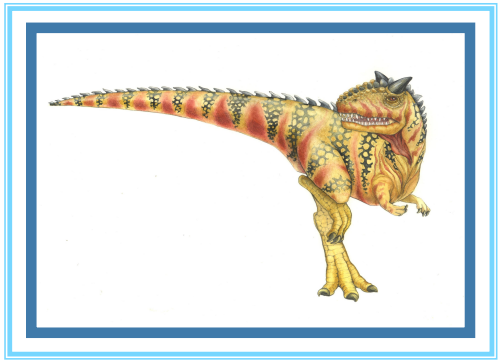
Chapter 9: File-System Interface



Chapter 9: File-System Interface

- File Concept
- Access Methods
- Disk and Directory Structure
- File-System Mounting
- File Sharing
- Protection

Objectives

- To explain the function of file systems
- To describe the interfaces to file systems
- To discuss file-system design tradeoffs, including access methods, file sharing, file locking, and directory structures
- To explore file-system protection

File Concept

- Uniform logical view of information storage (no matter the medium)
- OS abstracts from physical properties into a logical storage unit, the **file**
- Files mapped onto physical devices, usually nonvolatile
- File is a collection of related information
  - Smallest allotment of nameable storage
- Contiguous logical address space
- Types:
  - Data
    - numeric
    - character
    - binary
  - Program
  - May be free form or rigidly formed (**structured**)

File Structure

- None - sequence of words, bytes
- Simple record structure
  - Lines
  - Fixed length
  - Variable length
- Complex Structures
  - Formatted document
  - Relocatable load file
- Can simulate last two with first method by inserting appropriate control characters
- Who decides:
  - Operating system
  - Program / programmer

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
  - Typically file's name and identifier
    - Identifier locates other file attributes
- Attributes may be > 1KB
- Directory structures may be > 1MB

File Operations

- File is an **abstract data type**
- Operations include the following (and usually more)
- **Create** – find space, add entry to directory
- **Write** – write data at **current file position pointer** location and update pointer
- **Read** – read file contents at pointer location, update pointer
- **Reposition within file (seek)** – change pointer location
- **Delete** – free space and remove entry from directory
- **Truncate** – delete data starting at pointer

Open Files

- `Open(F_i)` – allow process to access a file
  - Returns a **file handle** for system call reference to the file
  - Search the directory structure on disk for entry F_i, and move the content or cache some of entry to memory
- `Close(file handle)` – end processes' access to the file
  - Move the content of entry F_i in memory to directory structure on disk

Open File Data Structures

- Usually a global table containing process-independent open file information
  - Size
  - Access dates
  - Disk location of the file: cache of data access information
  - File-open count: counter of number of times a file is open
    - To allow removal of data from **open-file table** when last processes closes it
- Per-process open file table contains pertinent info, plus pointer to entry in global open file table
  - Current file position pointer: pointer to next read/write location
  - Access rights: per-process access mode information
    - read, write, append

Open File Locking

- Provided by some operating systems and file systems
- Mediates access to a file
  - shared
  - exclusive
- Mandatory or advisory:
  - **Mandatory** – access is denied depending on locks held and requested
  - **Advisory** – processes can find status of locks and decide what to do

File Locking Example – Java API

```
import java.io.*;
import java.nio.channels.*;
public class LockingExample {
    public static final boolean EXCLUSIVE = false;
    public static final boolean SHARED = true;
    public static void main(String arsg[]) throws IOException {
        FileLock sharedLock = null;
        FileLock exclusiveLock = null;
        try {
                RandomAccessFile raf = new RandomAccessFile("file.txt", "rw");
                // get the channel for the file
                FileChannel ch = raf.getChannel();
                // this locks the first half of the file - exclusive
                exclusiveLock = ch.lock(0, raf.length()/2, EXCLUSIVE);
                /** Now modify the data . . . */
                // release the lock
                exclusiveLock.release();
```

File Locking Example – Java API (Cont.)

```
                // this locks the second half of the file - shared
                sharedLock = ch.lock(raf.length()/2+1, raf.length(),
                SHARED);
                /** Now read the data . . . */
                // release the lock
                sharedLock.release();
            } catch (java.io.IOException ioe) {
                System.err.println(ioe);
            }finally {
                if (exclusiveLock != null)
                exclusiveLock.release();
                if (sharedLock != null)
                sharedLock.release();
            }
        }
    }
```

File Types

- Most operating systems recognize file types
  - Filename *extension*
  - I.e. resume.doc, server.java, readerthread.c
- Most support them
  - Automatically open a type of file via a specific application (.doc)
  - Only execute files of a given extension (.exe, .com)
  - Run files of a given type via a scripting language (.bat)
- Can get more advanced
  - If source code modified since executable compiled, if attempt made to execute, recompile and then execute (TOPS-20)
  - Mac OS encodes creating program's name in file attributes
    - Double clicking on file passes the file name to appropriate application
  - Unix has **magic number** stored in file at first byte indicating file type

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 com-pressed, for archiving or storage
multimedia	mpeg, mov, rm, mp3, avi	binary file containing audio or A/V information

File Structure

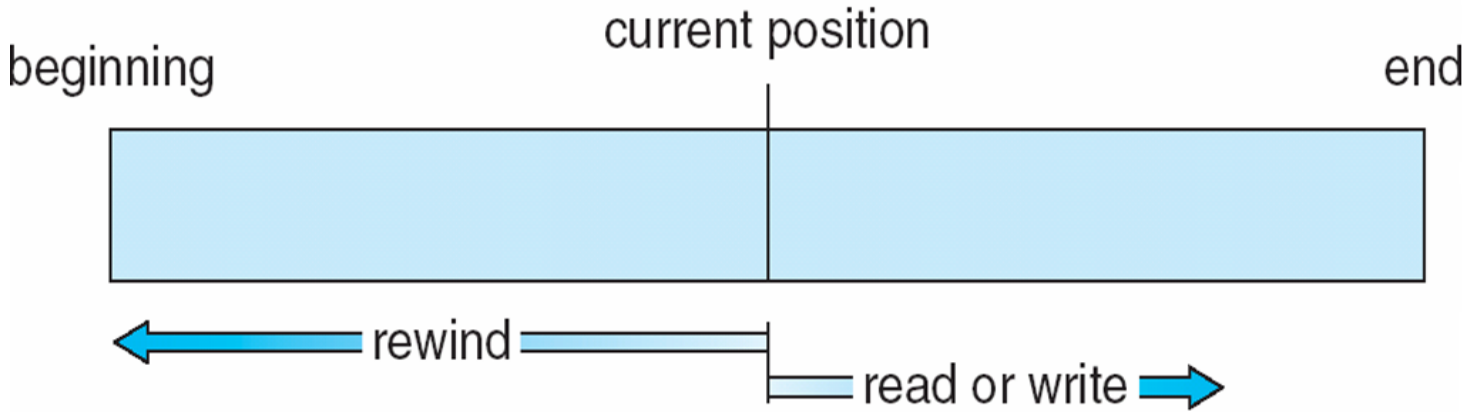
- Types can indicate internal file structure
  - Some Oses enforce, some use as hints, some ignore
- But some most conform to OS-required format
  - I.e. executable file
  - Some support more formats
    - DEC VMS supported 3
  - The more that are supported, the more kernel code, etc
  - Some enforce access methods
  - Others allow arbitrary access
    - Unix supports directory files, executable files
    - But all files are strings of bytes
      - Can open a directory file via a text editor
- Files stored in fixed-size disk blocks
  - Can have internal fragmentation

Access Methods

- **Sequential Access –** tape model of a file
  - read next
  - write next
  - reset
  - no read after last write
    - (rewrite)
- **Direct Access –** random access, relative access
  - read *n*
  - write *n*
  - position to *n*
    - read next
    - write next
  - rewrite *n*

  n = relative block number
- Can accommodate structured data in file by mapping record number to block number
- Oses usually support both kinds, sometimes require access method declaration during `create()`

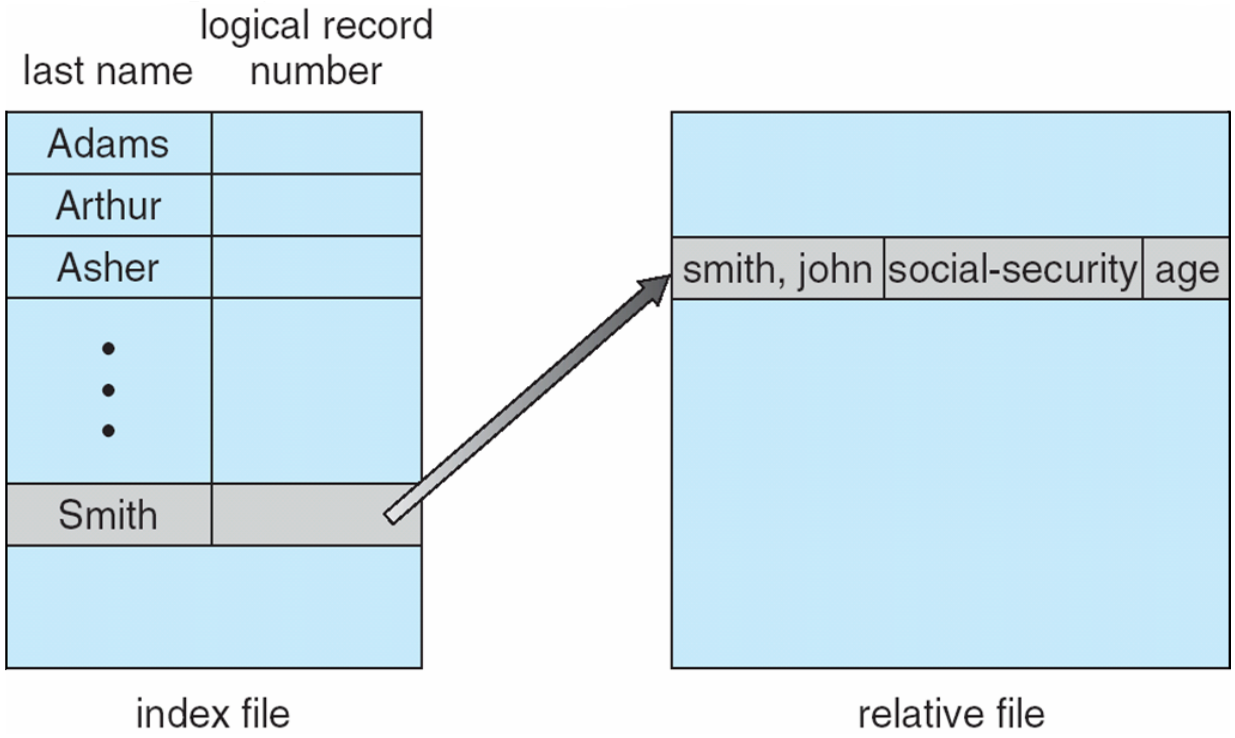
Sequential-access File



Simulation of 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*; $cp = cp + 1;$

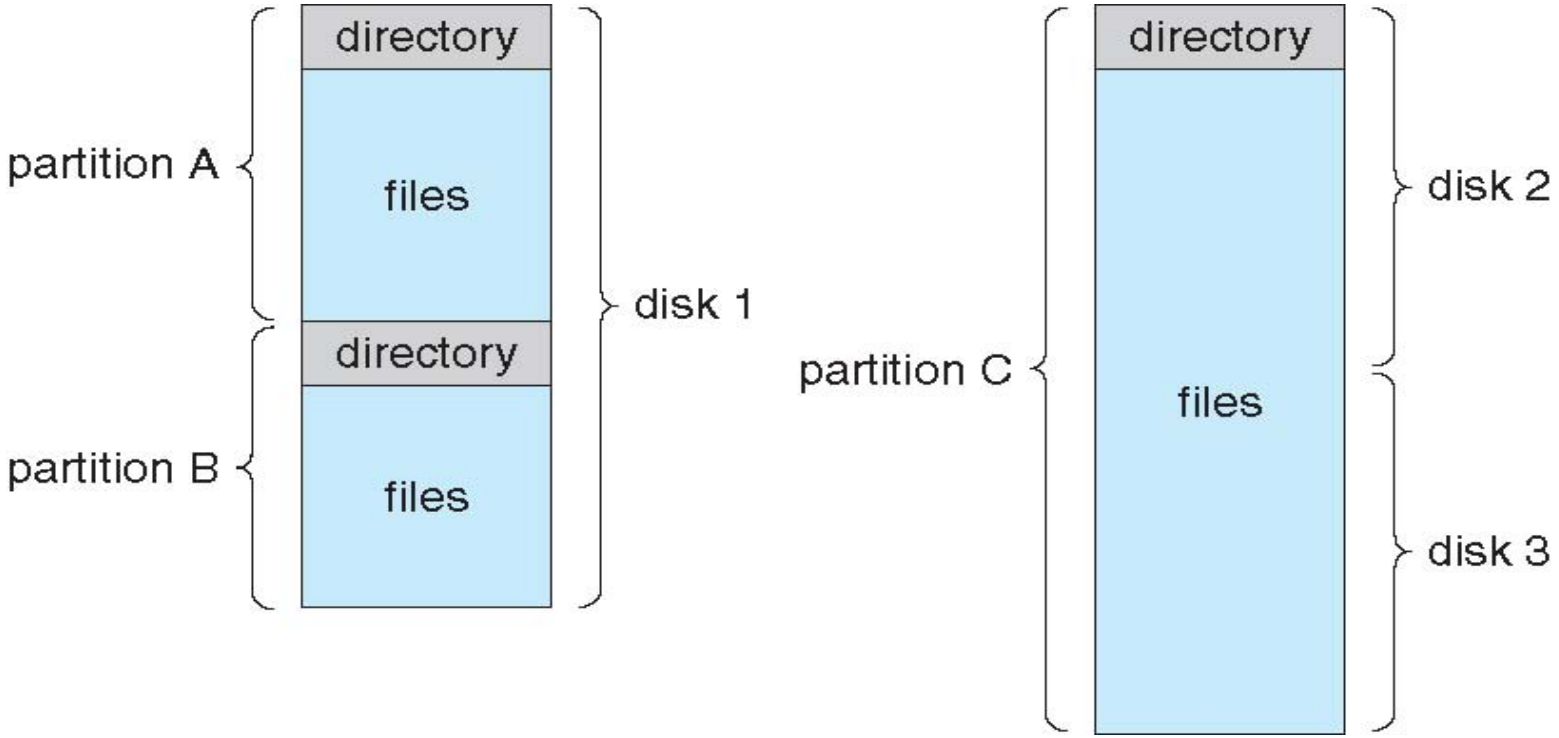
Example of Index and Relative Files



Disk Structure

- Disk can be subdivided into **partitions**
- Disks or partitions can be **RAID** protected against failure
- Disk or partition can be used **raw** – without a file system, or **formatted** with a file system
- Partitions also known as **minidisks**, **slices**
- Entity containing file system known as a **volume**
- Each volume containing file system also tracks that file system's info in **device directory** or **volume table of contents** or **directory)**
  - Records information for all files on the volume
- As well as **general-purpose file systems** there are many **special-purpose file systems**, frequently all within the same operating system or computer

A Typical File-system Organization



File System Types

- Operating systems have multiple file system types
  - One or more general-purpose (for storing user files)
  - One or more special-purpose, i.e.
    - **tmpfs**—"temporary" file system in volatile main memory, contents erased if the system reboots or crashes
    - **objfs**—a "virtual" file system (essentially an interface to the kernel that looks like a file system) that gives debuggers access to kernel symbols
    - **ctfs**— a virtual file system that maintains "contract" information to manage which processes start when the system boots and must continue to run during operation
    - **lofs**—a "loop back" file system that allows one file system to be accessed in place of another one
    - **procfs**—a virtual file system that presents information on all processes as a file system

Directory Overview

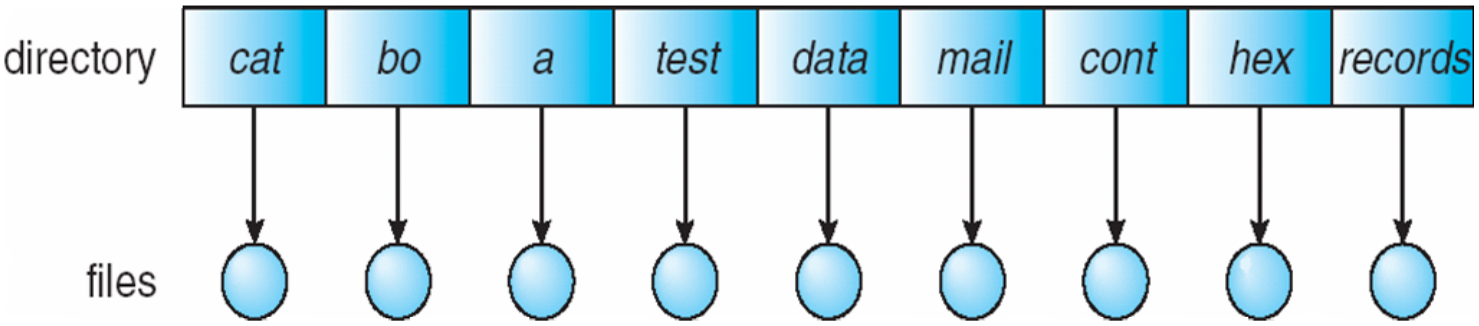
- Directory similar to symbol table translating file names to their directory entries
  - Can be organized in many ways
- Organization needs to support operations including:
  - Search for a file or multiple files
  - Create a file
  - Delete a file
  - List a directory
  - Rename a file
  - Traverse the file system

Directory Organization

- Should have the features
  - Efficiency – locating a file quickly
  - Naming – convenient to users
    - Two users can have same name for different files
    - The same file can have several different names
  - Grouping – logical grouping of files by properties, (e.g., all Java programs, all games, …) or arbitrarily

Single-Level Directory

- A single directory for all users

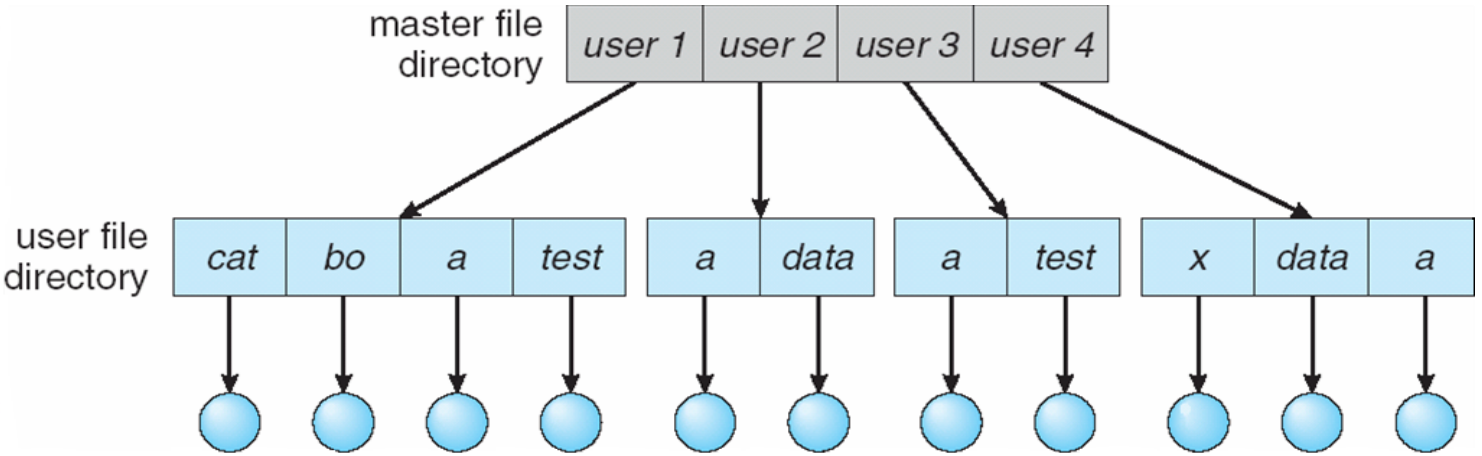


Naming problem

Grouping problem

Two-Level Directory

- Separate directory for each user

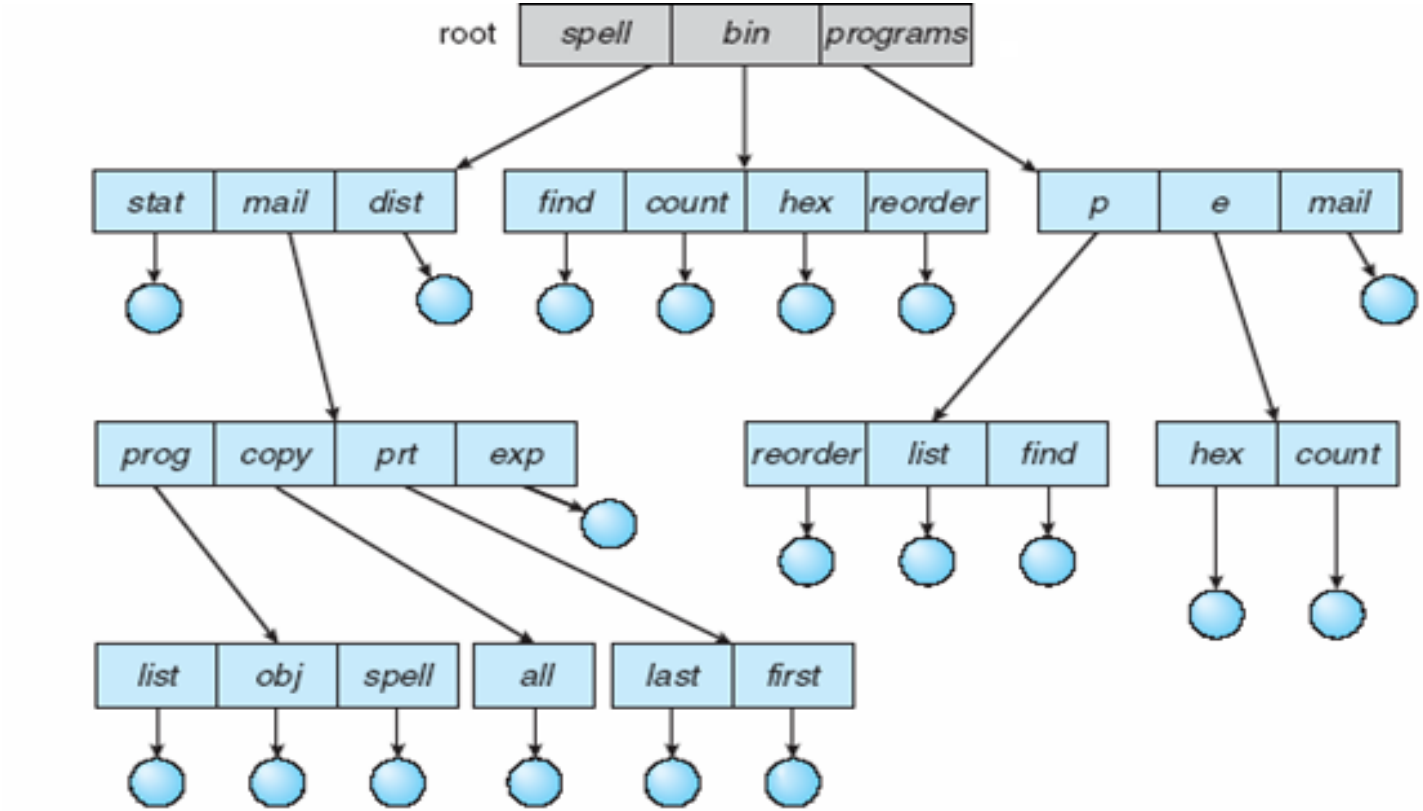


- Path name
- Can have the same file name for different users
- Efficient searching
- No grouping capability

Added Directory Concepts

- Many variations, but some components essential
- Idea of **current directory** – default location for activities
- Now need a **path** specification
  - If file is in current directory, just name it
  - If in another directory, must specify by more detailed name
  - Also need way to specify different filesystems
  - MS-DOS gives letter to each volume, "\" separates directory name from file name – C:\userb\test
  - VMS uses letter for volume and "[]" for directory specification – u:[sst.jdeck]login.com;1
    - Note the support for versions via the trailing number
  - Unix treats volume name as part of directory name - /u/pbg/test
- Many Oses search a set of paths for command names
  - "ls" might search in current directory then in system directories

Tree-Structured Directories



Tree-Structured Directories (Cont.)

- Most common
- For example, allows users to can create directories within their directory
- Directory can then contain files or other directories
- Directory can be another file with defined formatting and attribute indicating its type
- Separate system calls to manage directory actions
- Absolute path is full specification of file local - /foo/bar/baz
- Relative path is location relative to current directory - ../baz
- Efficient searching
  - Search path
- Grouping Capability
- Current directory (working directory)
  - **cd /spell/mail/prog**
  - **type list**

Tree-Structured Directories (Cont)

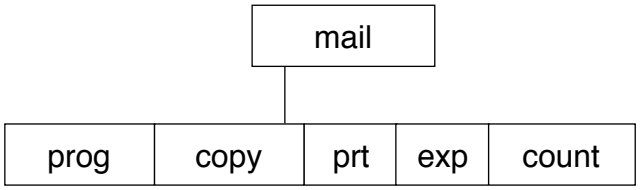
- Creating a new file is done in current directory
- Delete a file

  rm <file-name>
- Creating a new subdirectory is done in current directory

  mkdir <dir-name>

  Example: if in current directory **/mail**

  mkdir count

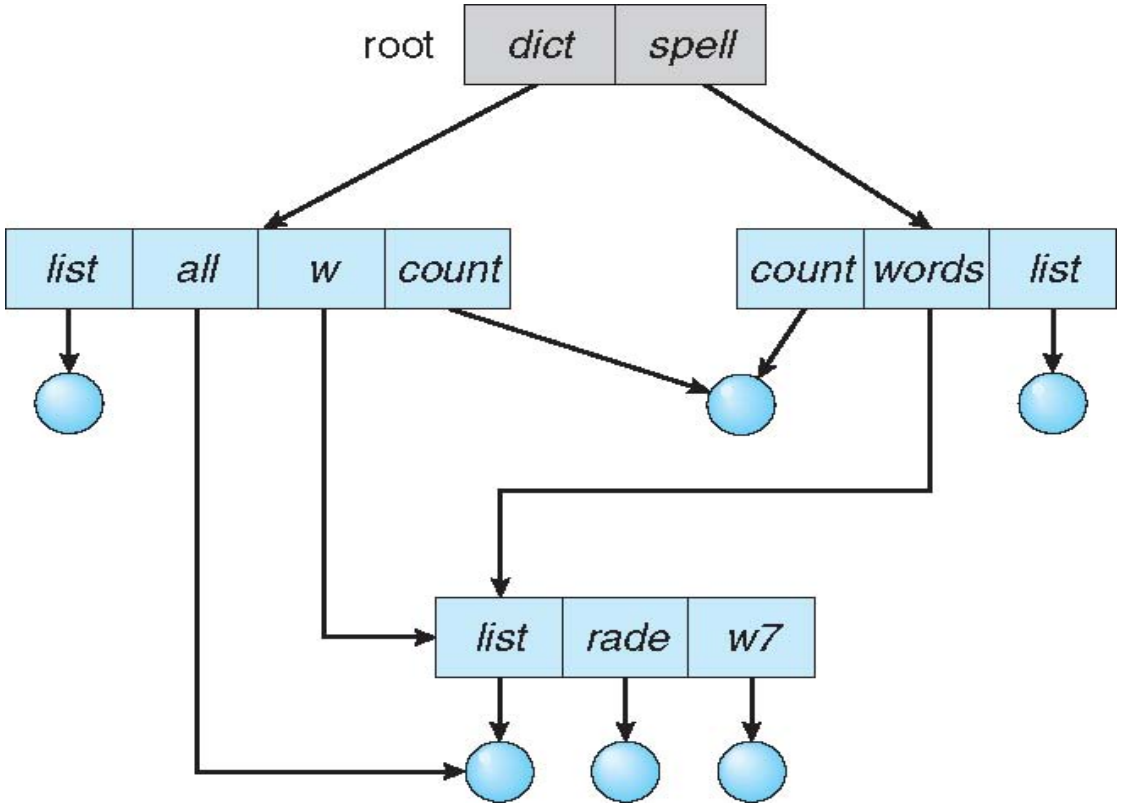


Deleting "mail" ⇒ deleting the entire subtree rooted by "mail"?

- Make users manually delete contents (and subcontents) first (MS-DOS)
- Provide an option to delete all contents (Unix)

Acyclic-Graph Directories

- Have shared subdirectories and files

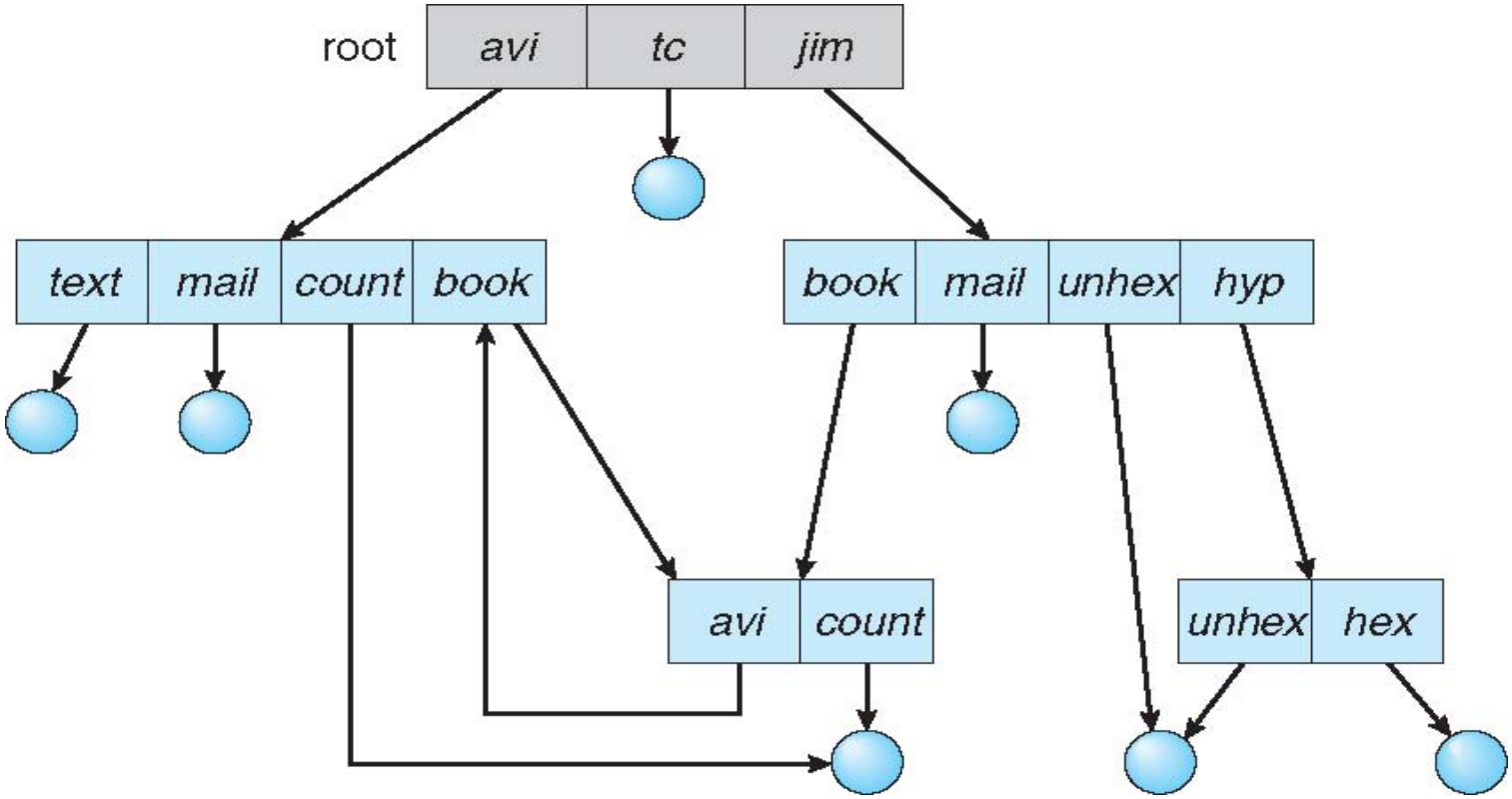


Acyclic-Graph Directories (Cont.)

- Adds ability to directly share directories between users
  - But can now have multiple absolute paths to the same file
- Two different names (aliasing)
- If *dict* deletes *list* ⇒ dangling pointer

  Solutions:
  - Backpointers, so we can delete all pointers
    Variable size records a problem
  - Entry-hold-count solution
- New directory entry type
  - **Link** – another name (pointer) to an existing file
    - Indirect pointer
    - Delete link separate from the files
    - Hard and symbolic
  - **Resolve the link** – follow pointer to locate the file

General Graph Directory



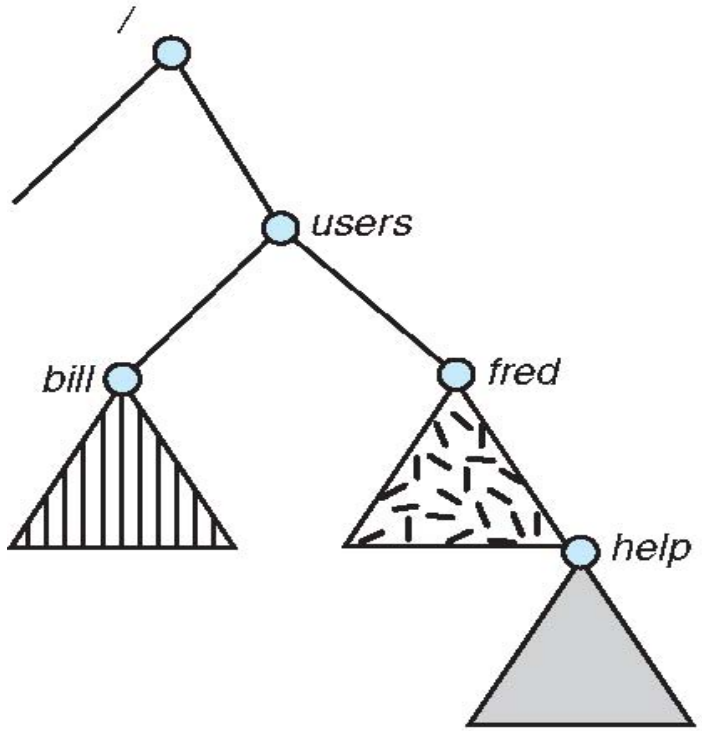
General Graph Directory (Cont.)

- How do we guarantee no cycles?
  - Allow only links to file not subdirectories
  - Garbage collection
  - Every time a new link is added use a cycle detection algorithm to determine whether it is OK
  - Or just bypass links during directory traversal

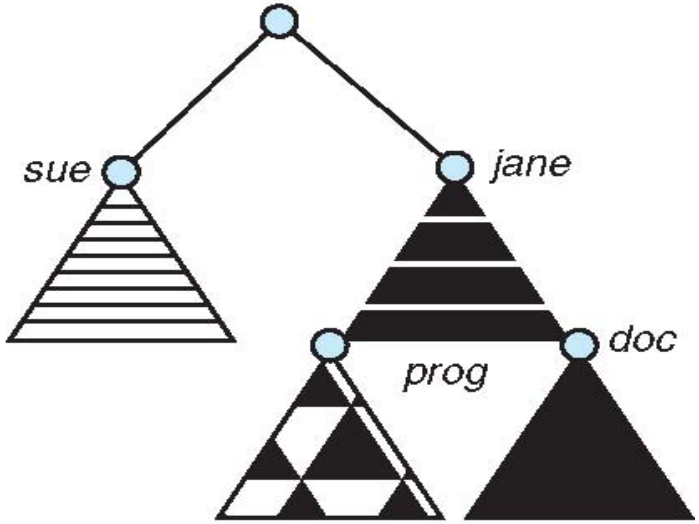
File System Mounting

- A file system must be **mounted** before it can be accessed
  - Privileged operation
  - First check for valid file system on volume
  - Kernel data structure to track mount points
- Some systems have separate designation for mount point (i.e. “c:”)
- Others integrate mounted file systems into existing directory naming system
  - In separate space (i.e. /volumes) or within current name space
- A unmounted file system on */device/dsk* (i.e., Fig. 11-11(b)) is mounted at a **mount point**
- What if the mount point already has contents?
- Configuration file or data structure to track default mounts
  - Used at reboot or to reset mounts
- What if files are open on a device that is being **unmounted**?

(a) Existing (b) Unmounted Partition

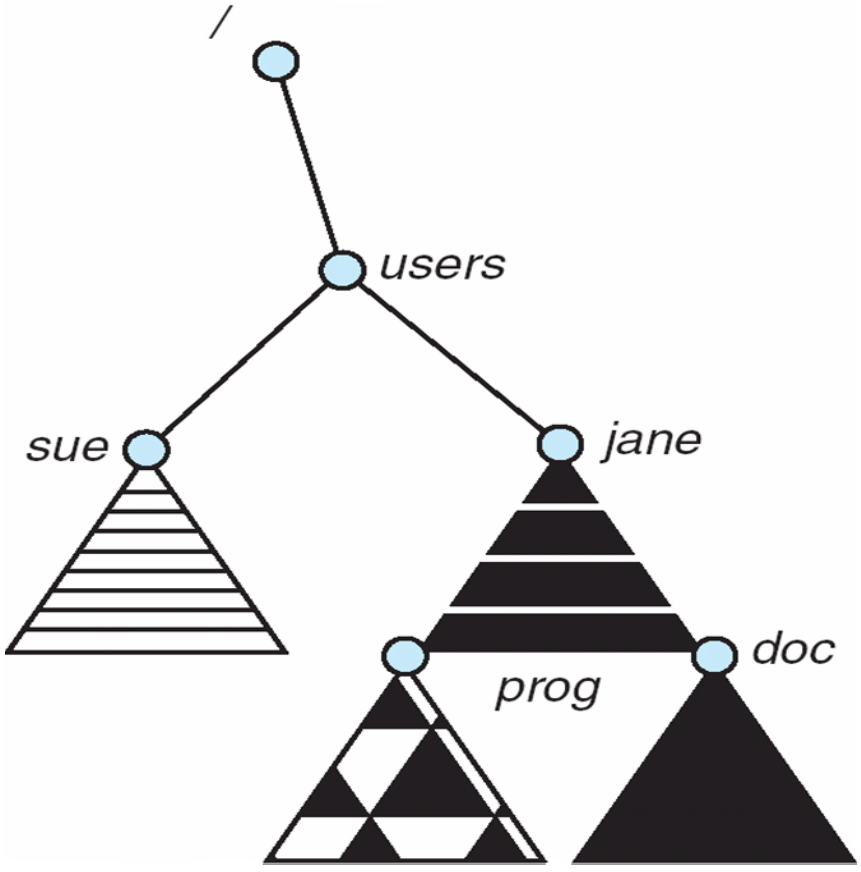


(a)



(b)

Mount Point



File Sharing

- Sharing of files on multi-user systems is desirable
- Sharing may be done through a **protection** scheme
- On distributed systems, files may be shared across a network
- Network File System (NFS) is a common distributed file-sharing method

File Sharing – Multiple Users

- **User IDs** identify users, allowing permissions and protections to be per-user
- **Group IDs** allow users to be in groups, permitting group access rights

File Sharing – Remote File Systems

- Uses 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**
    - Using FTP under the covers
- **Client-server** model allows clients to mount remote file systems from servers
  - Server can serve multiple clients
  - Client and user-on-client identification is insecure or complicated
  - **NFS** is standard UNIX client-server file sharing protocol
  - **CIFS** is standard Windows protocol
  - Standard operating system file calls are translated into remote calls
- Distributed Information Systems **(distributed naming services)** such as **LDAP**, **DNS**, **NIS**, **Active Directory** implement unified access to information needed for remote computing
  - LDAP / Active Directory becoming industry standard -> **Secure Single Sign-on**
  - IP addresses can be **spoofed**
  - Protect remote access via firewalls
- Open file request to remote server first checked for client-to-server permissions, then user-id checked for access permissions, then file handle returned
  - Client process then uses file handle as it would for a local file

File Sharing – Failure Modes

- Remote file systems add new failure modes, due to network failure, server failure
  - Data or **metadata** loss or corruption
- Recovery from failure can involve state information about status of each remote request
- Stateless protocols such as NFS include all information in each request, allowing easy recovery but less security
  - But **stateless** protocols can lack features, so NFS V4 and CIFS are both **state-ful**

File Sharing – Consistency Semantics

- **Consistency semantics** specify how multiple users are to access a shared file simultaneously
  - Similar to Ch 7 process synchronization algorithms
    - Tend to be less complex due to disk I/O and network latency (for remote file systems)
  - Andrew File System (AFS) implemented complex remote file sharing semantics
  - Unix file system (UFS) implements:
    - Writes to an open file visible immediately to other users of the same open file
    - Sharing file pointer to allow multiple users to read and write concurrently
  - AFS has session semantics
    - Writes only visible to sessions starting after the file is closed
  - Easier to implement is **immutable shared files**
    - Once file is declared "shared", can't be renamed or modified

Protection

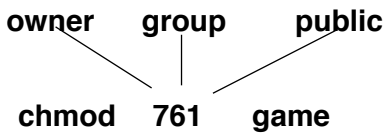
- File owner/creator should be able to manage **controlled access**:
  - What can be done
  - By whom
  - But never forget physical security
- Types of access
  - **Read**
  - **Write**
  - **Execute**
  - **Append**
  - **Delete**
  - **List**
  - Others can include renaming, copying, editing, etc
  - System calls then check for valid rights before allowing operations
    - Another reason for `open()`
  - Many solutions proposed and implemented

Access Lists and Groups

- Mode of access: read, write, execute
- Three classes of users

			RWX
a) **owner access**	7	⇒	1 1 1
b) **group access**	6	⇒	RWX 1 1 0
c) **public access**	1	⇒	RWX 0 0 1

- Ask manager to create a group (unique name), say G, and add some users to the group.
- For a particular file (say *game*) or subdirectory, define an appropriate access.



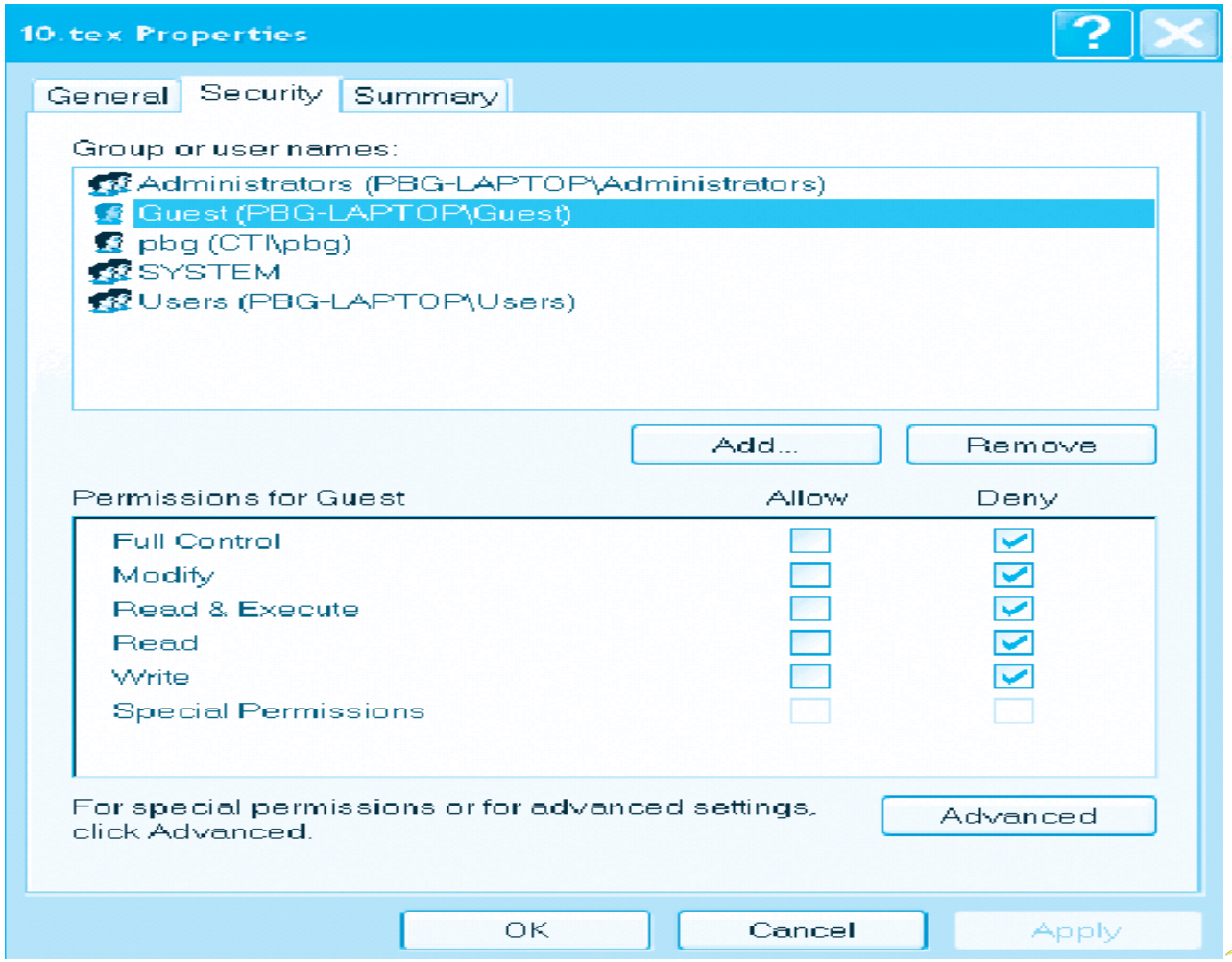
Attach a group to a file

chgrp G game

Access Control

- More generally solved via **access control lists**
  - For a given entity, keep list of user-ids allowed to access and what access methods
  - Constructing such as list can be tedious and unrewarding
  - Data structure must be stored somewhere
    - Variable size

Windows XP Access-Control List Management



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/

End of Chapter 9