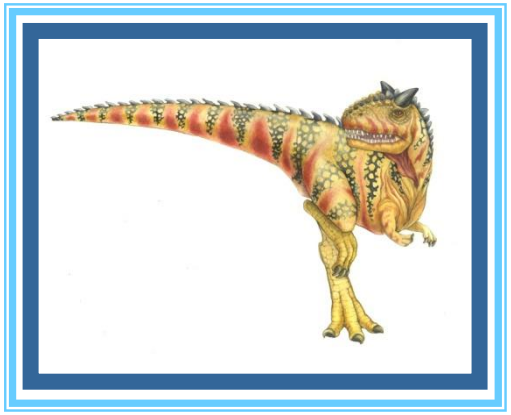
# Chapter 10: File System

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# Chapter 10: File System

- 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

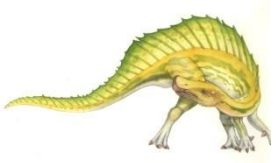
- Contiguous logical address space
- Types:
  - Data
    - numeric
    - character
    - binary
  - Program
- Contents defined by file's creator
  - Many types
    - Consider **text file, source file, executable file**

# 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

# 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
- Information kept in the directory structure



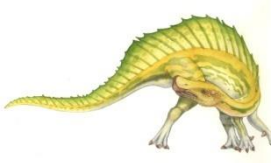
# File info Window on Mac OS X


# File Operations

- File is an **abstract data type**
- **Create**
- **Write –** at **write pointer** location
- **Read –** at **read pointer** location
- **Reposition within file - seek**
- **Delete**
- **Truncate**
- ***Open*($F_i$)** – search the directory structure on disk for entry $F_i$, and move the content of entry to memory
- ***Close*** ($F_i$) – move the content of entry $F_i$ in memory to directory structure on disk

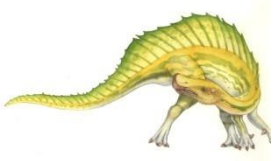
# Open Files

- Several pieces of data are needed to manage open files:
  - **Open-file table**: tracks open files
  - File pointer:  pointer to last read/write location, per process that has the file open
  - **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
  - Disk location of the file: cache of data access information
  - Access rights: per-process access mode information



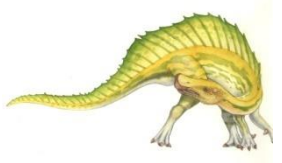
# Open File Locking

- Provided by some operating systems and file systems
  - Similar to reader-writer locks
  - **Shared lock** similar to reader lock – several processes can acquire concurrently
  - **Exclusive lock** similar to writer lock
- Mediates access to a file
- 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 – 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

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- Simple record structure
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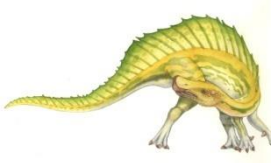
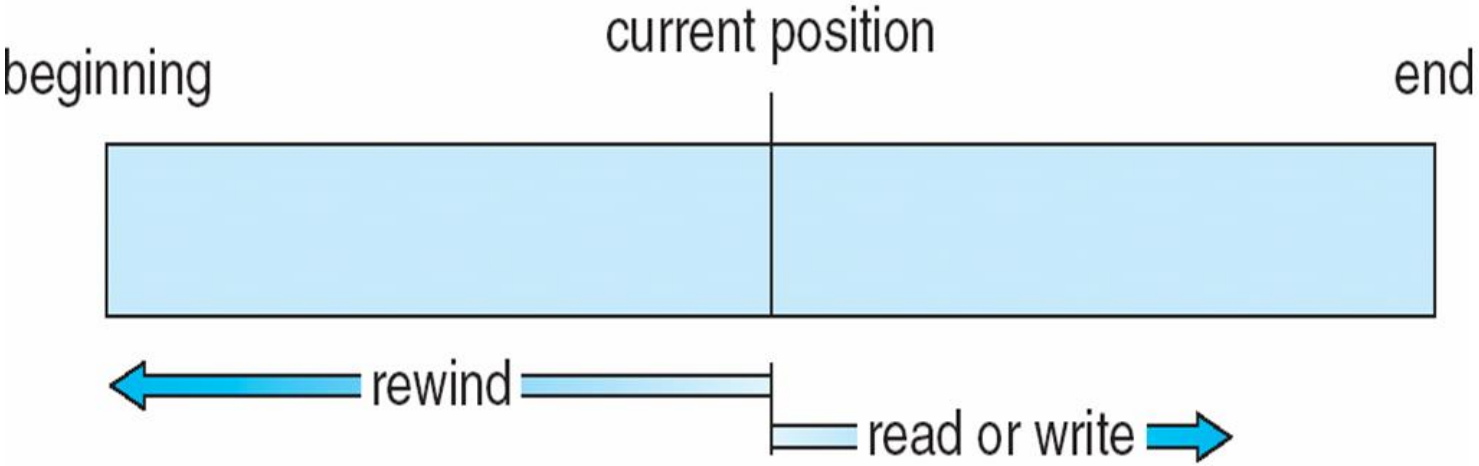


# Sequential-access File




# Access Methods

- **Sequential Access**

```
read next
write next
reset
no read after last write
        (rewrite)
```

- **Direct Access –** file is fixed length logical records

```
read n
write n
position to n
        read next
        write next
rewrite n
```

*n* = relative block number

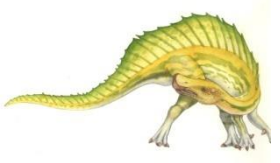
- Relative block numbers allow OS to decide where file should be placed
  - See allocation problem in Ch 11

# Simulation of Sequential Access on Direct-access File

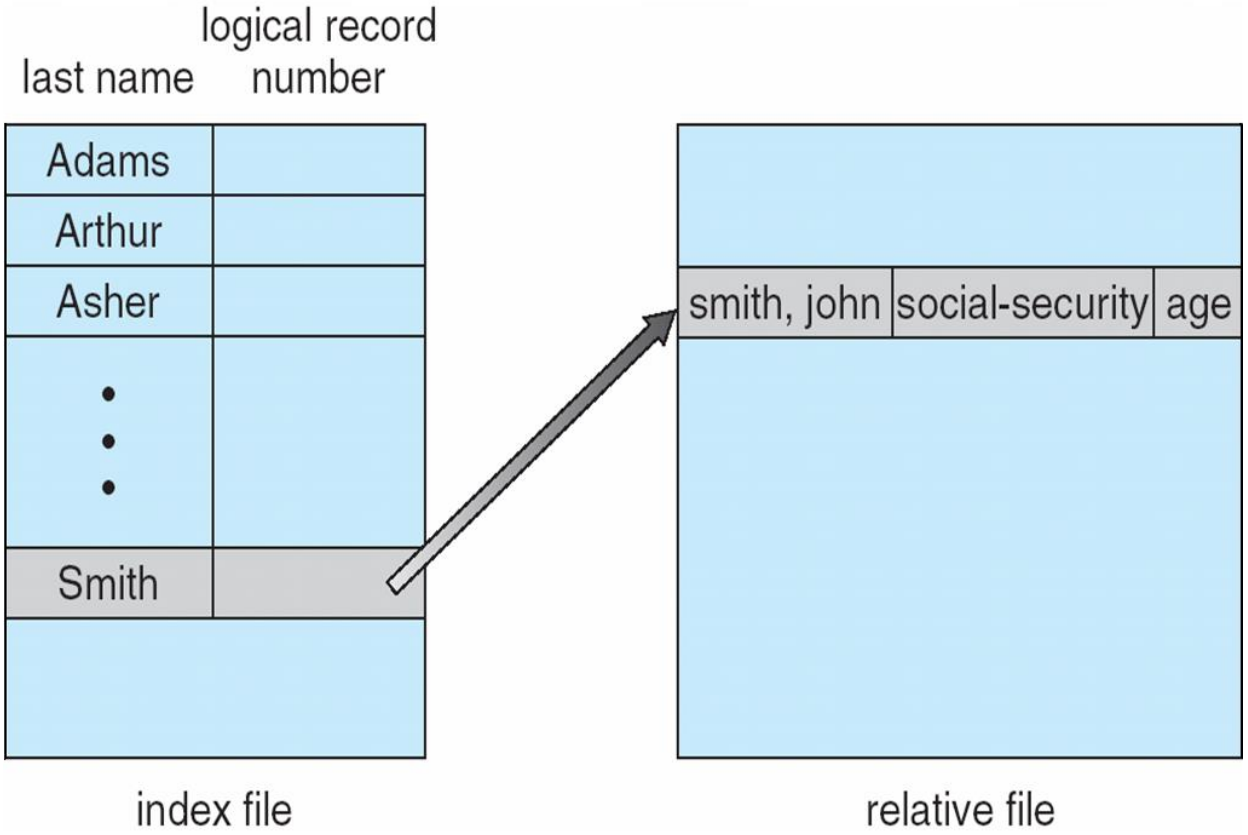
| sequential access | implementation for direct access |
|---|---|
| *reset* | $cp = 0;$ |
| *read next* | *read cp*;<br>$cp = cp + 1;$ |
| *write next* | *write cp*;<br>$cp = cp + 1;$ |

# Other Access Methods

- Can be built on top of base methods
- General involve creation of an index for the file
- Keep index in memory for fast determination of location of data to be operated on (consider UPC code plus record of data about that item)
- If too large, index (in memory) of the index (on disk)
- IBM indexed sequential-access method (ISAM)
  - Small master index, points to disk blocks of secondary index
  - File kept sorted on a defined key
  - All done by the OS
- VMS operating system provides index and relative files as another example (see next slide)

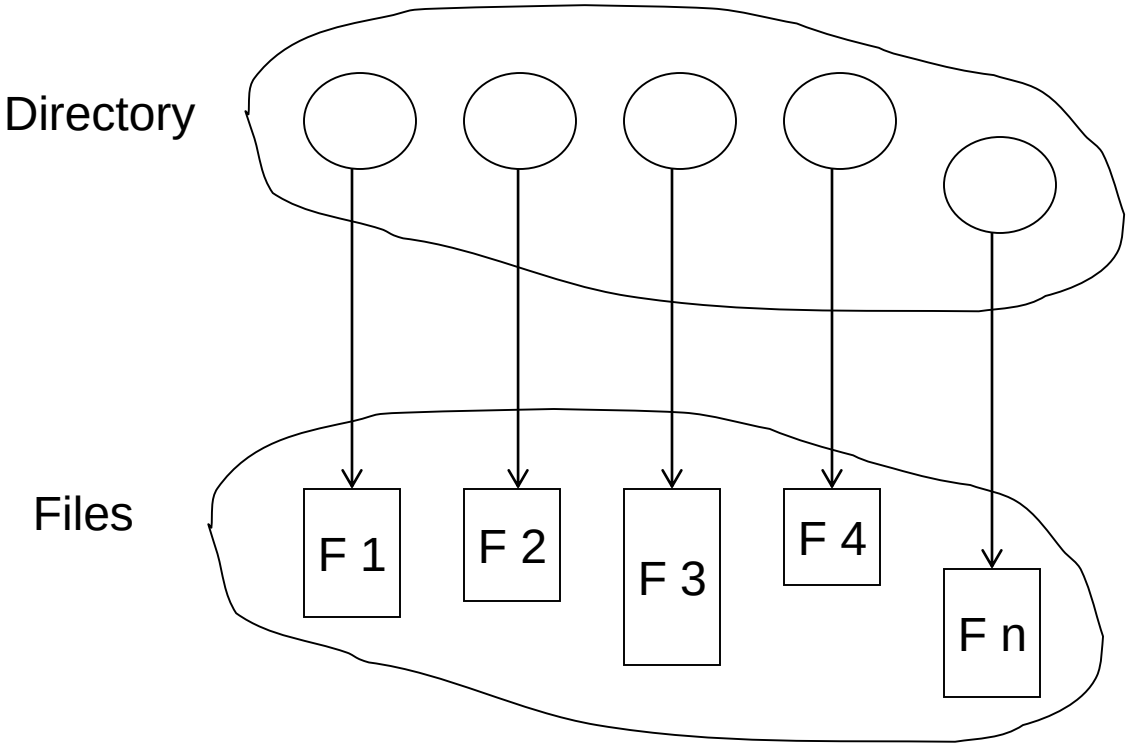


# Example of Index and Relative Files

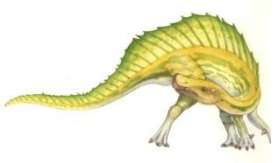


# Directory Structure

- A collection of nodes containing information about all files

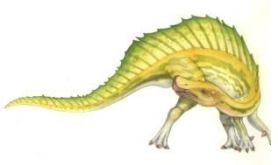



Both the directory structure and the files reside on disk

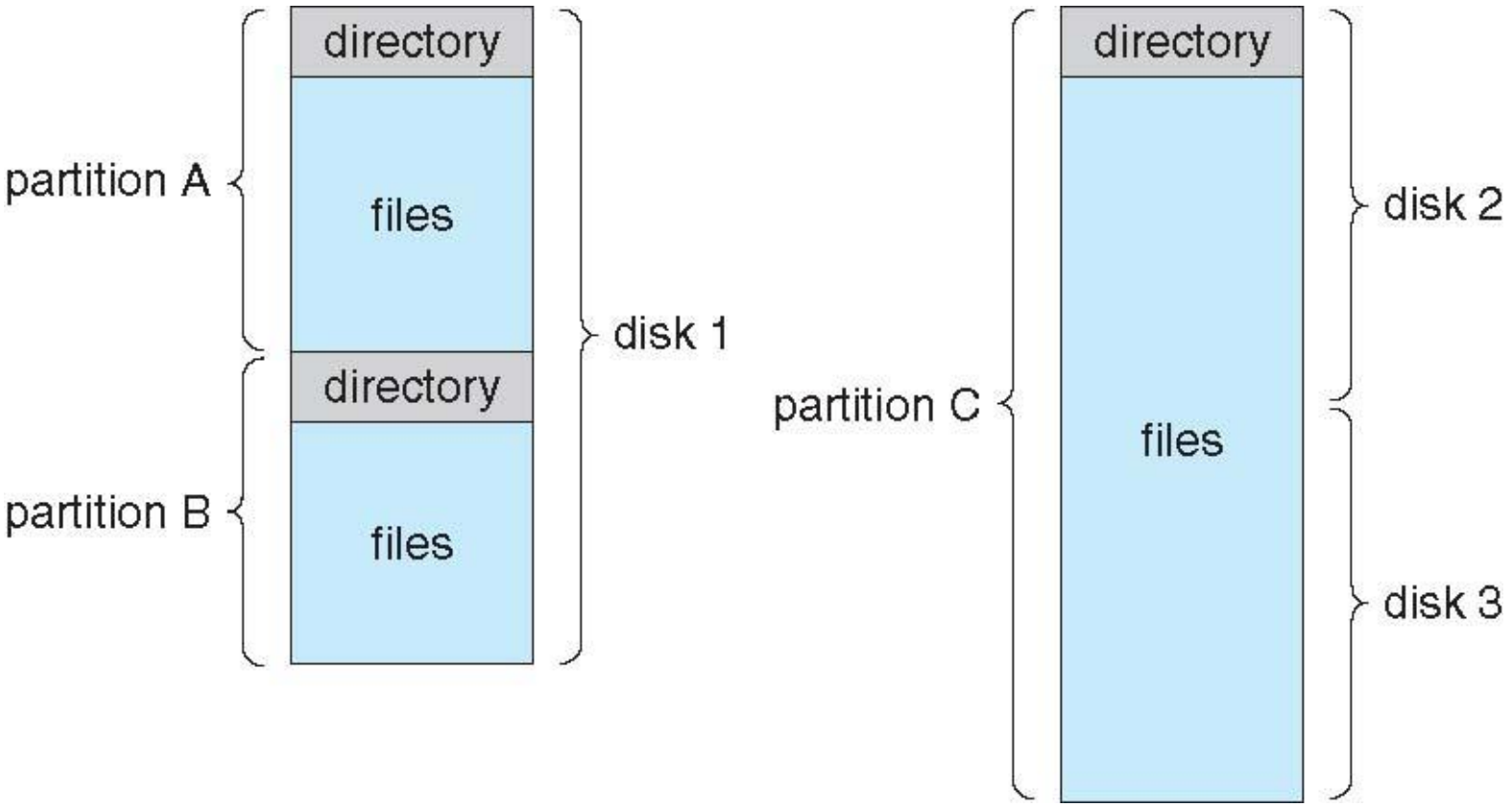


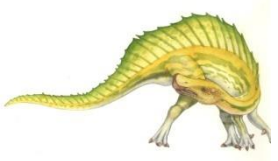
# Disk Structure

- Disk can be subdivided into **partitions**
- 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**
- As well as **general-purpose file systems** there are many **special-purpose file systems**, frequently all within the same operating system or computer



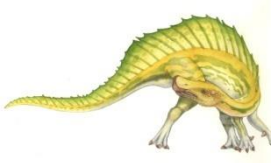
# A Typical File-system Organization



# Types of File Systems

- We mostly talk of general-purpose file systems
- But systems frequently have may file systems, some general- and some special- purpose
- Consider Solaris has
  - tmpfs – memory-based volatile FS for fast, temporary I/O
  - objfs – interface into kernel memory to get kernel symbols for debugging
  - ctfs – contract file system for managing daemons
  - lofs – loopback file system allows one FS to be accessed in place of another
  - procfs – kernel interface to process structures
  - ufs, zfs – general purpose file systems

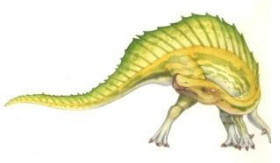


# Operations Performed on Directory

- Search for a file
- Create a file
- Delete a file
- List a directory
- Rename a file
- Traverse the file system

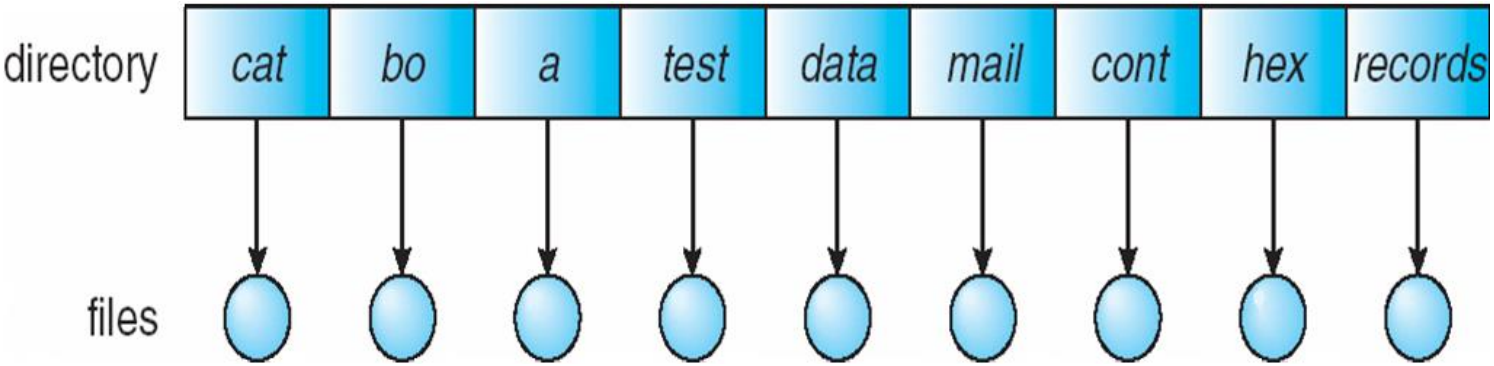
# Organize the Directory (Logically) to Obtain

- 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, …)



# Single-Level Directory

- A single directory for all users

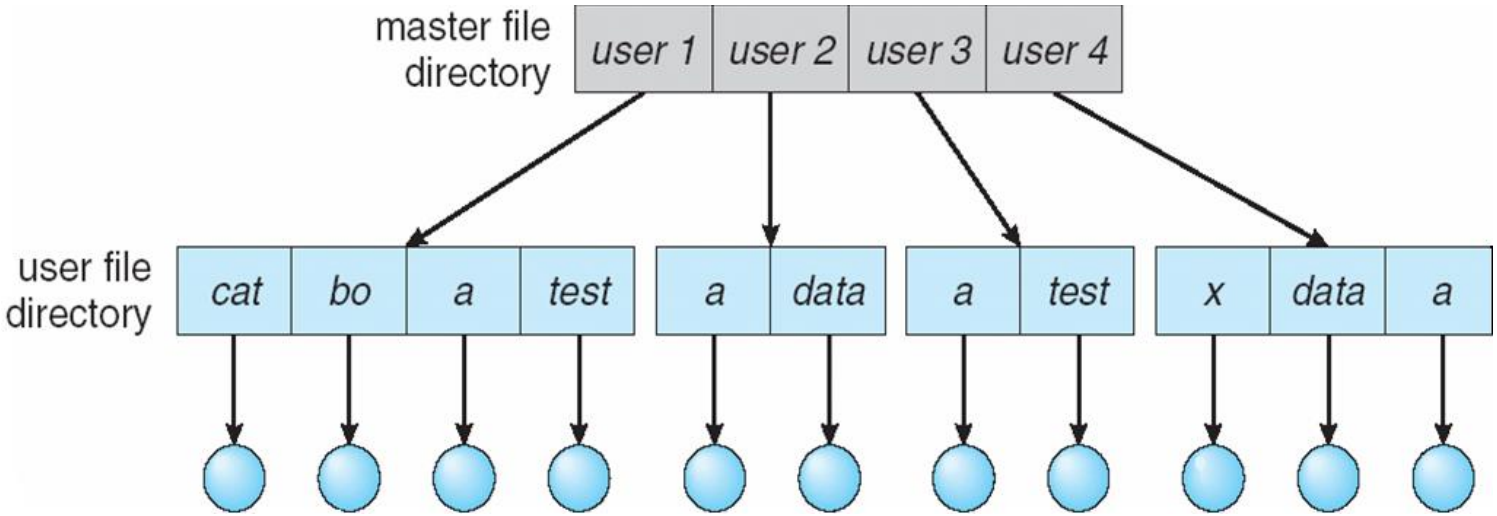



Naming problem

Grouping problem

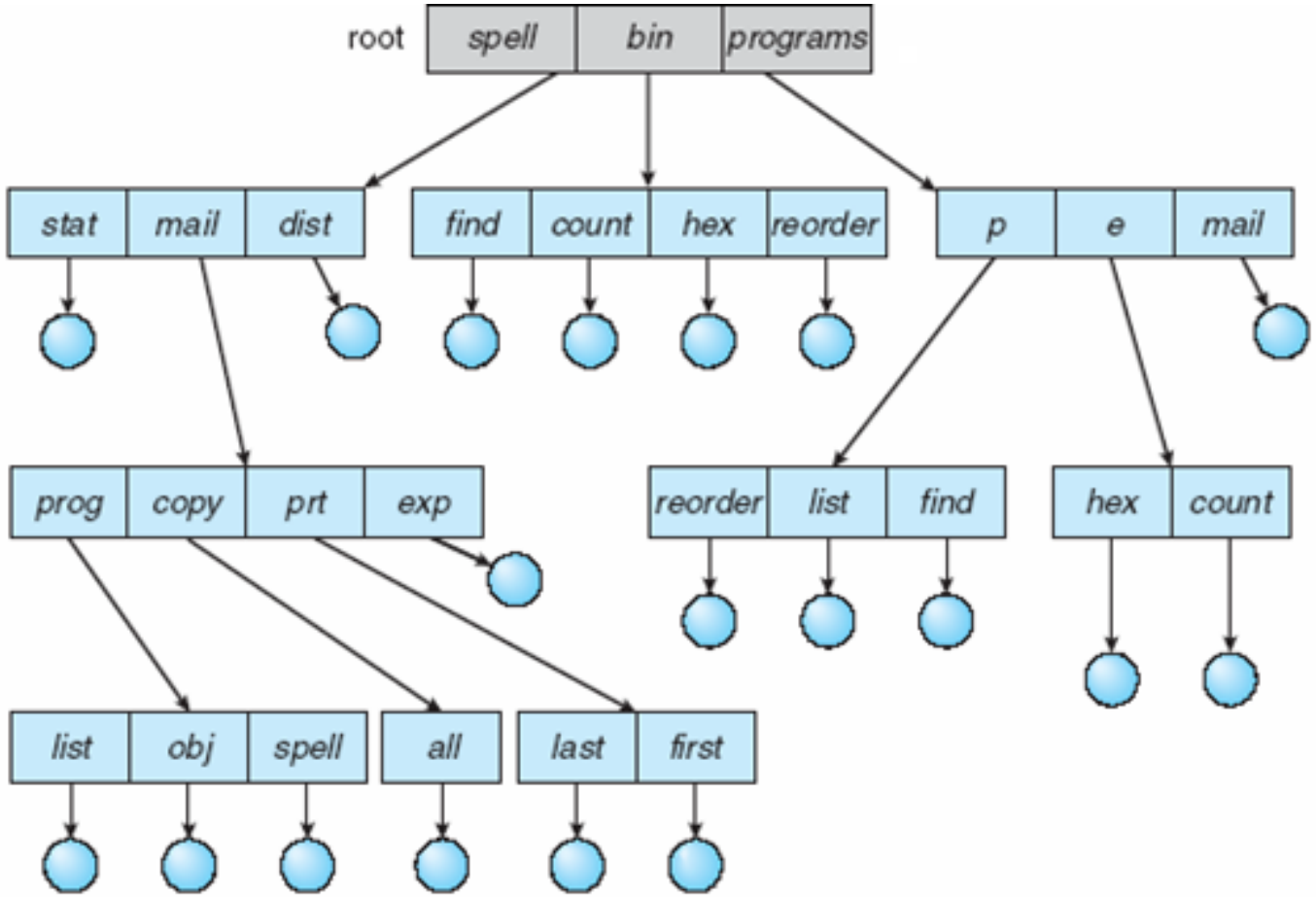
# Two-Level Directory

- Separate directory for each user




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

# Tree-Structured Directories




# Tree-Structured Directories (Cont.)

- Efficient searching
- Grouping Capability
- Current directory (working directory)
  - `cd /spell/mail/prog`
  - `type list`

# Tree-Structured Directories (Cont)

- **Absolute** or **relative** path name
- Creating a new file is done in current directory
- Delete a file

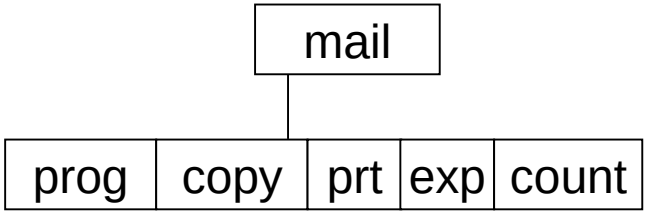
```
rm <file-name>
```

- Creating a new subdirectory is done in current directory

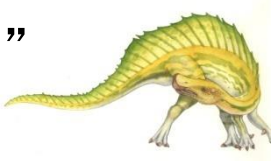
```
mkdir <dir-name>
```

Example: if in current directory `/mail`

```
mkdir count
```

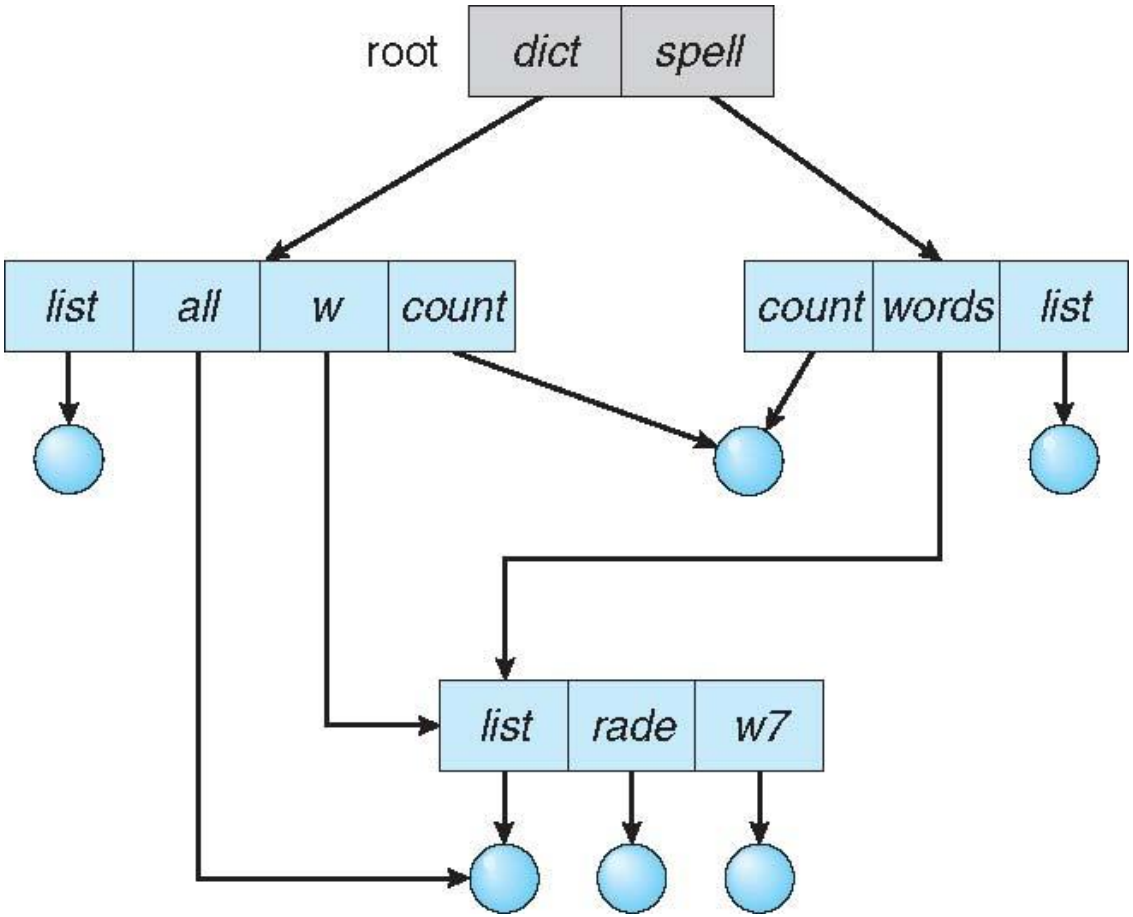


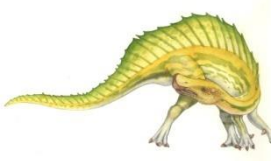

Deleting “mail” ⇒ deleting the entire subtree rooted by “mail”



# Acyclic-Graph Directories

- Have shared subdirectories and files

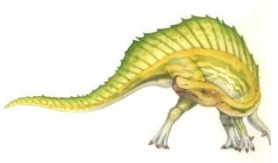


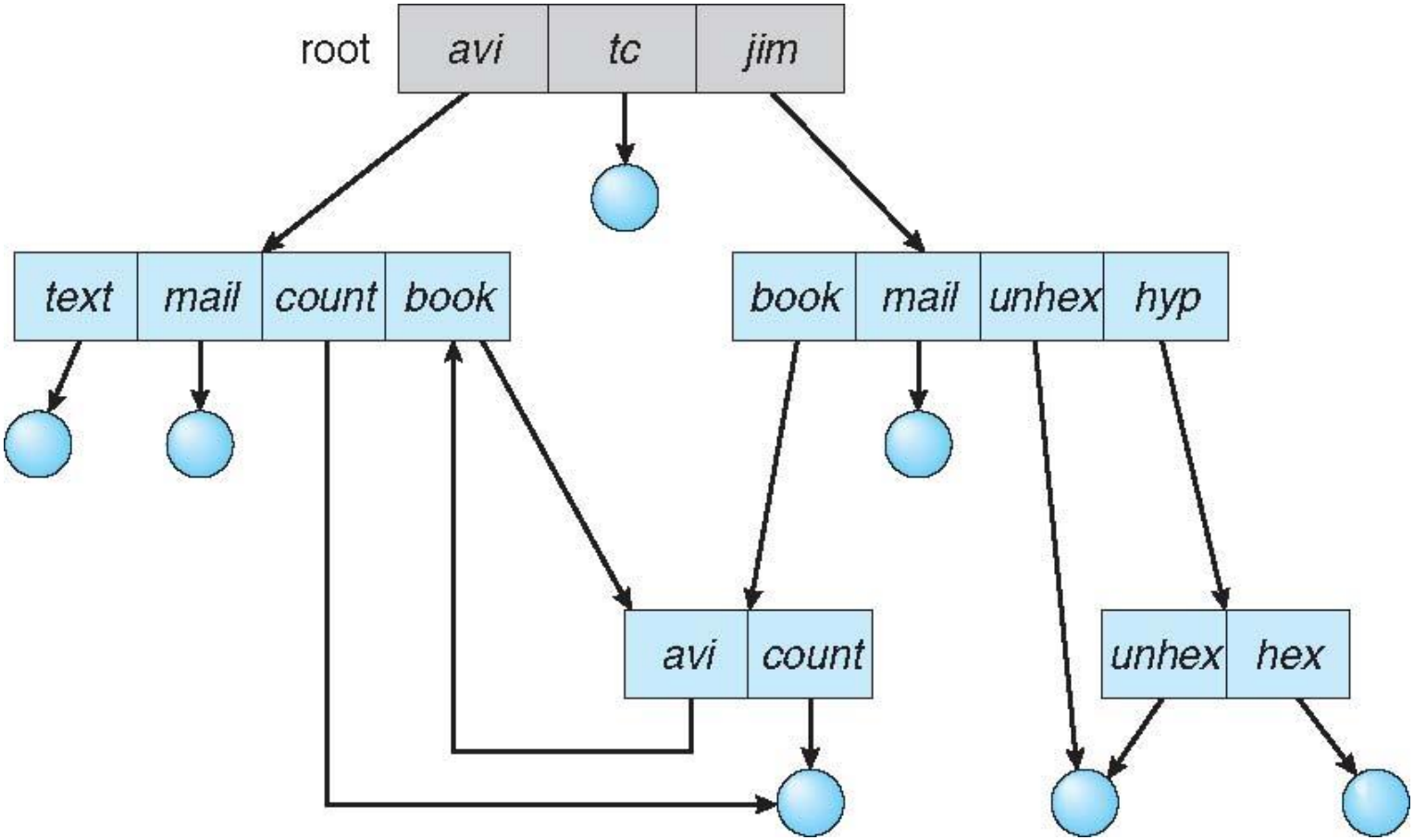
# Acyclic-Graph Directories (Cont.)

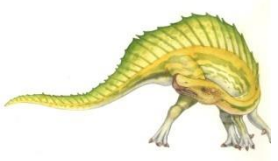
- Two different names (aliasing)
- If ***dict*** deletes ***list*** ⇒ dangling pointer

  Solutions:
  - Backpointers, so we can delete all pointers
    Variable size records a problem
  - Backpointers using a daisy chain organization
  - Entry-hold-count solution
- New directory entry type
  - **Link** – another name (pointer) to an existing file
  - **Resolve the link** – follow pointer to locate the file



# General Graph Directory



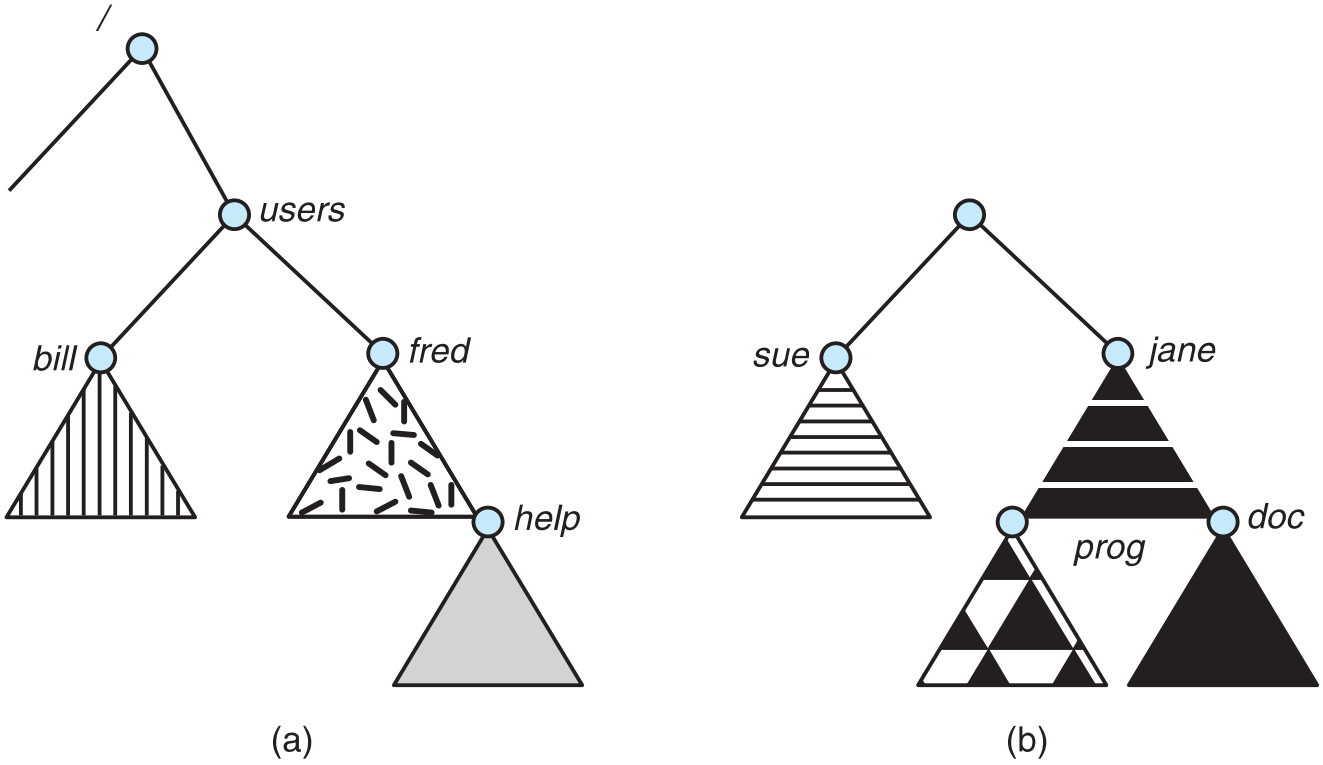



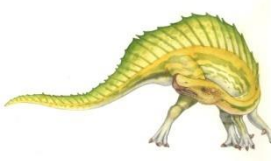
# General Graph Directory (Cont.)

- 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

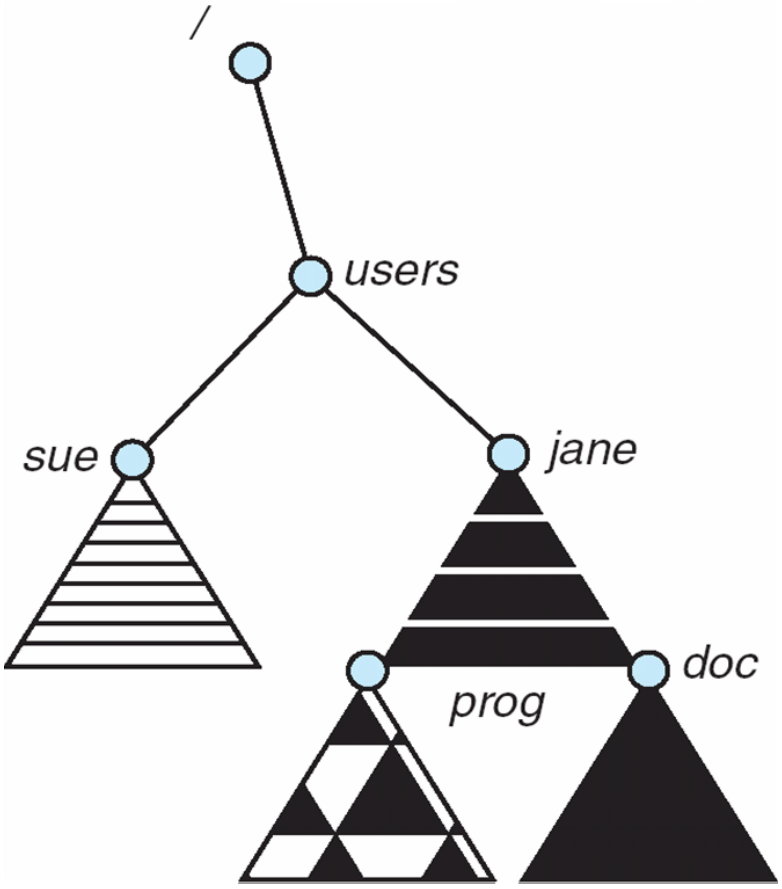
# File System Mounting

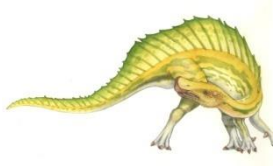
- A file system must be **mounted** before it can be accessed
- A unmounted file system (i.e., Fig. 10-11(b)) is mounted at a **mount point**



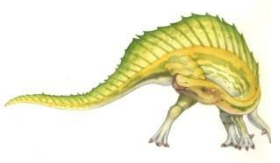
# Mount Point



# 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
- If multi-user system
  - **User IDs** identify users, allowing permissions and protections to be per-user
    **Group IDs** allow users to be in groups, permitting group access rights
  - Owner of a file / directory
  - Group of a file / directory



# 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**
- **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

# File Sharing – Failure Modes

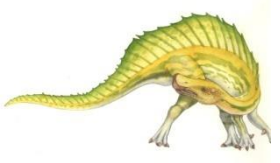
- All file systems have failure modes
  - For example corruption of directory structures or other non-user data, called **metadata**
- Remote file systems add new failure modes, due to network failure, server failure
- Recovery from failure can involve **state information** about status of each remote request
- **Stateless** protocols such as NFS v3 include all information in each request, allowing easy recovery but less security

# File Sharing – Consistency Semantics

- Specify how multiple users are to access a shared file simultaneously
  - Similar to Ch 6 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

# Protection

- File owner/creator should be able to control:
  - what can be done
  - by whom
- Types of access
  - **Read**
  - **Write**
  - **Execute**
  - **Append**
  - **Delete**
  - **List**

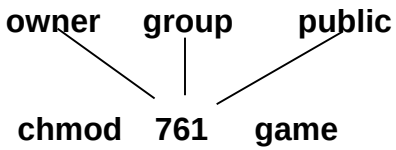


# Access Lists and Groups

- Mode of access: read, write, execute
- Three classes of users on Unix / Linux

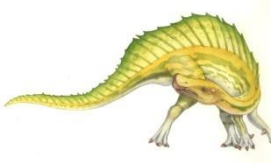
| | | | RWX |
|---|---|---|---|
| a) **owner access** | 7 | ⇒ | 1 1 1 |
| b) **group access** | 6 | ⇒ | RWX 1 1 0 |
| c) **public access** | 1 | ⇒ | RWX 0 0 1 |

- 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.

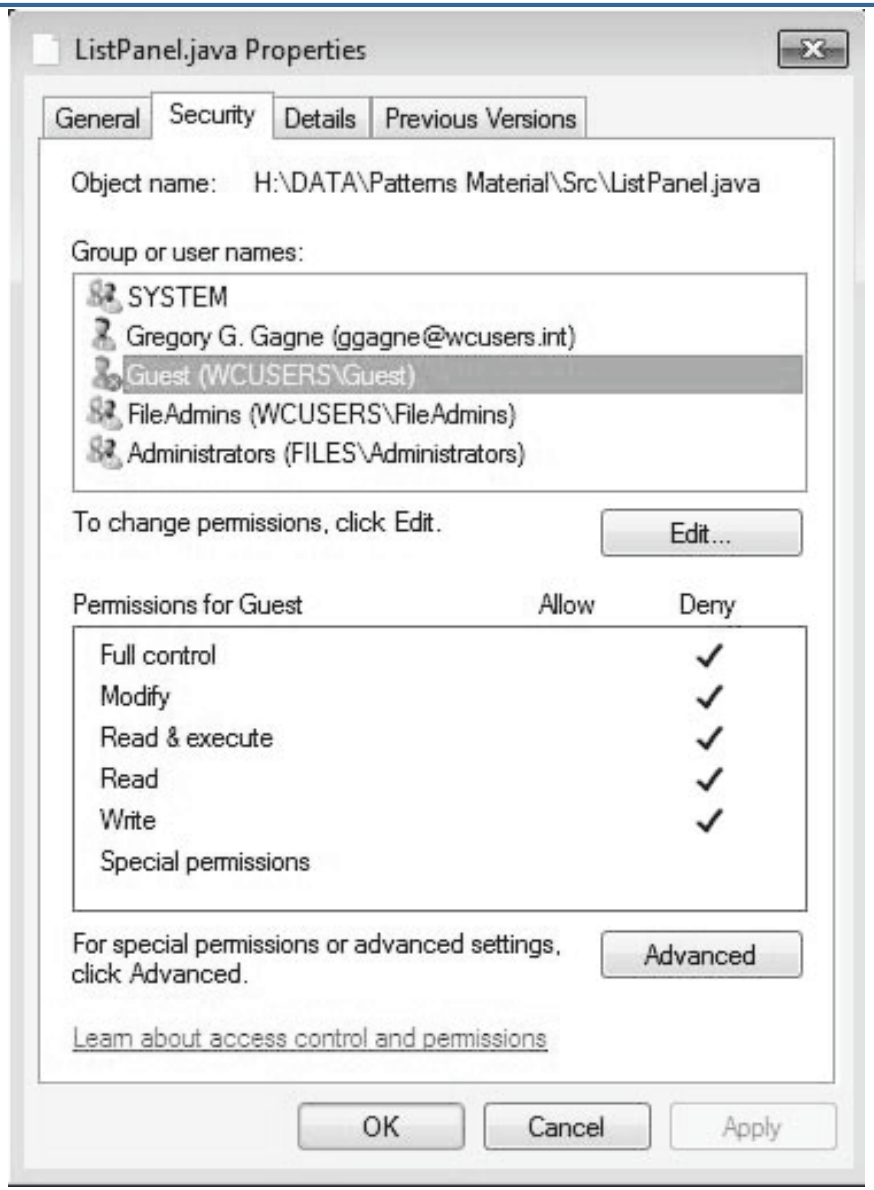



Attach a group to a file

```
chgrp       G       game
```



# Windows 7 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/ |

# Exercise



structures to make them available. The naming scheme varies by operating system. Once mounted, the files within the volume are available for use. File systems may be unmounted to disable access or for maintenance.

File sharing depends on the semantics provided by the system. Files may have multiple readers, multiple writers, or limits on sharing. Distributed file systems allow client hosts to mount volumes or directories from servers, as long as they can access each other across a network. Remote file systems present challenges in reliability, performance, and security. Distributed information systems maintain user, host, and access information so that clients and servers can share state information to manage use and access.

Since files are the main information-storage mechanism in most computer systems, file protection is needed. Access to files can be controlled separately for each type of access—read, write, execute, append, delete, list directory, and so on. File protection can be provided by access lists, passwords, or other techniques.

## Exercises

**10.1** Consider a file system in which a file can be deleted and its disk space reclaimed while links to that file still exist. What problems may occur if a new file is created in the same storage area or with the same absolute path name? How can these problems be avoided?

**10.2** The open-file table is used to maintain information about files that are currently open. Should the operating system maintain a separate table for each user or maintain just one table that contains references to files that are currently being accessed by all users? If the same file is being accessed by two different programs or users, should there be separate entries in the open-file table? Explain.

**10.3** What are the advantages and disadvantages of providing mandatory locks instead of advisory locks whose use is left to users' discretion?

**10.4** Provide examples of applications that typically access files according to the following methods:

- Sequential
- Random

**10.5** Some systems automatically open a file when it is referenced for the first time and close the file when the job terminates. Discuss the advantages and disadvantages of this scheme compared with the more traditional one, where the user has to open and close the file explicitly.

**10.6** If the operating system knew that a certain application was going to access file data in a sequential manner, how could it exploit this information to improve performance?

**10.7** Give an example of an application that could benefit from operating-system support for random access to indexed files.



**10.8** Discuss the advantages and disadvantages of supporting links to files that cross mount points (that is, the file link refers to a file that is stored in a different volume).

**10.9** Some systems provide file sharing by maintaining a single copy of a file. Other systems maintain several copies, one for each of the users sharing the file. Discuss the relative merits of each approach.

**10.10** Discuss the advantages and disadvantages of associating with remote file systems (stored on file servers) a set of failure semantics different from that associated with local file systems.

**10.11** What are the implications of supporting UNIX consistency semantics for shared access to files stored on remote file systems?

## Bibliographical Notes

Database systems and their file structures are described in full in [Silberschatz et al. (2010)].

A multilevel directory structure was first implemented on the MULTICS system ([Organick (1972)]). Most operating systems now implement multilevel directory structures. These include Linux ([Love (2010)]), Mac OS X ([Singh (2007)]), Solaris ([McDougall and Mauro (2007)]), and all versions of Windows ([Russinovich and Solomon (2005)]).

The network file system (NFS), designed by Sun Microsystems, allows directory structures to be spread across networked computer systems. NFS Version 4 is described in RFC3505 (http://www.ietf.org/rfc/rfc3530.txt). A general discussion of Solaris file systems is found in the Sun *System Administration Guide: Devices and File Systems* (http://docs.sun.com/app/docs/doc/817-5093).

DNS was first proposed by [Su (1982)] and has gone through several revisions since. LDAP, also known as X.509, is a derivative subset of the X.500 distributed directory protocol. It was defined by [Yeong et al. (1995)] and has been implemented on many operating systems.

## Bibliography

**[Love (2010)]** R. Love, *Linux Kernel Development*, Third Edition, Developer's Library (2010).

**[McDougall and Mauro (2007)]** R. McDougall and J. Mauro, *Solaris Internals*, Second Edition, Prentice Hall (2007).

**[Organick (1972)]** E. I. Organick, *The Multics System: An Examination of Its Structure*, MIT Press (1972).

**[Russinovich and Solomon (2005)]** M. E. Russinovich and D. A. Solomon, *Microsoft Windows Internals*, Fourth Edition, Microsoft Press (2005).

**[Silberschatz et al. (2010)]** A. Silberschatz, H. F. Korth, and S. Sudarshan, *Database System Concepts*, Sixth Edition, McGraw-Hill (2010).