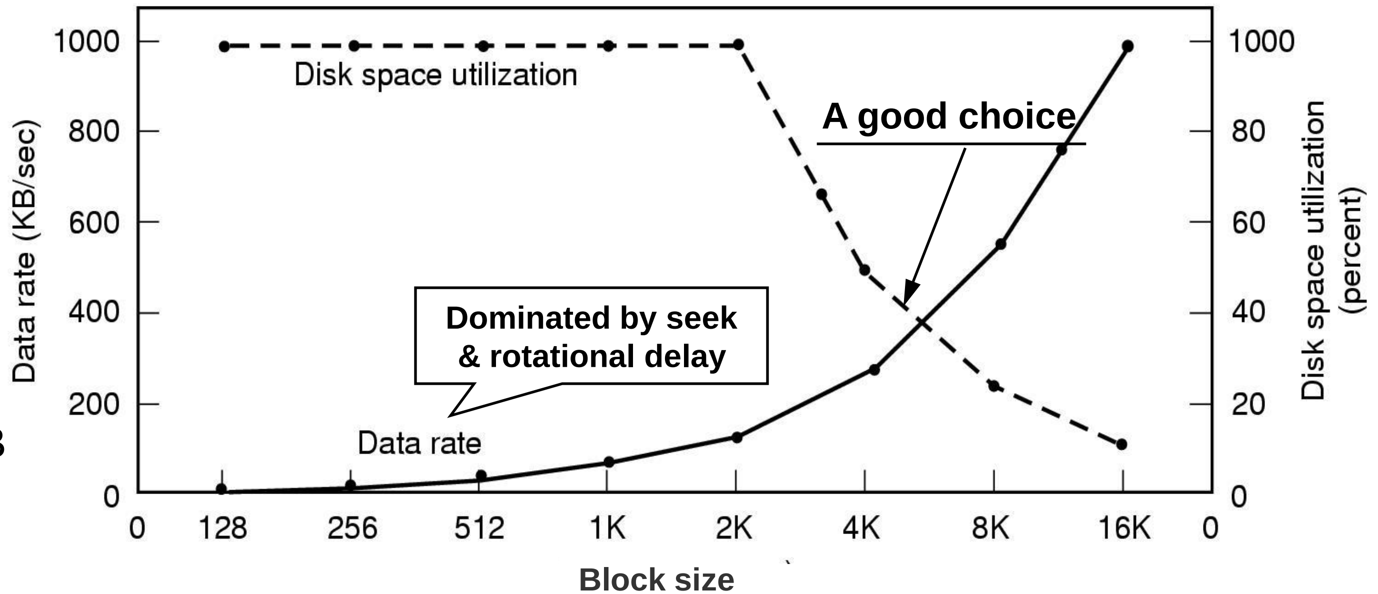
Dark line (left) gives data rate of a disk

Dotted line (right) gives disk space efficiency

Assume all files 2KB



File system reliability

- Need for backups
  - Bad things happen & while HW is cheap, data is not
- Backup - needs to be done efficiently & conveniently
  - Not all needs to be included – /bin?
  - Not need to backup what has not changed – incremental
    - Shorter backup time, longer recovery time
  - Still, large amounts of data – compress?
  - Backing up active file systems
  - Security
- Strategies for backup
  - Physical dump – from block 0, one at a time
    - Simple and fast
    - You cannot skip directories, make incremental backups, restore individual files

File system reliability

- Logical dumps
  - Keep a bitmap indexed by i-node number
  - Bits are set for
    - Modified files
    - Directories
  - Unmarked directories w/o modified files in or under them
  - Dump directories and files marked
- Some more details
  - Free list is not dump, reconstructed
  - Unix files may have holes (core files are a good example)
  - Special files, named pipes, etc. are not dumped

File system reliability

- File system consistency
- fsck/scandisk ideas
  - Two kind of consistency checks: blocks & files
  - Blocks:
    - Build two tables – a counter per block and one pass
  - Similar check for directories – link counters kept in i-nodes

Consistent state

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Blocks in use	1	1	0	1	0	1	1	1	1	0	0	1	1	1	0	0
Free blocks	0	0	1	0	1	0	0	0	0	1	1	0	0	0	1	1

Missing block

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Blocks in use	1	1	0	1	0	1	1	1	1	0	0	1	1	1	0	0
Free blocks	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	1

Solution – add it to the free list

Twice in free list

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Blocks in use	1	1	0	1	0	1	1	1	1	0	0	1	1	1	0	0
Free blocks	0	0	1	0	2	0	0	0	0	1	1	0	0	0	1	1

Solution – rebuild the free list

Part of more than one file

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Blocks in use	1	1	0	1	0	2	1	1	1	0	0	1	1	1	0	0
Free blocks	0	0	1	0	1	0	0	0	0	1	1	0	0	0	1	1

Solution – duplicate data block

File system performance

- Caching – to reduce disk access
  - Hash (device & disk address) to find block in cache
  - Cache management ~ page replacement
  - Plain LRU is undesirable
    - Essential blocks should be written out right away
    - If blocks would not be needed again, no point on caching
  - Unix sync and MS-DOS write-through cache
- Block read ahead
  - Clearly useless for non-sequentially read files
- Reducing disk arm motion
  - Put blocks likely to be accessed in seq. close to each other
  - I-nodes placed at the start of the disk
  - Disk divided into cylinder groups - each with its own blocks & i-nodes

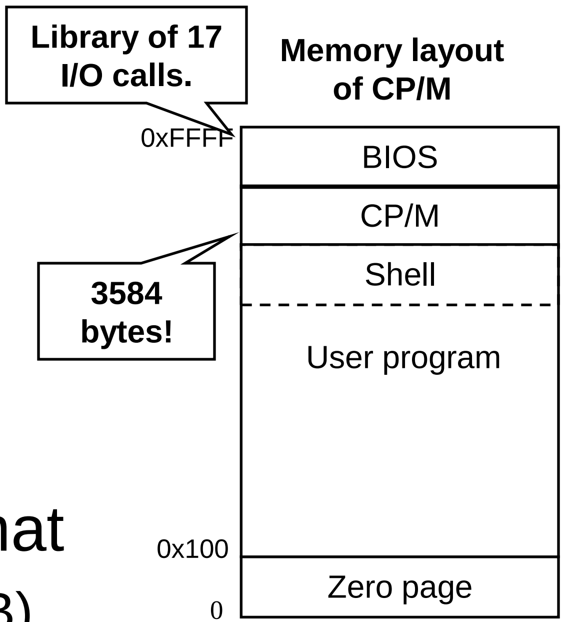
Log-structured file systems

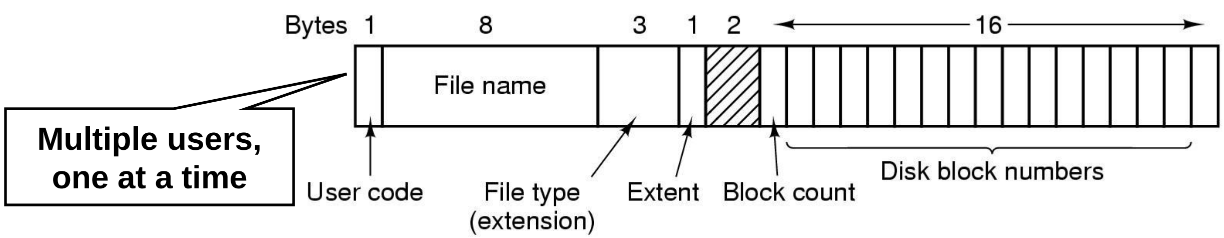
- CPUs getting faster, memories larger, disks bigger
  - But disk seek time lags behind
  - Since disk caches can also be larger → increasing number of read requests can come from cache
  - *Thus, most disk accesses will be writes*

- LFS strategy - structure entire disk as a log
  - All writes initially buffered in memory
  - Periodically write buffer to end of disk log
    - Each new segment has a summary at the start
  - When file opened, locate i-node, then find blocks
    - Keep an i-node map in disk, index by i-node, and cache it
  - To deal with finite disks: cleaner thread
    - Compact segments starting at the front, first reading the summary, creating a new segment, marking the old one free

The CP/M file system

- Control Program for Microcomputers
- Run on Intel 8080 and Zilog Z80
  - 64KB main memory
  - 720KB floppy as secondary storage
- Separation bet/ BIOS and CP/M for portability
- Multiple users (but one at a time)
- The CP/M (one) directory entry format
  - Each block – 1KB (but sectors are 128B)
  - Beyond 16KB – Extent
  - (soft-state) Bitmap for free space

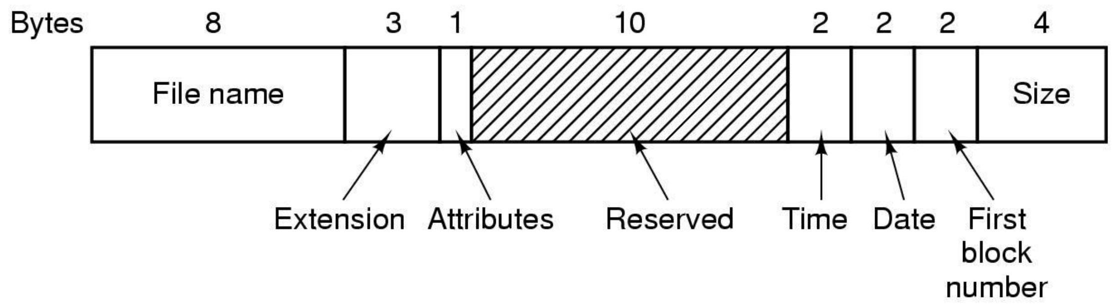




The MS-DOS file system

- Based on CP/M
- Biggest improvement: hierarchical file systems (v2.0)
  - Directories stored as files – no bound on hierarchy
  - No links – so basic tree
- Attributes include: read-only, hidden, archived, system
- Time – 5b for seconds, 6b for minutes, 5b for hours
  - Accurate only to +/-2 sec (2B – 65,536 sec of 86,400 sec/day)
- Date – 7b for year (128 years) starting at 1980 (5b for day, 4b for month)

MS-DOS directory entry

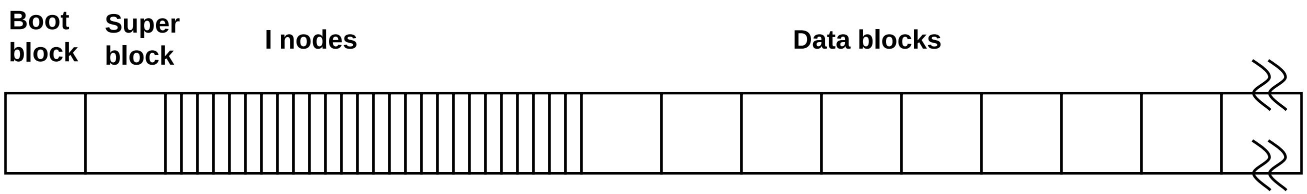


The MS-DOS file system

- Another difference with CP/M – FAT
  - First version FAT-12 with 512-byte blocks:
  - Max. partition 2^{12}x 512 ~ 2MB
  - FAT with 4096 entries of 2 bytes each – 8KB
- Later versions' FATs: FAT-16 and FAT-32 (actually a misnomer – only the low-order 28-bits are used)
- Disk block sizes can be set to multiple of 512B
- FAT-16:
  - 128KB of memory
  - Largest partition – 2GB ~ with block size 32KB
  - Largest disk - 8GB

The UNIX V7 file system

- Unix V7 on a PDP-11
- Tree structured as a DAG
- File names up to 14 chars (anything but “/” and NUL)
- Disk layout in classical UNIX systems

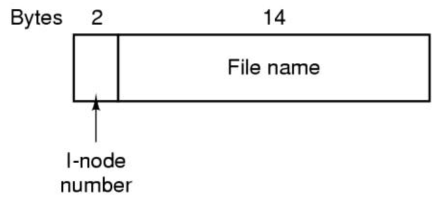


- Each i-node – 64 bytes long
- I-node’s attributes
  - file size, three times (creation, last access, last modif.), owner, group, protection info, # of dir entries pointing to it
- Following the i-nodes – data blocks in no particular order

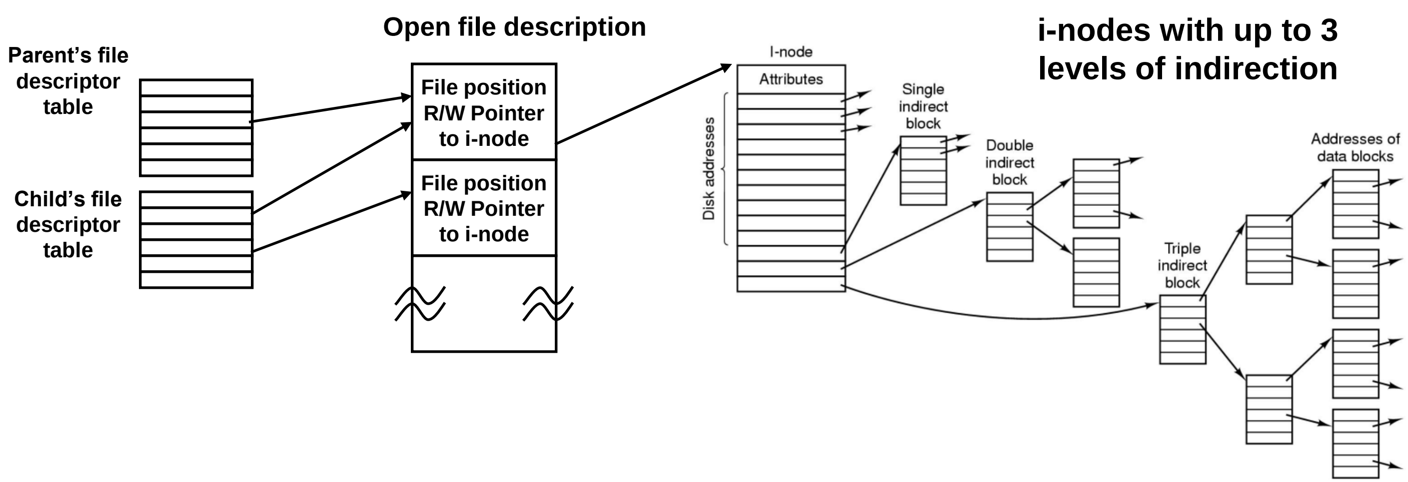
The UNIX V7 file system

- A directory – an unsorted collection of 16-bytes entries

Directory entry

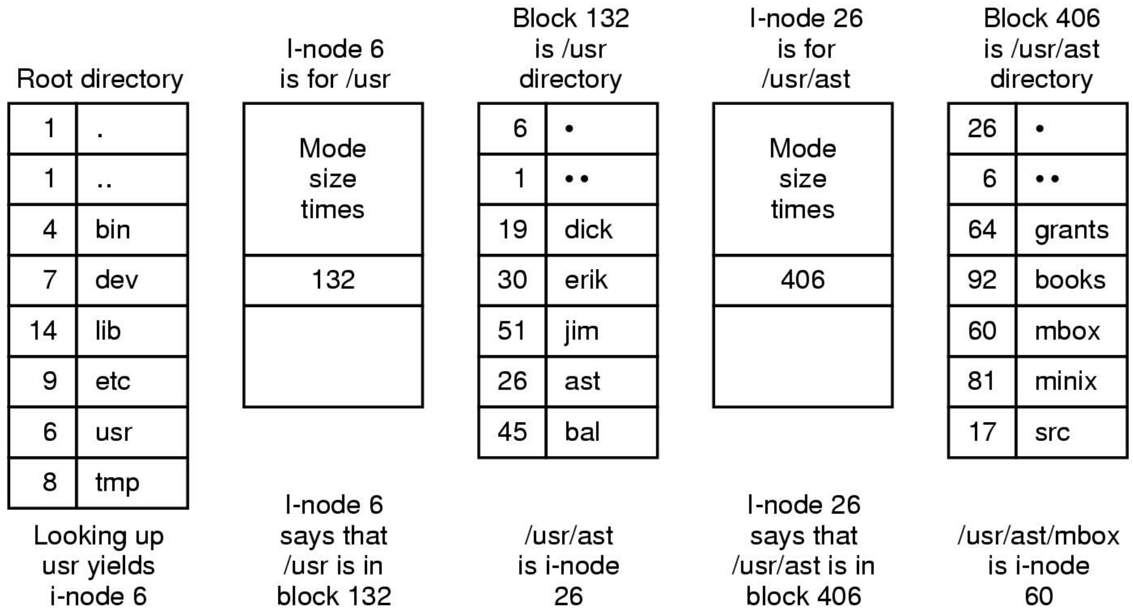


- File descriptor table, open file descriptor table and i-node table – starting from file descriptor, get the i-node
  - Pointer to i-node in the file descriptor table? No, where do you put the current pointer? Multiple processes each w/ their own
  - New table – the open file description



The UNIX V7 file system

- Steps in looking up /usr/ast/mbox
  - Locate root directory – i-node in a well-known place
  - Read root directory
  - Look for i-node for /usr
  - Read /usr and look for ast
  - …



Next Time

- Mass storage and I/O