File System Interface

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Review

- Page replacement: FIFO, Optimal, LRU (stack, counter), Approximation (reference bit, second chance), Counting (LFU, MFU)
- Global vs local allocation
- Reclaiming pages, OOM
- MAJOR/Minor page fault, NUMA
- Thrashing, Working-Set Model, How to track working set
- Kernel memory allocation: buddy, slab
- Other consideration: Prepaging, pagesize, TLB reach …

File Concept

- **File** is a contiguous logical address space for storing information
  - database, audio, video, web pages…
- There are different types of file:
  - data: numeric, character, binary
  - program
  - special one: proc file system - use file-system interface to retrieve system information

File Attributes

- **Name** – only information kept in **human-readable form**
- **Identifier** – unique tag (number) identifies file **within file system**
- **Type** – needed for systems that support different types
- **Location** – pointer to **file location on device**
- **Size** – current file size
- **Protection** – controls who can do reading, writing, executing
- **Time, date, and user identification** – data for protection, security, and usage monitoring
- Information about files are kept in the directory structure, which is maintained on the disk
- Many variations, including **extended file attributes** such as file checksum

File info Window on Mac OS X

File Operations

- OS provides file operations to
  - create:
    - space in the file system should be found
    - an entry must be allocated in the directory
  - open: most operations need to file to be opened first
    - return a handler for other operations
  - read/write: need to maintain a **pointer**

File Operations

- reposition within file - seek
- delete
  - Release file space
    - Hardlink: maintain a counter - delete the file until the last link is deleted
  - truncate: delete a file but maintains its attributes
- Other operations can be implemented using these ones
  - Copying: create and read/write

Open Files

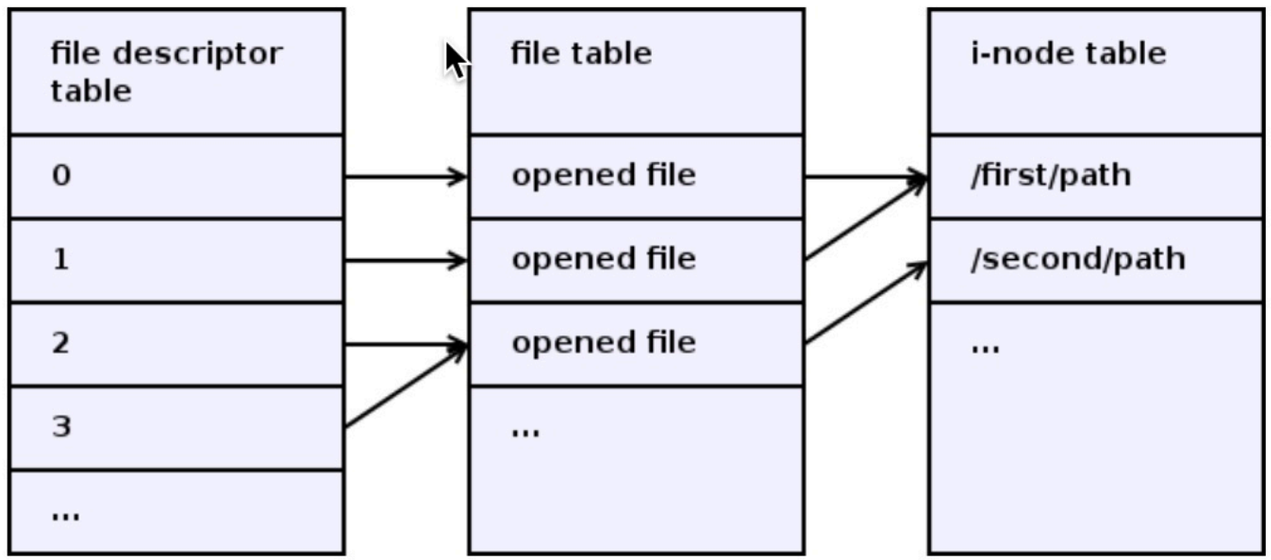
- Most of file operations need to search the directory to find the named file
  - To avoid the searching, OS maintains a table - **open-file table** contains information about all open files
    - Then following operation is specified via an index to the table - no searching is required
- For os that several processes may open the file simultaneously
  - **Per-process table:** current location pointer, access rights
  - **System-wide table:** location on the disk …

Information with Open Files

- Several pieces of information are associated with an open file
  - file position: pointer to last read/write location
    - file position is **per-process** that has the file open - since file could be opened by multiple processes
  - **file-open count**: the number of a file is open
    - to allow removal of data from open-file table when last processes closes it
  - disk location: cache of data access information
  - access rights: per-process access mode information

Open Files

- Some file systems provide file lock to mediates access to a file
- Two types of lock
  - **Shared lock** - multiple processes can acquire the lock concurrently
  - **Exclusive lock** - one process can acquire such an lock\
- Two locking mechanisms
  - **mandatory lock**: access is denied depending on locks held and requested
  - **advisory lock**: processes can find status of locks and decide what to do



A *file descriptor* is an index in the per-process file descriptor table (in the left of the picture). Each file descriptor table entry contains a reference to a *file object*, stored in the file table (in the middle of the picture). Each file object contains a reference to an i-node, stored in the i-node table (in the right of the picture).

A file descriptor is just a number that is used to refer a file object from the user space. A file object represents an opened file. It contains things likes current read/write offset, non-blocking flag and another non-persistent state. An i-node represents a filesystem object. It contains things like file meta-information (e.g. owner and permissions) and references to data blocks.

File descriptors created by several `open()` calls for the same file path point to different file objects, but these file objects point to the same i-node. Duplicated file descriptors created by `dup2()` or `fork()` point to the same file object.

A BSD lock and an Open file description lock is associated with a file object, while a POSIX record lock is associated with an `[i-node, pid]` pair. We'll discuss it below.

BSD locks (flock)

- Features:
  - not specified in POSIX, but widely available on various Unix systems
  - always lock the entire file
  - associated with a **file object**
    - **duplicated file descriptors**, e.g. created using dup2 or fork, share the lock acquisition
    - **independent file descriptors**, e.g. created using two open calls (even for the same file), don't share the lock acquisition
    - This means that with BSD locks, threads or processes **can't be synchronized on the same or duplicated file descriptor**, but nevertheless, both can be synchronized on **independent file descriptors.**
  - Work in both locking modes (exclusive and shared)
- up to Linux 2.6.11, didn't work on NFS; since Linux 2.6.12, flock() locks on NFS are emulated using fcntl() POSIX record byte-range locks on the entire file (unless the emulation is disabled in the NFS mount options)

Name

flock - apply or remove an advisory lock on an open file

Synopsis

#include <sys/file.h>

int flock(int *fd*, **int** *operation*);

Description

Apply or remove an advisory lock on the open file specified by *fd*. The argument *operation* is one of the following:

LOCK_SH
: Place a shared lock. More than one process may hold a shared lock for a given file at a given time.

LOCK_EX
: Place an exclusive lock. Only one process may hold an exclusive lock for a given file at a given time.

LOCK_UN
: Remove an existing lock held by this process.

File Types

- File types: as part of the file names - file extension
- File type: magic number of the file - elf

File Types – Name, Extension

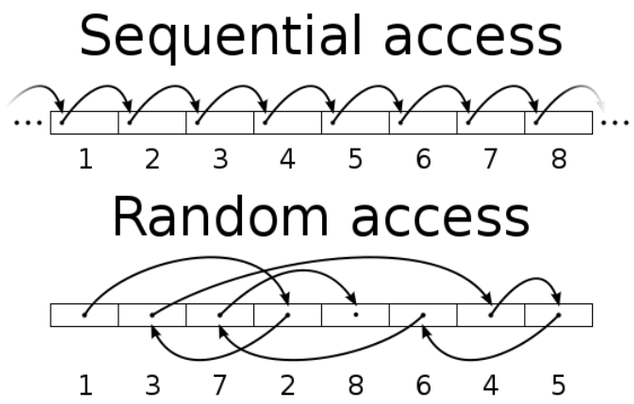
file type	usual extension	function
executable	exe, com, bin or none	ready-to-run machine-language program
object	obj, o	compiled, machine language, not linked
source code	c, cc, java, pas, asm, a	source code in various languages
batch	bat, sh	commands to the command interpreter
text	txt, doc	textual data, documents
word processor	wp, tex, rtf, doc	various word-processor formats
library	lib, a, so, dll	libraries of routines for programmers
print or view	ps, pdf, jpg	ASCII or binary file in a format for printing or viewing
archive	arc, zip, tar	related files grouped into one file, sometimes compressed, for archiving or storage
multimedia	mpeg, mov, rm, mp3, avi	binary file containing audio or A/V information

File Structure

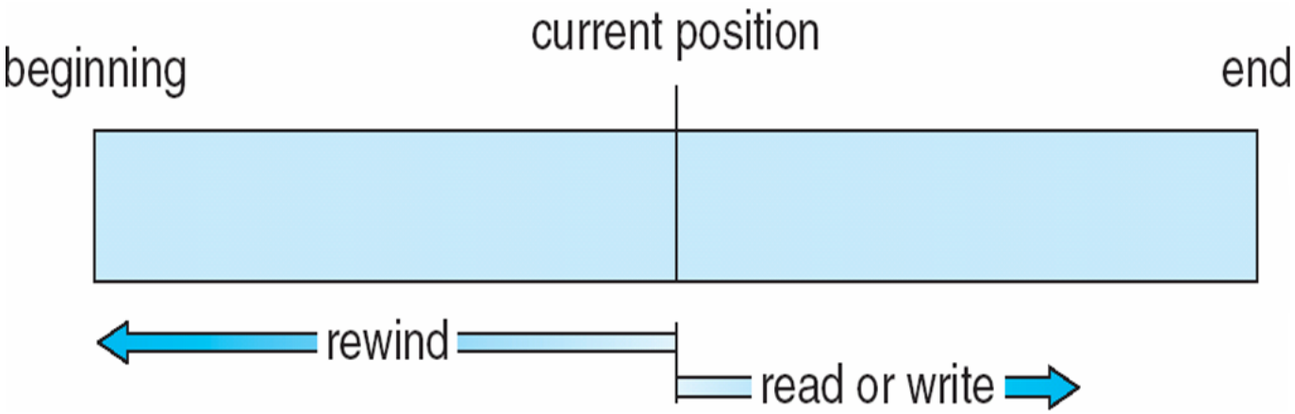
- A file can have different structures, determined by OS or program
  - **no structure**: a stream of bytes or words
    - linux files
  - **simple record structure**
    - lines of records, fixed length or variable length
    - e.g., database
  - **complex structures**
    - e.g., word document, relocatable program file
  - simple and complex structure can be encoded in the first method
- Usually user programs are responsible for identifying file structure

Access Methods

- Sequential access
  - a group of elements is access **in a predetermined order**
  - for some media types, the only access mode (e.g., **tape**)
- Direct access
  - access an element at an **arbitrary position** in a sequence in (roughly) **equal time**, independent of sequence size
    - it is possible to emulate random access in a tape, but access time varies
- sometime called random access



Sequential-access File



Sequential Access on Direct-access File

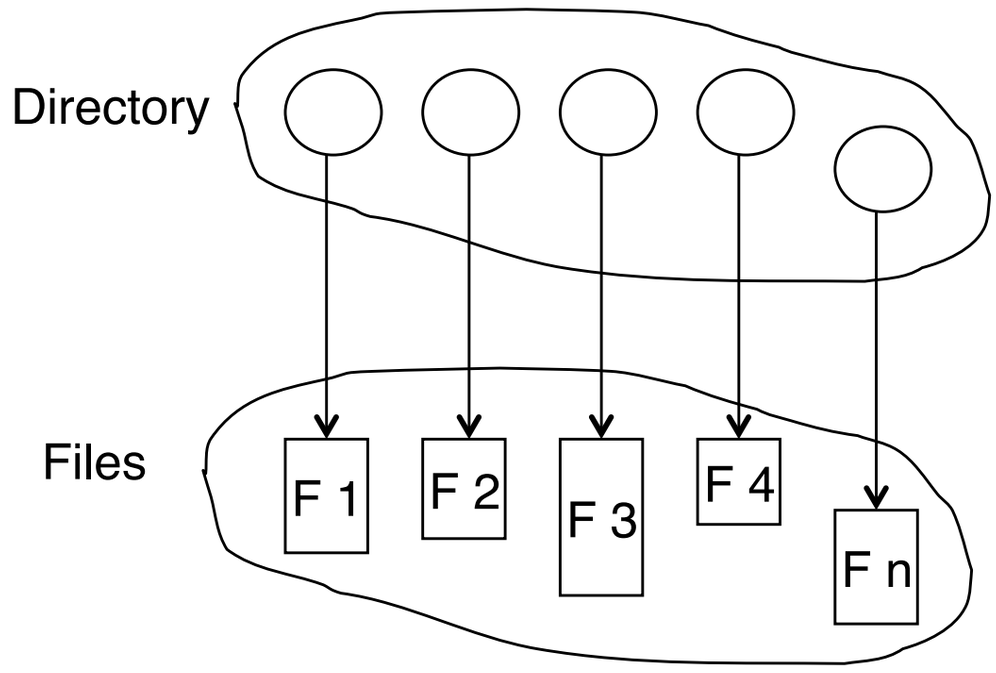
sequential access	implementation for direct access
reset	$cp = 0;$
read next	*read cp*; $cp = cp + 1;$
write next	*write cp*; $cp = cp + 1;$

Other methods

- Based on direct-access method
- An index for the file points to blocks
  - Find a record in the file, first search the index and then use the pointer to access the block
  - We may use multiple layers of index

Directory Structure

- Directory is a collection of nodes containing information about all files

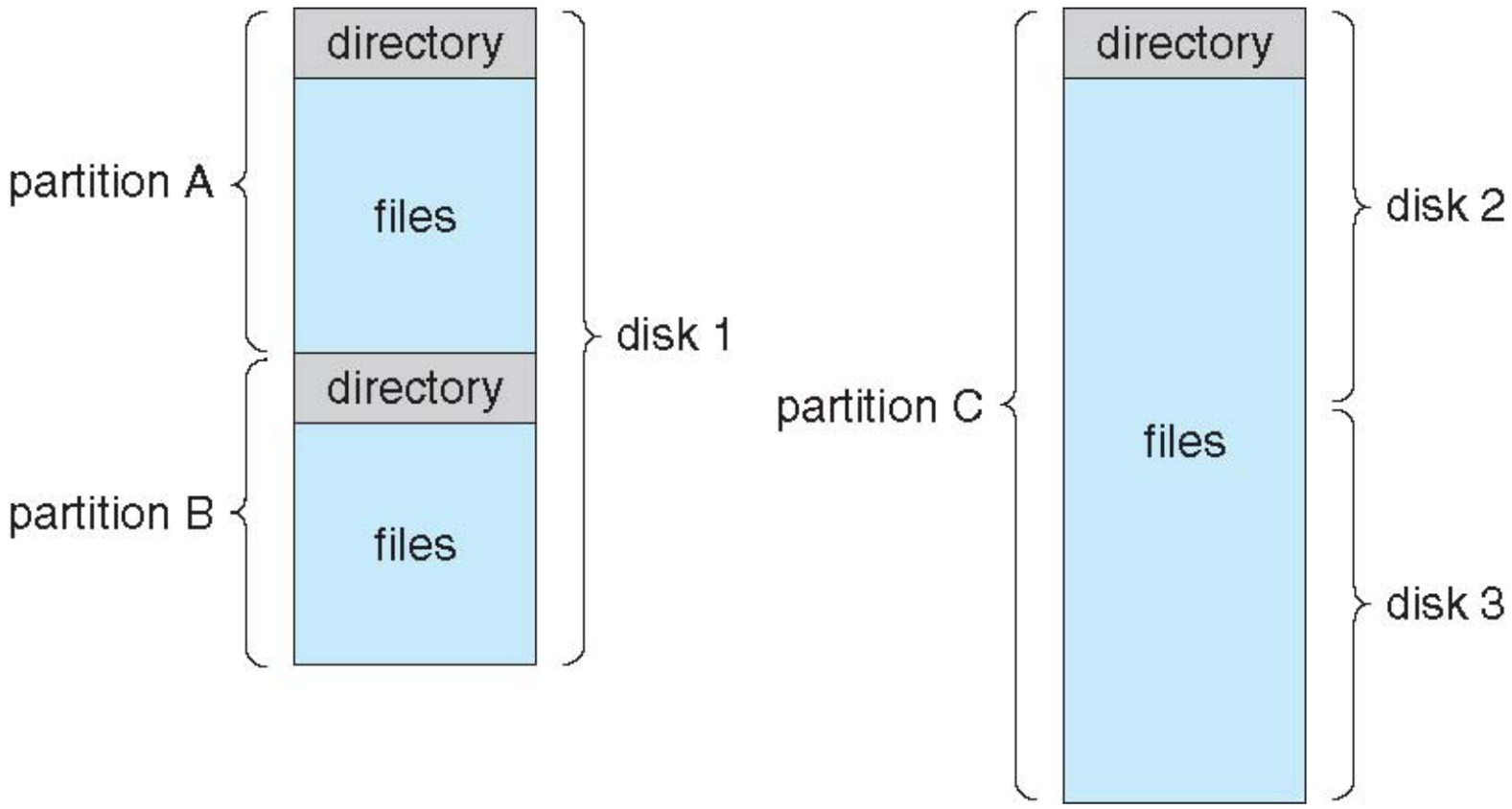


both the directory structure and the files reside on disk

Disk Structure

- Disk can be subdivided into **partitions**
  - partitions also known as **minidisks**, **slices**
  - different partitions can have different file systems
    - a partition containing file system is known as a **volume**
    - each volume tracks file system info in the volume's table of contents
    - a file system can be general purpose or special purpose
- disk or partition can be used **raw** (without a file system)
  - applications such as database prefer raw disks

A Typical File-system Organization



Operations Performed on Directory

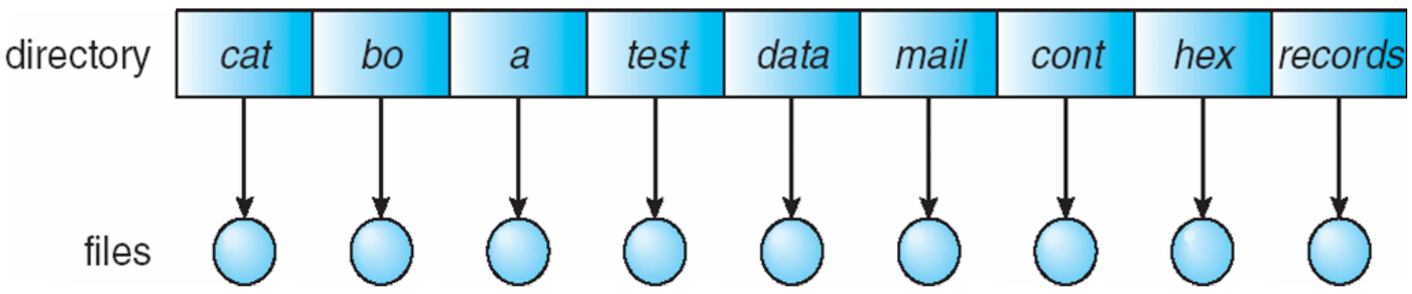
- Create a file: new files need tone created and added to directory
- delete a file: remove a file from directory
- List a directory: list all files in directory
- Search for a file: pattern matching
- Traverse the file system: access every directory and fil with a directory
- …

Directory Organization

- Organize directories to achieve
  - **efficiency**: to locate a file quickly
  - **naming**: organize the directory structure to be convenient to users
    - two users can have same name for different files
    - the same file can have several different names
- **grouping**: provide a way to logically group files by properties
  - e.g., all Java programs, all games, …
- …

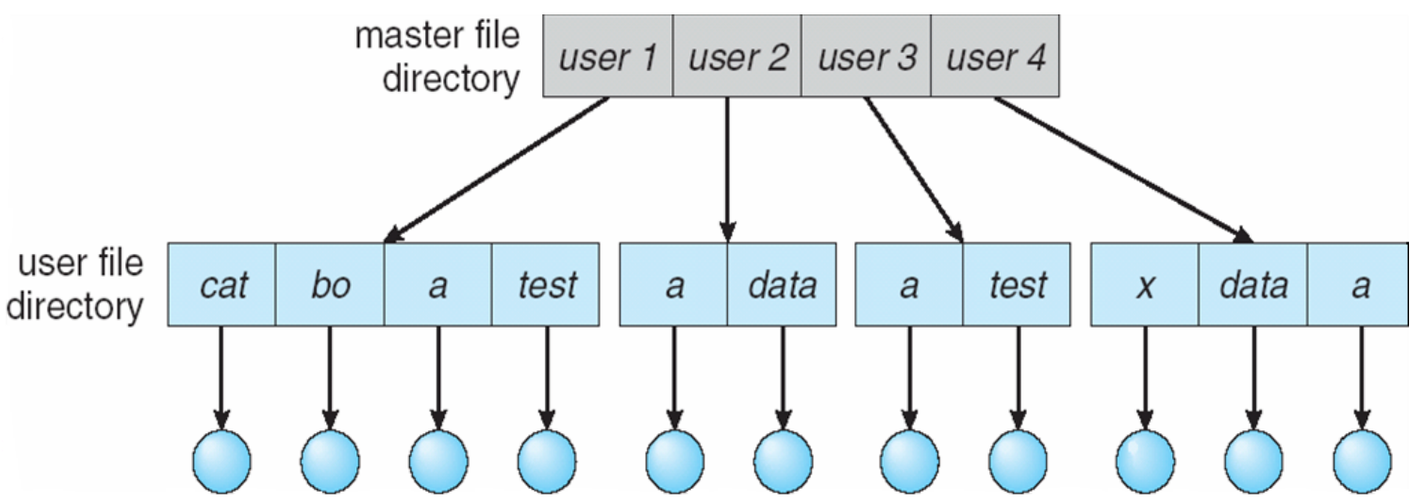
Single-Level Directory

- A single directory for all users
  - naming problems and grouping problems
    - Two users want to have same file names
  - Hard to group files



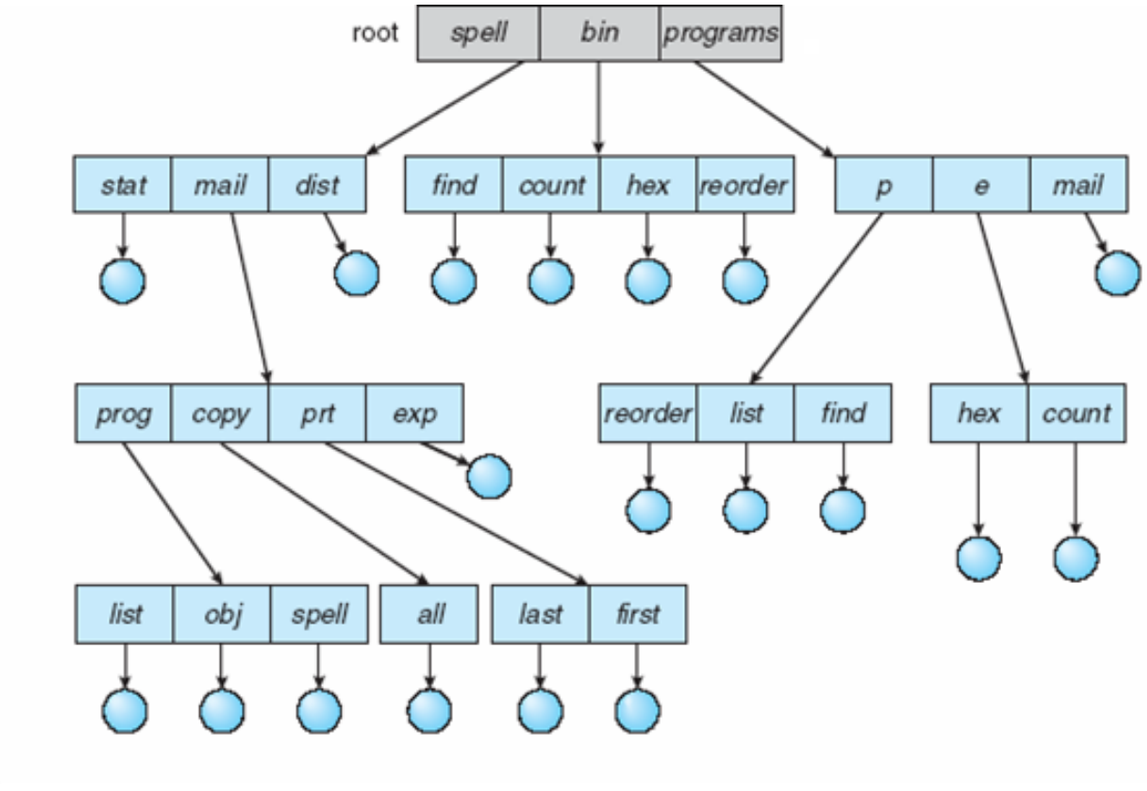
Two-Level Directory

- Separate directory for each user
  - different user can have the same name for different files
    - Each user has his own user file directory (UFD), it is in the master file directory (MFD)
  - efficient to search, cannot group files
- How to share files between different users, and how to share the system files?



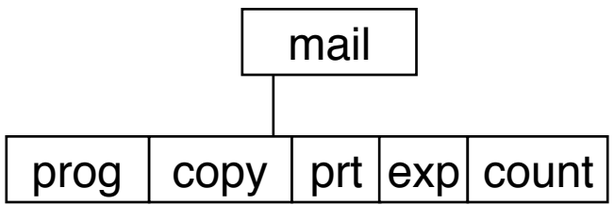
Tree-Structured Directories

- Files organized into trees
  - efficient in searching, can group files, convenient naming



Tree-Structured Directories

- File can be accessed using **absolute** or **relative** path name
  - absolute path name: /home/alice/..
  - relative path is relative to the **current directory** (*pwd*)
    - creating a new file, delete a file, or create a sub-directory
      - e.g., if current directory is /mail, a **mkdir count** will create /mail/count
- How to share a file/directory? -> it's not allowed

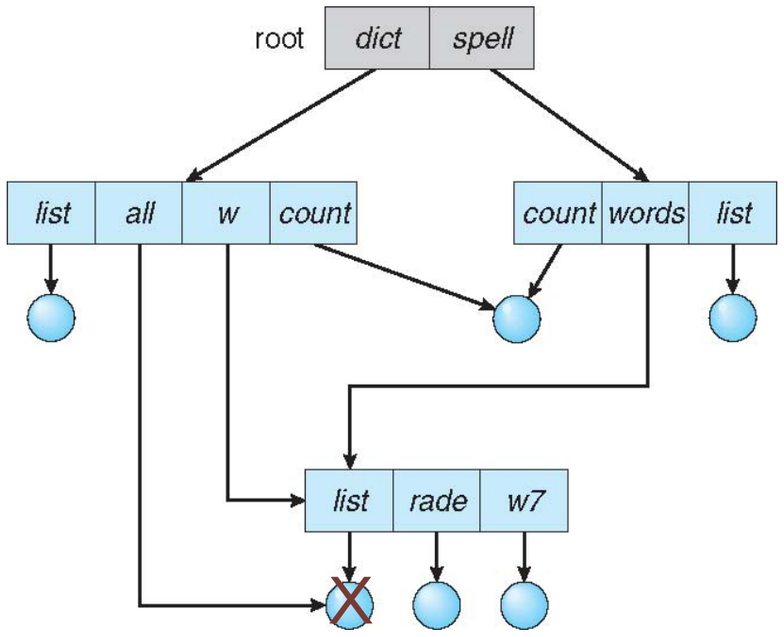


Tree-Structured Directories

- Delete directory
  - If directory is empty, then it's easy to handle
  - If not
    - Option I: directory cannot be deleted, unless it's empty
    - Option II: delete all the files, directories and sub-directories
    - rm -rf /

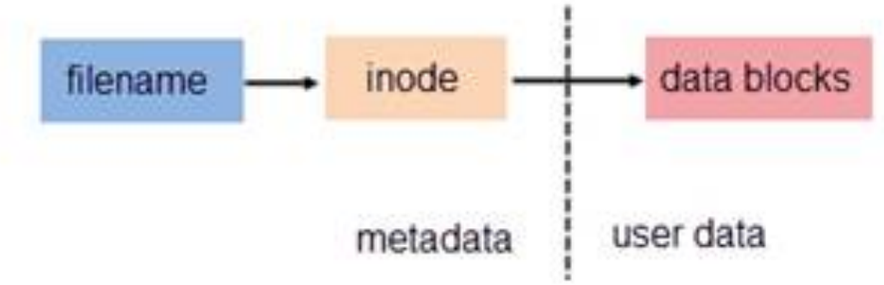
Acyclic-Graph Directories

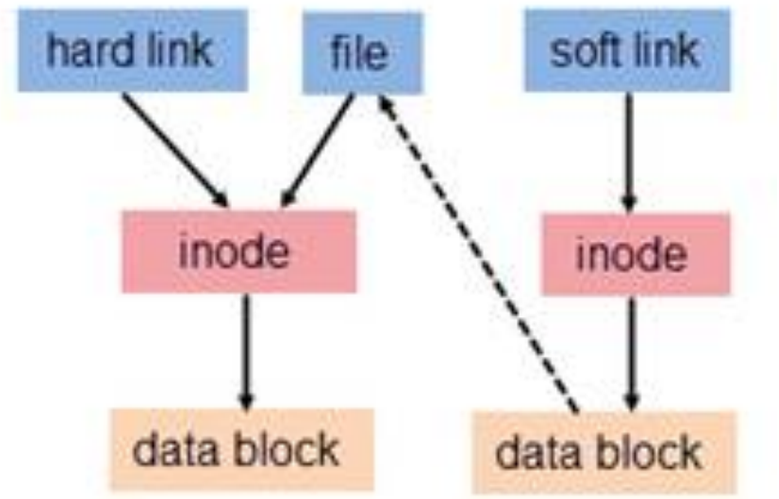
- Organize directories into acyclic-graphs
  - allow links to a directory entry/files for **aliasing** (no longer a tree)
- Dangling pointer problem:
  - e.g., if delete **file** /dict/all, /dict/w/list and /spell/words/list are dangling pointers
  - Solution: **backpointers/reference counter**
    - backpointers record all the pointers to the entity, a variable size record
    - Or count # of links to it and only (physically) delete it when counter is zero



Acyclic-Graph Directories

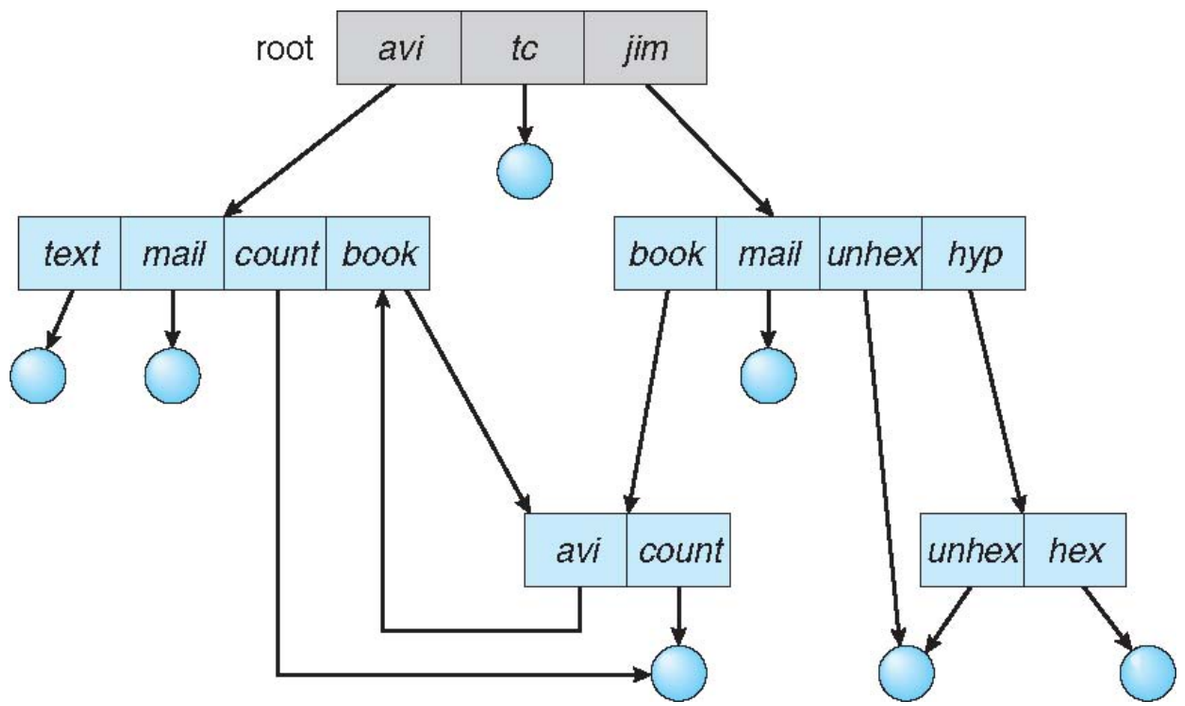
- Share files
  - Hardlink
    - Reference count
  - Softlink





General Graph Directory

- Allowing arbitrary links may generate cycles in the directory structure
- Solution
  - allow cycles, but use **garbage collection** to reclaim disk spaces
  - every time a new link is added use a **cycle detection** algorithm



Review

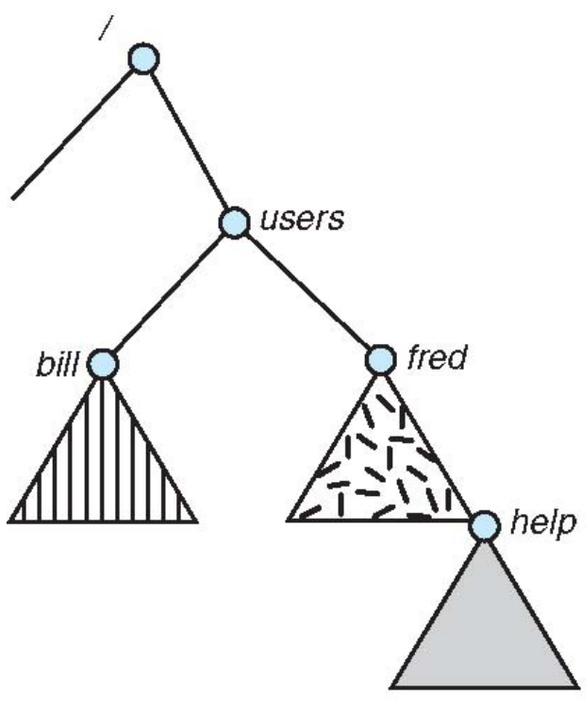
- File attributes
- File operations: create, open/close, read/write, seek, delete, truncate
- Opened files
  - Two tables: open-file table, system-wide table
- File lock: shared vs exclusive, advisory vs mandatory
- File type
- Access method
- Directory operations: create/delete a file, list, search,
- Directory structure: single, two, tree, acyclic-graph, general graph
  - Hardlink vs softlink

File System Mounting

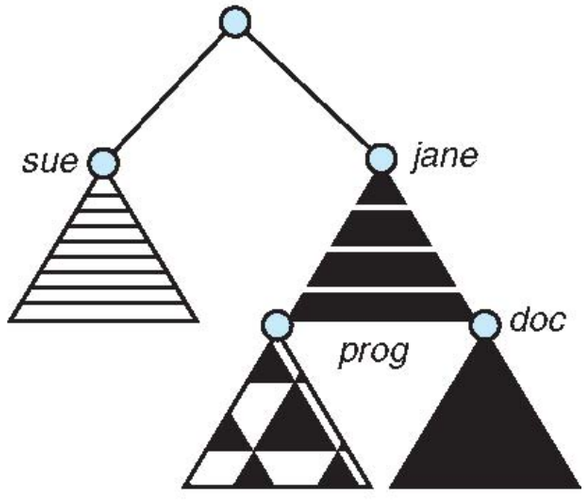
- A file system must be **mounted** before it can be accessed
  - mounting link a file system to the system, usually forms a **single name space**
  - the location of the file system being mounted is call the **mount point**
  - a mounted file system makes the old directory at the mount point **invisible**

File System Mounting

- **a**: existing file system
- **b**: an unmounted partition
- **c**: the partition mounted at **/users**



(a)



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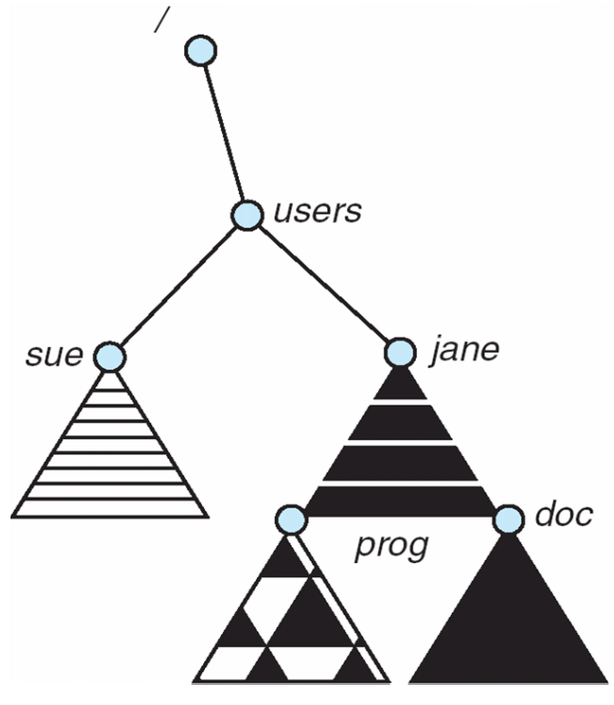


(c)

File Sharing

- Sharing of files on multi-user systems is desirable
  - sharing must be done through a protection scheme
    - **User ID**s identify users, allowing protections to be per-user
    - **Group ID**s allow users to be in groups, permitting group access rights
- On distributed systems, files may be shared across a network
  - Network File System (NFS) is a common distributed file-sharing method

Remote File Sharing

- **Use networking** to allow file system access between systems
  - manually via programs like FTP
  - automatically, seamlessly using distributed file systems
  - semi automatically via the world wide web
- Client-server model allows clients to **mount** remote FS from servers
  - a server can serve multiple clients
  - client and user-on-client identification is complicated
    - server cannot assume the client is trusted
    - standard OS file calls are translated into remote calls
  - **NFS** is standard UNIX file sharing protocol, **CIFS** is standard for Windows

Protection

- File owner/creator should be able to control
  - what can be done
  - by whom
- Types of access
  - read, write, append
  - execute
  - delete
  - list

ACL

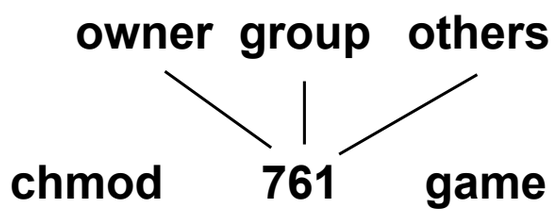
- Assign each file and directory with an access control list (ACL)
- Advantages: fine-grained control
- Disadvantages
  - How to construct the list
  - How to store the list in directory

Unix Access Control

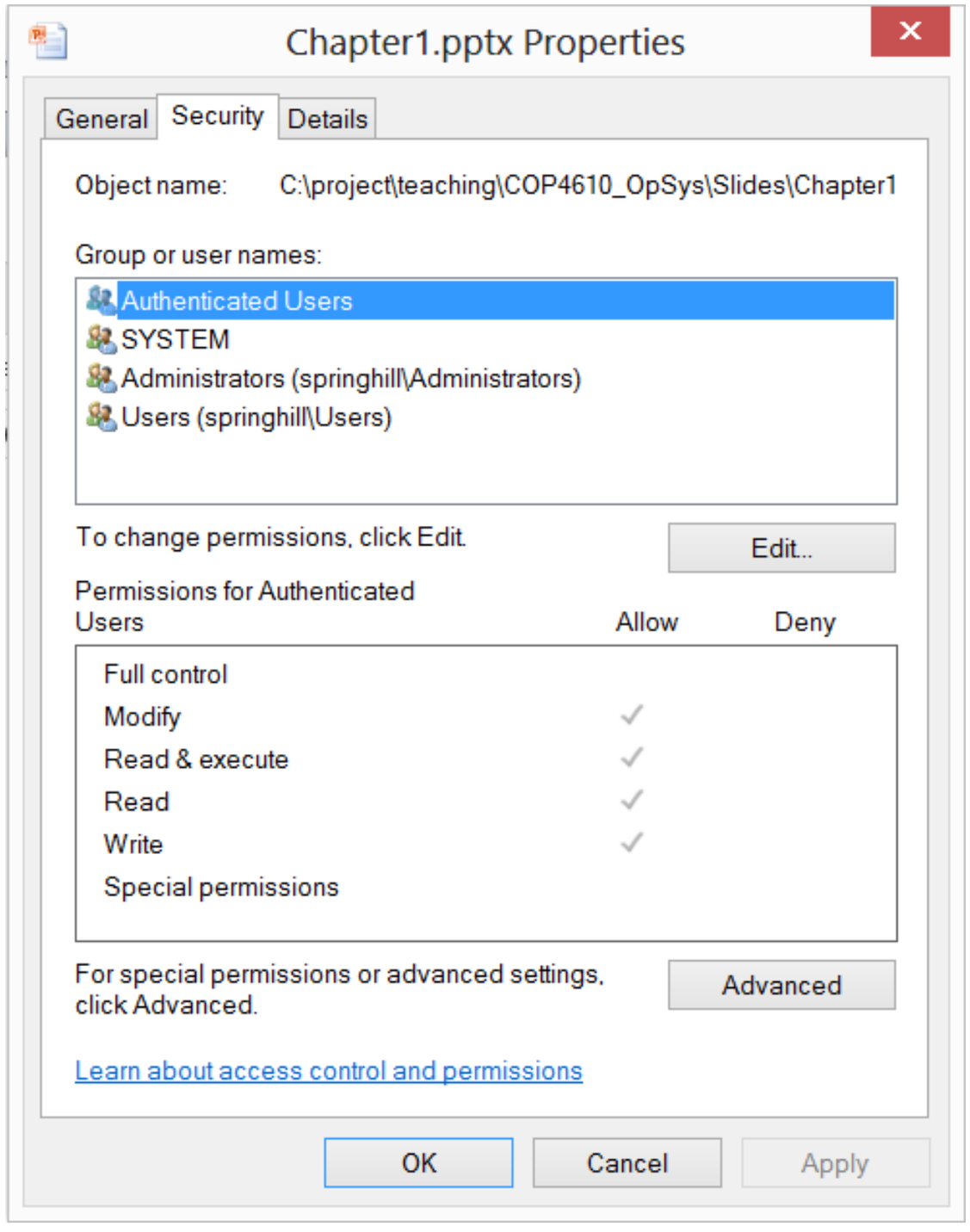
- Three modes of access: **read**, **write**, **execute** (encoded in three bits)
- Three classes of users: **owner**, **group**, and **others**

		RWX
a) owner access:	7	1 1 1
b) group access:	6	1 1 0
c) others access:	1	0 0 1

- To grant access to users, create a group and change its access mode
  - in Linux, use **chmod** and **chgrp**



Windows 8 File Access-Control



A Sample UNIX Directory Listing

-rw-rw-r--	1 pbg	staff	31200	Sep 3 08:30	intro.ps
drwx------	5 pbg	staff	512	Jul 8 09.33	private/
drwxrwxr-x	2 pbg	staff	512	Jul 8 09:35	doc/
drwxrwx---	2 pbg	student	512	Aug 3 14:13	student-proj/
-rw-r--r--	1 pbg	staff	9423	Feb 24 2003	program.c
-rwxr-xr-x	1 pbg	staff	20471	Feb 24 2003	program
drwx--x--x	4 pbg	faculty	512	Jul 31 10:31	lib/
drwx------	3 pbg	staff	1024	Aug 29 06:52	mail/
drwxrwxrwx	3 pbg	staff	512	Jul 8 09:35	test/

ACL in practice

```
os@os:~/os2018fall/test$ ls -l
total 0
-rw-rw-r-- 1 os os 0 Dec 18 23:21 testacl
os@os:~/os2018fall/test$ getfacl testacl
# file: testacl
# owner: os
# group: os
user::rw-
group::rw-
other::r--

os@os:~/os2018fall/test$ setfacl -m u:test:rw testacl
os@os:~/os2018fall/test$ getfacl testacl
# file: testacl
# owner: os
# group: os
user::rw-
user:test:rw-
group::rw-
mask::rw-
other::r--

os@os:~/os2018fall/test$ ls -l
total 0
-rw-rw-r--+ 1 os os 0 Dec 18 23:21 testacl
os@os:~/os2018fall/test$
```