File System

Computer Operating Systems
BLG 312E

2016-2017 Spring

Longterm Storage

- need to store very large amounts of data
- Stored data should not be lost after process terminates
- processes should be able to share access to the stored data

File System Functions

- file naming
- file access
- file use
- protection and sharing
- implementation

File System Properties

- from the point of view of the user
  - file contents
  - file names
  - file protection and sharing
  - file operations
  - ...

⇒ User interface

- from the point of view of the designer
  - implementation of files
  - free space handling
  - logical block size
  - ....

⇒ File system implementation

File Types

- Files
  - ASCII files
  - binary files
- Directories
  - in most operating systems directory ≈ file

Access within a File

- sequential access
- random access

File Attributes

- information stored in directory structure (resides in secondary storage)
- directory entry: file name and unique id (used to locate file attributes)
  - name: symbolic file name
  - identifier: unique tag used for identification in file system
  - type: for systems that support different types of files
  - location: pointer to device and location of file on device
  - size: current size of file (in bytes, words or blocks) and maximum allowed size
  - protection: access control information (who can read/write/execute, etc)
  - time, date and used identification: for creation, last modification, last use

File Operations

- create / delete
- rename
- open / close / truncate
- read / write / append
- position the file pointer
- query/change file attributes

⇒ through system calls (*open*, *creat*, *read*, *write*, *close*, ...)

Operating System Tables

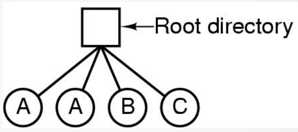
- operating system keeps *open-file* table
  - *system-wide table*: contains process independent info (e.g. location of file on disk, access dates, file size, open count, ...)
  - *per-process table*: keeps track of all files opened by process (info stored: current file pointer, access rights, accounting info, ...)
- each entry in the per-process table, points to an entry in the system-wide open-file table
- when a process opens a file
  - an entry is added to the system-wide open-file table
  - open count is incremented
  - an entry is added to the per-process open-file table, pointing to the entry in the system-wide open-file table
- upon each file close
  - open count is decremented
  - pointer in the per-process open-file table is removed
  - if open count is zero, the entry is removed from the system-wide open-file table

Directories

- can be viewed as a symbol table that translates file names into their directory entries
- operations:
  - searching for a file
  - create / delete a file
  - list a directory
  - rename a file
  - traverse the file system
- logical structure of a directory: single-level, two-level, tree structure, ...

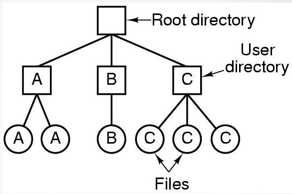
Single-Level Directory Systems

- Provides fast access
- Not suitable for multi-user systems (problem if different users create files with same name)
- May be suitable for embedded systems (e.g. store driver profiles in a car)



Two-Level Directory Systems

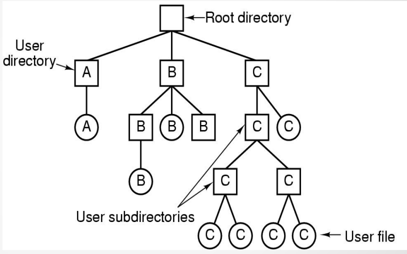
- A directory per user (hence users may have files with same name)
- May be suitable personal computers with multi-users
- System login with a user name and password may be possible



(**Note:** letters show the owners of the files/directories)

Hierarchical Directory Systems (tree structure)

- users wish to keep their files in a logical grouping
- directory tree
- used in modern operating systems



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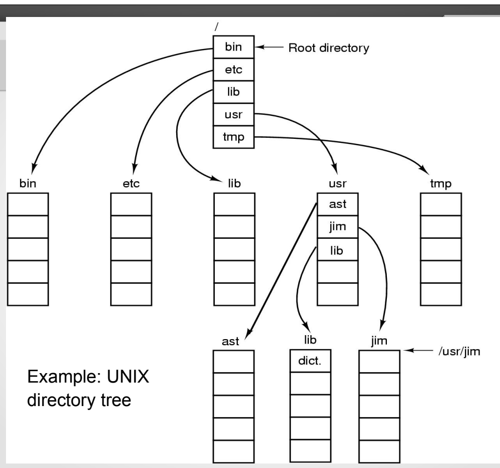


File System Implementation

file system has a layered structure:

application programs *(top level)*
logical file system
file-organization module
basic file system
I/O control *(lowest level)*
devices

I/O Control Level

- consists of device drivers and interrupt handlers
- device driver translates high-level commands such as “retrieve block 123” into hardware-specific instructions used by hardware controller (interface of I/O device to system)

Basic File System

- issues generic commands to appropriate device driver
- manages memory buffers and caches holding file-system, directory and data blocks
- a block in the buffer is allocated before a disk block transfer can occur

File-Organization Module

- knows about files' logical and physical blocks
- translates logical block addresses to physical block addresses
- also manages free space: keeps track of unallocated blocks

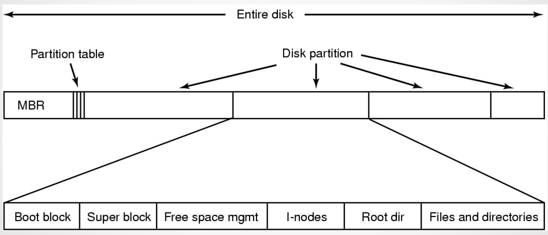
Logical File System

- manages meta-data information
  - meta-data: all of the file system structure except the contents of the files
- manages the directory structure
  - provides the file-organization module with the necessary info when given a symbolic file name
- maintains file structure via file control blocks (FCB)
  - a.k.a. *inode* in UNIX systems
  - FCB contains info on file, such as ownership, permissions, location of file contents, …
- also responsible for protection and security

Layered File System Discussion

- duplication of code minimized: I/O control and sometimes the basic file system can be used by multiple file systems
- introduces operating system overhead, decreasing performance
- decision to use layering and the number of layers including each layer's responsibilities is an operating system design issue

File System Implementation



Example file system structure (UNIX file system UFS)

File System Implementation

- Boot control block (per volume)
  - info needed by system to boot an operating system from that volume
  - if no operting system on volume, block is empty (raw disk e.g. swap space in UNIX can use a raw partition)
  - typically the first block of a volume
  - in UFS: boot block
  - in NTFS: partition boot sector

File System Implementation

- Volume control block (per volume)
  - contains volume (or partition) details (e.g. no of blocks in partition,
  - size of blocks, free block count, free block pointers, free FCB count and free FCB pointers, ...
  - in UFS: superblock
  - in NTFS: stored in the master file table

File System Implementation

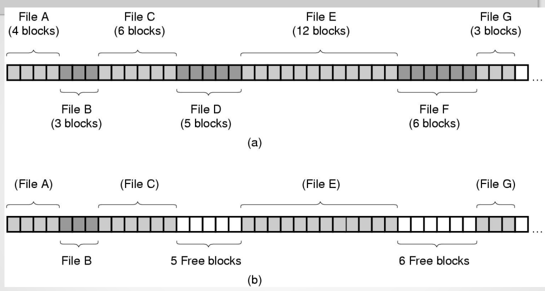
- Directory structure (per file system)
  - for organizing files
  - in UFS: includes file names and associated inode numbers
  - in NTFS: stored in the master file table

File System Implementation

- per-file FCB
  - contains details about file
  - has a unique id to associate with a directory entry
  - inodes in UFS
  - in NTFS: stored in the master file table which uses a relational database structure with a row pre file

File System Implementation

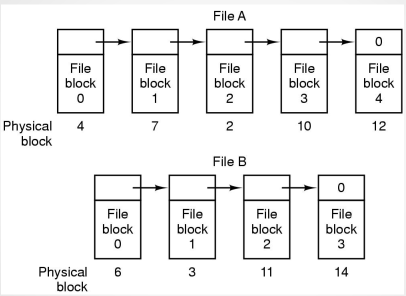
- using contiguous allocation
  - disk addresses define a linear ordering on the disk
  - keep a list of addresses of first blocks and number of blocks for each file
  - advantages
    - easy implementation
    - more efficient “read” operation
  - disadvantages
    - fragmentation on disk (need to compact disk)
    - keep a list of free spaces
      - file size must be known at creation (cannot change)
      - limited maximum file size
  - good for CD-ROM file systems (only one write)



(a) contiguous allocation example: 7 files
(b) view of the disk after files *D* and *E* have been deleted

File System Implementation

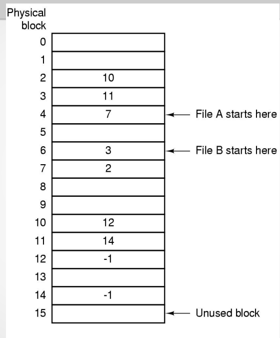
- using linked lists
  - first word of each block is a pointer to the next block
  - no fragmentation (internal fragmentation only in the last block)
  - only the address of the first block of a file is kept
  - access to data in a file: easy sequential access; random access is harder
  - data size in blocks are no longer a power of 2: few bytes taken up by pointer
  - most reads performed in sizes as powers of 2 (need to read two blocks to achieve the required amount of data)



Using linked lists

File System Implementation

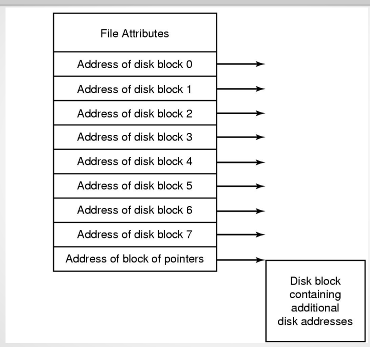
- using file tables in memory
  - keep the pointers in a table in memory (instead of in the blocks on the disk)
  - FAT (File Allocation Table) (used e.g. in MS-DOS)
  - section of disk at the beginning of each volume set for FAT
  - easier random access
    - since table is in memory
  - only need to know the address of the starting block
  - the whole table must be in memory
  - size of table depends on size of disk
    - e.g.: for a 20 GB disk and a block size 1K: need 20 million records of a minimum of 3 bytes in the table (20MB)



using file tables in memory

File System Implementation

- keep an i-node (index-node) for each file
  - contains file attributes
  - contains disk addresses of blocks
- keep only the i-nodes of open files in memory
  - total memory size needed is proportional to the number of maximum files allowed to be open at the same time
- in the simplest implementation, the maximum number of blocks for a file is limited
  - solution: reserve the last entry of the i-node for a pointer to a block containing more block addresses

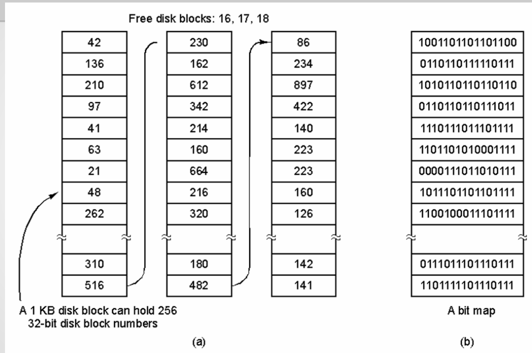


example i-node

Disk Space Management

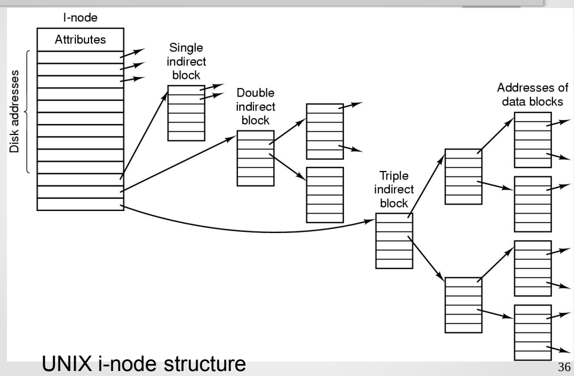
- files split up into blocks of fixed size which do not need to be adjacent on disk
- what should the block size be (unit of allocation) ?
  - same as sector, track, cylinder size?
    - device dependent
  - selection of the size of blocks is crucial
    - performance and efficient disk space usage are contradictory objectives
    - better to choose depending on average file size
    - size is usually pre-determined for each system
      - UNIX systems: usually 1K

Keeping Track of Free Blocks on Disk (Free-Space List)



Storing the free space info: (a) in a linked list (b) as a bitmap

UNIX File System (UFS)



UNIX i-node structure

Example:

Consider a UNIX-like file system that uses i-nodes to represent files. Disk blocks are 8 KB in size, and a pointer to a disk block requires 4 bytes. This file system has 12 direct disk blocks, as well as single, double and triple indirect disk blocks (as shown in the previous slide).

What is the maximum size of a file that can be stored in this file system?