Part III
Storage Management
Chapter 10: File-System Interface

Fall 2010

Files

- **A file is a named collection of related information that is recorded on secondary storage.**
- **The operating systems maps this logical storage unit to the physical view of information storage.**
- **A file may have the following characteristics**
  - **File Attributes**
  - **File Operations**
  - **File Types**
  - **File Structures**
  - **Internal Files**

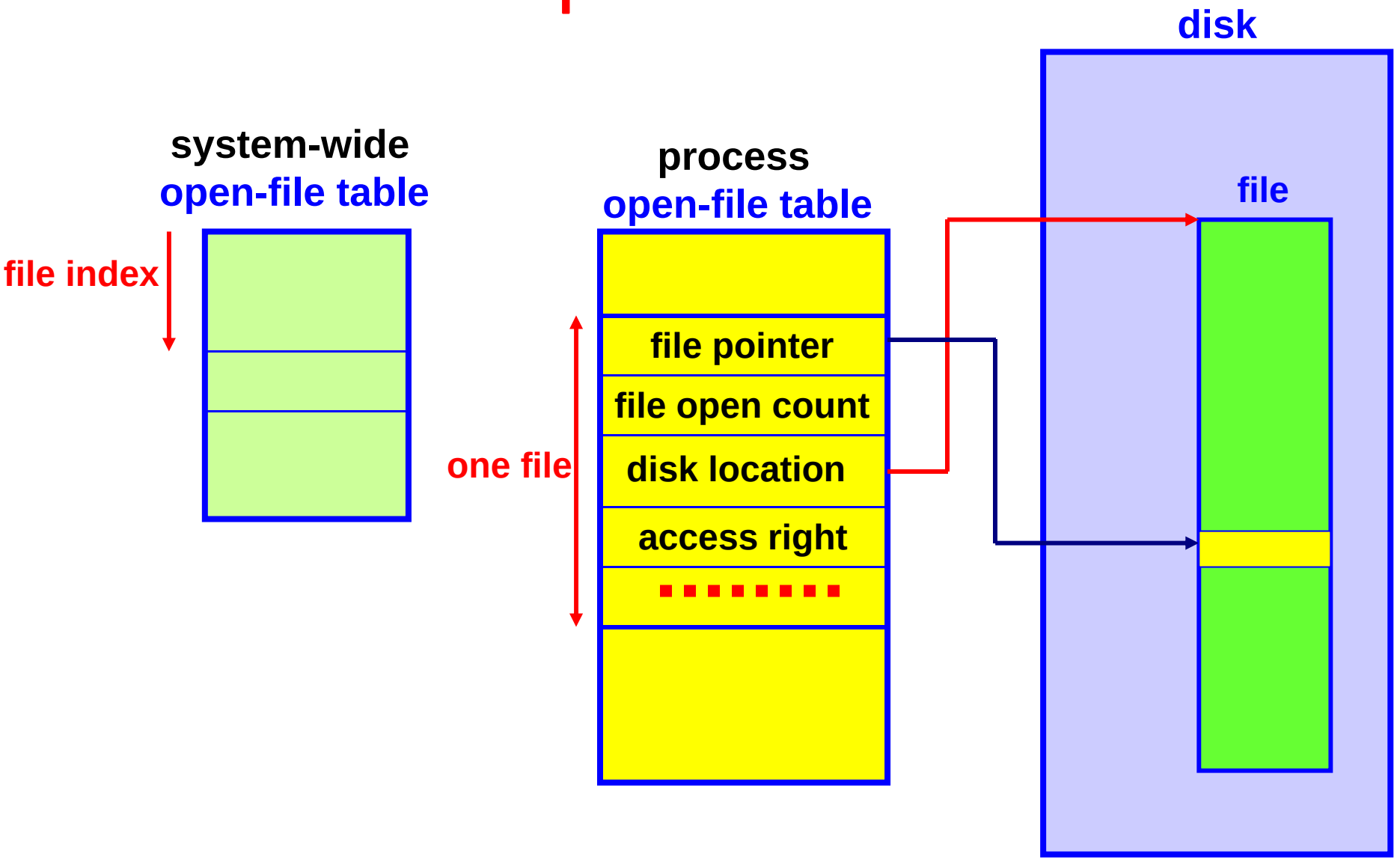
File Attributes

- **File Name: The symbolic name is perhaps the only human readable file attribute.**
- **Identifier: A unique number assigned to each file for identification purpose.**
- **File Type: Some systems recognize various file types. Windows is a good example.**
- **File Location: A pointer to a device to find a file.**
- **File Size: The current size of a file, or the maximum allowed size.**
- **File Protection: This is for access-control.**
- **File Date, Time, Owner, etc.**

File Operations: 1/2

- **A file can be considered as an abstract data type that has data and accompanying operations.**
- **Creating a file**
- **Writing a file**
- **Reading a file**
- **Repositioning within a file**
- **Deleting a file**
- **Truncating a file**
- **Other operations (*e.g.*, appending a file, renaming a file)**

File Operations: 2/2



File Structure

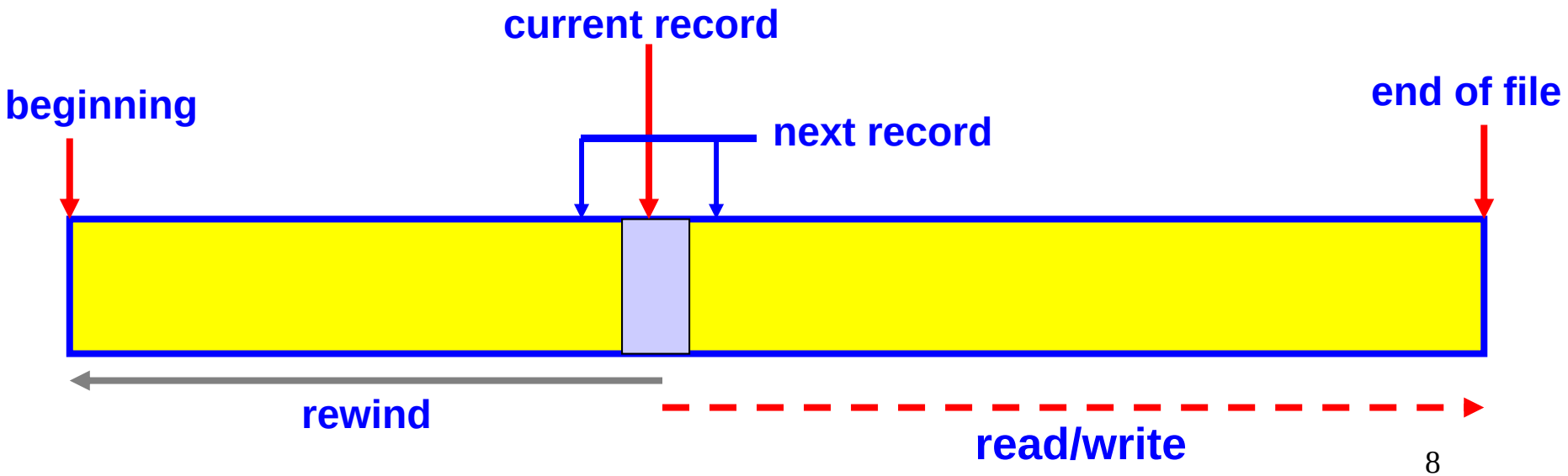
- **Some systems support specific file types that have special file structures.**
- **For example, files that contain binary executables.**
- **An operating system becomes more complex when more file types (*i.e.*, file structures) are supported.**
- **In general, the number of supported file types is kept to minimum.**

File Access Methods

- **Access method: how a file be used.**
- **There are three popular ones:**
  - **Sequential access method for sequential files**
  - **Direct access method for direct files**
  - **Indexed access method for indexed files.**

Sequential Access Method

- With the sequential access method, a file is processed in order, one record after the other.
- If *p* is the file pointer, the next record to be accessed is either *p*+1 (forward) or *p*-1 (*i.e.*, backward).

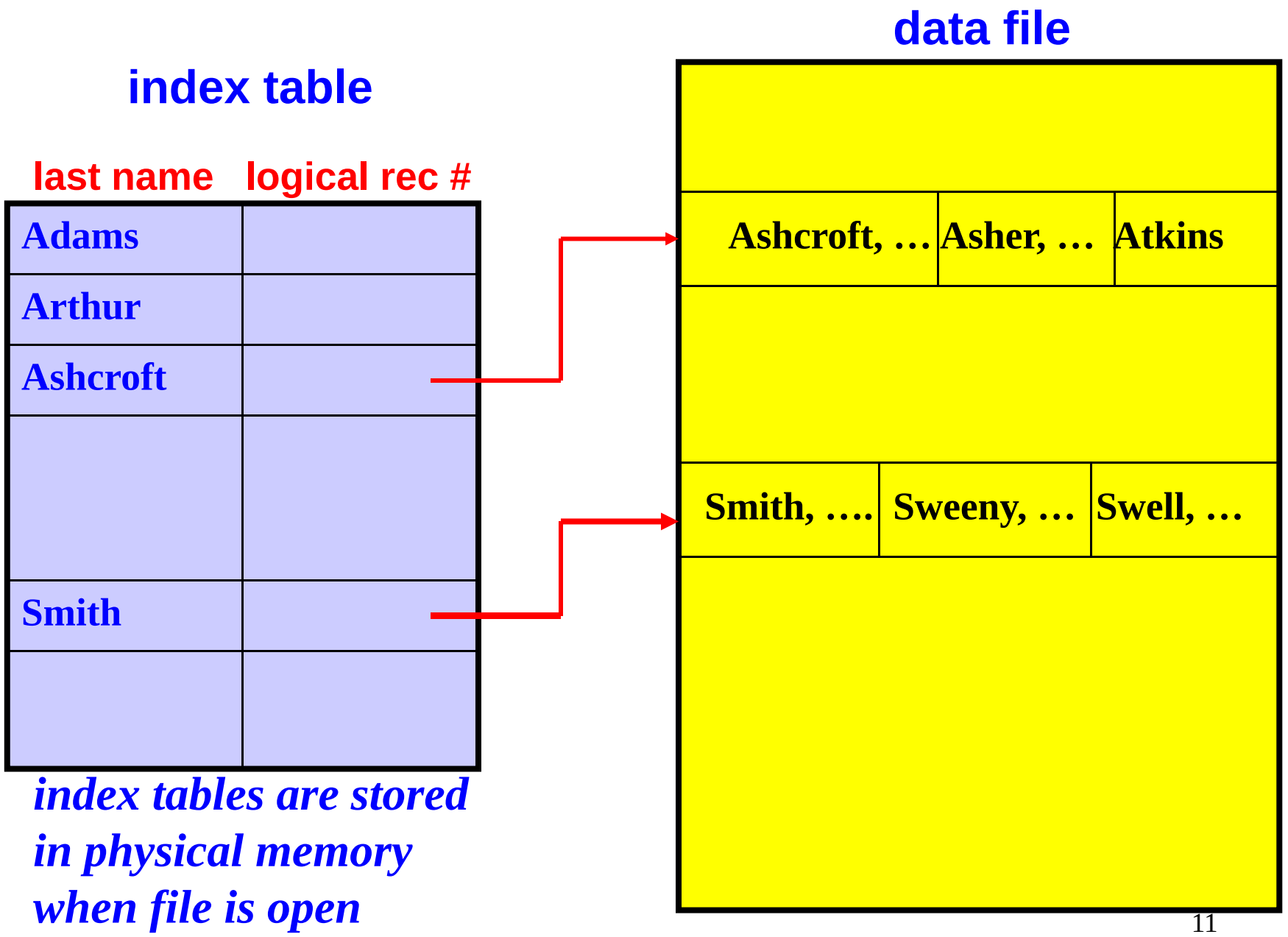


Direct Access Method

- **A file is made up of fixed-length logical records.**
- **The direct access method uses a record number to identify each record. For example, *read rec 0*, *write rec 100*, *seek rec 75*, etc.**
- **Some systems may use a key field to access a record (*e.g.*, *read rec "Age=24"* or *write rec "Name=Dow"*). This is usually achieved with hashing.**
- **Since records can be accessed in random order, direct access is also referred to as random access.**
- **Direct access method can simulate sequential access.**

Indexed Access Method

- With the indexed access method, a file is sorted in ascending order based on a number of keys.
- Each disk block may contain a number of fixed-length logical records.
- An index table stores the keys of the first block in each block.
- We can search the index table to locate the block that contains the desired record. Then, search the block to find the desired record.
- This is exactly a one-level B-, B+ or B* tree.
- Multi-level index access method is also possible.


data file
index table
last name
logical rec #
Adams
Arthur
Ashcroft
Smith
Ashcroft, …
Asher, …
Atkins
Smith, ….
Sweeny, …
Swell, …
index tables are stored
in physical memory
when file is open

Directory Structure: 1/2

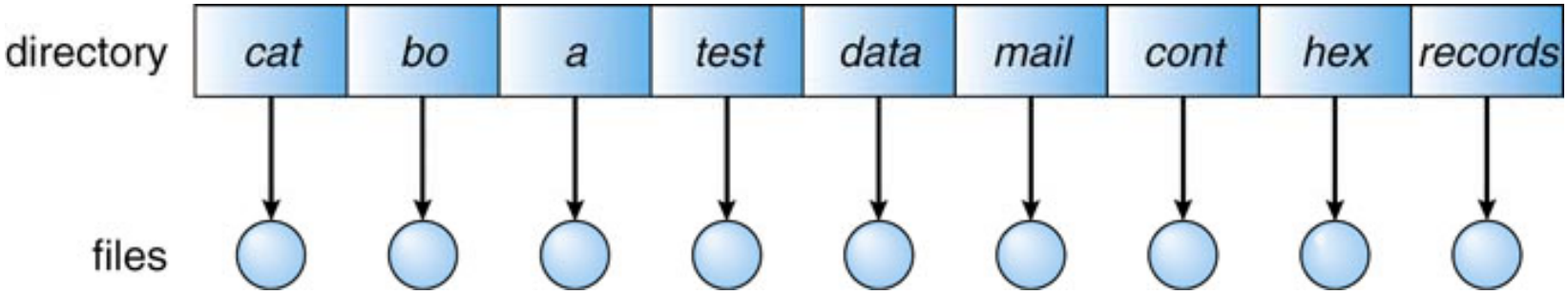
- A large volume disk may be partitioned into partitions, or mini disks, or volumes.
- Each partition contains information about files within it. This information is stored in entries of a device directory or volume table of content (VTOC).
- The device directory, or directory for short, stores the name, location, size, type, access method, etc of each file.
- Operations perform on directory: search for a file, create a file, delete a file, rename a file, traverse the file system, etc.

Directory Structure: 2/2

- **There are five commonly used directory structures:**
  - **Single-Level Directory**
  - **Two-Level Directory**
  - **Tree-Structure Directories**
  - **Acyclic-Graph Directories**
  - **General Graph Directories**

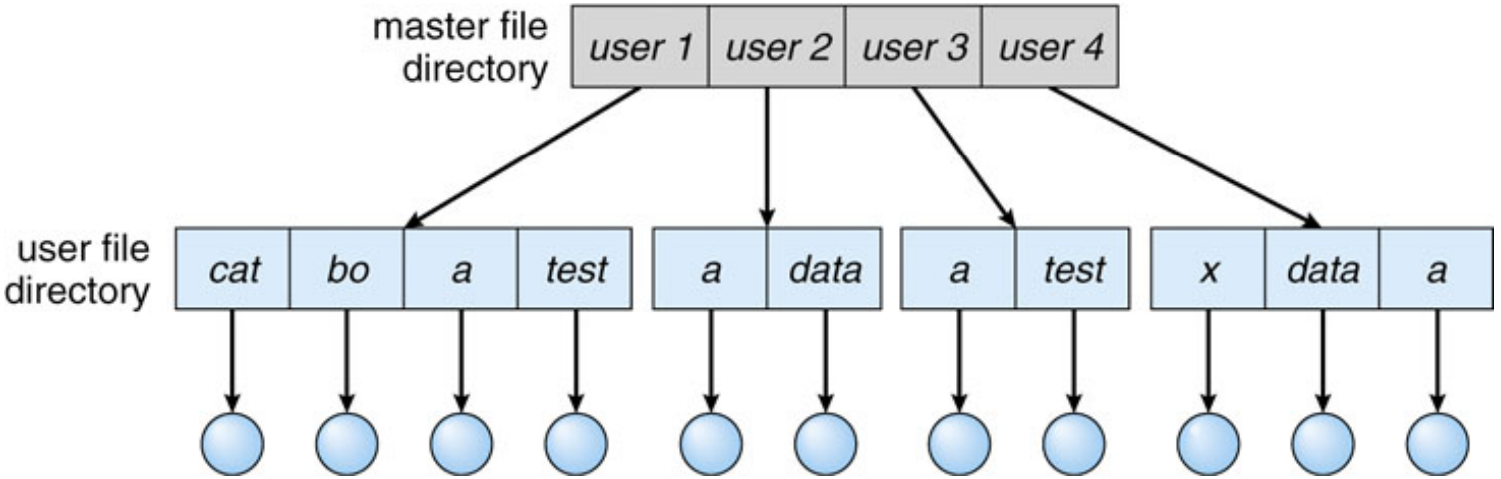
Single-Level Directory

- All files are contained in the same directory.
- It is difficult to maintain file name uniqueness.
- CP/M-80 and early version of MS-DOS use this directory structure.



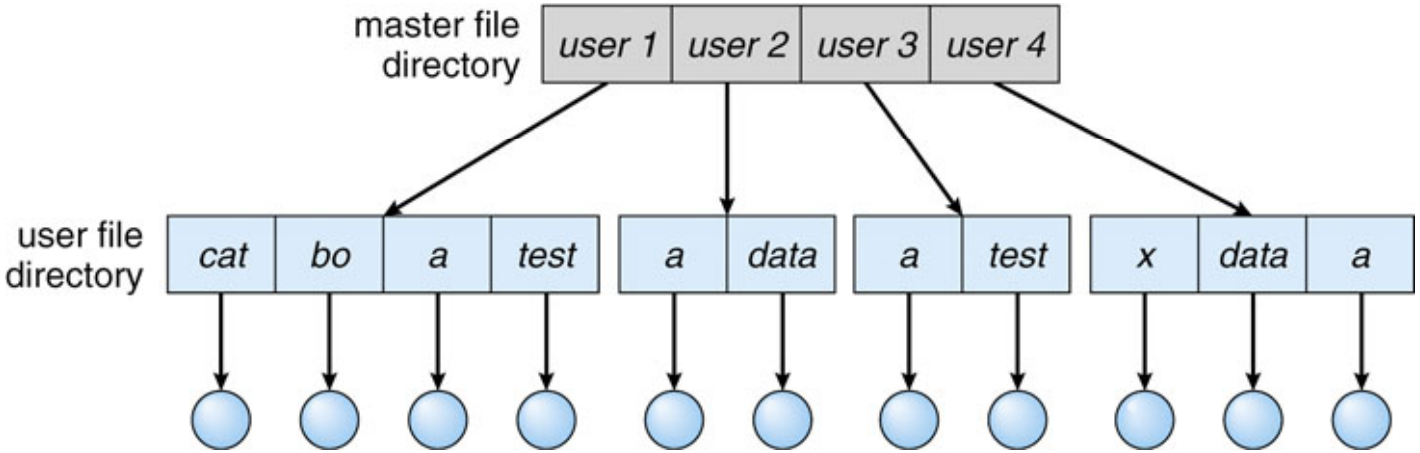
Two-Level Directory: 1/2

- **This is an extension of the single-level directory for multi-user system.**
- **Each user has his/her user file directory. The system's master file directory is searched for the user directory when a user job starts.**
- **Early CP/M-80 multi-user systems use this structure.**



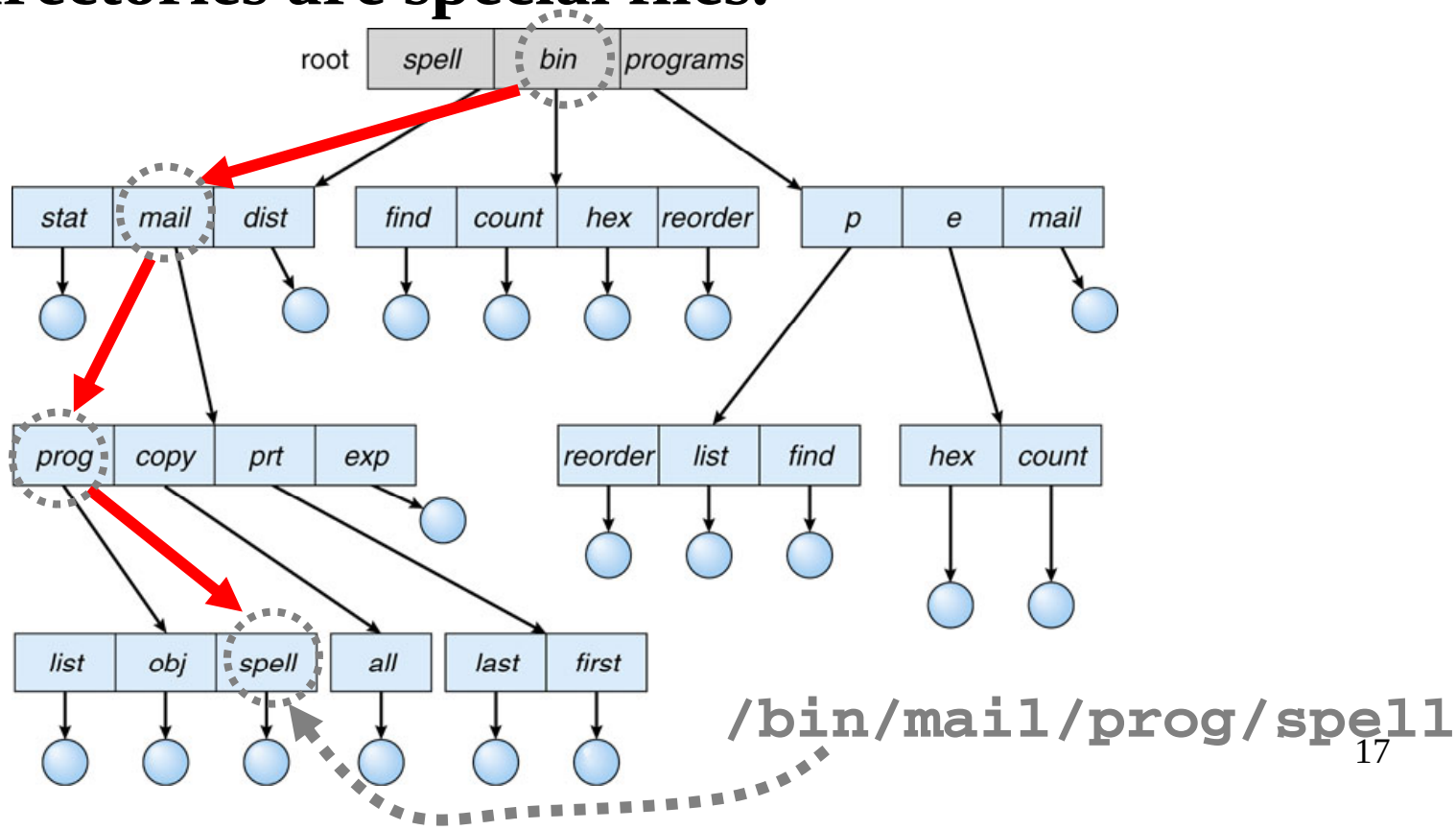
Two-Level Directory: 2/2

- To locate a file, path name is used. For example, `/user2/a` is the file `a` of `user 2`.
- Different systems use different path names. For example, under MS-DOS it is `C:\user2\a`.
- The directory of a special user, say `user 0`, may contain all system files.



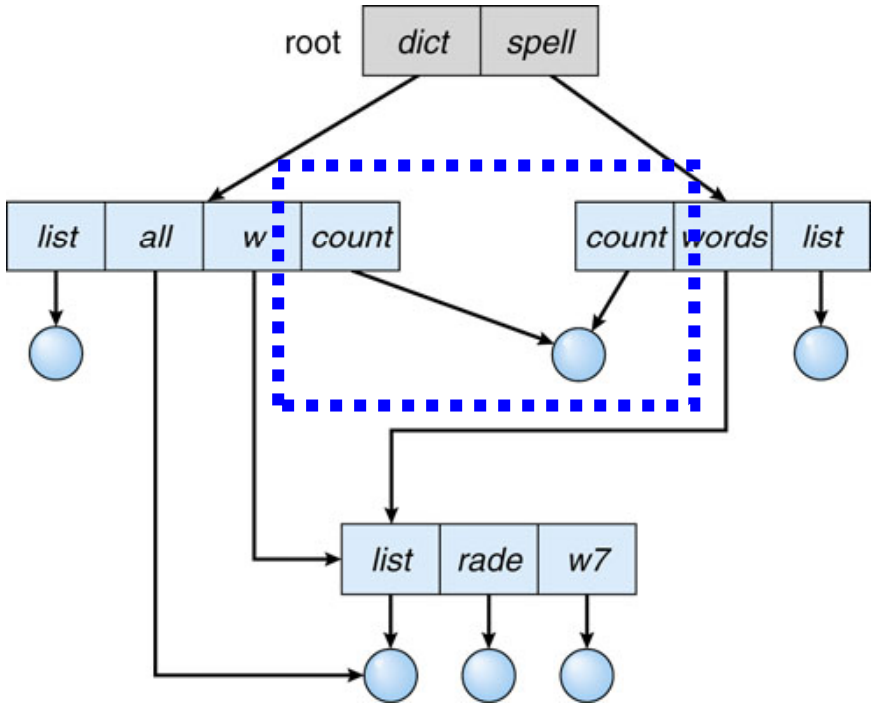
Tree-Structured Directory

- Each directory or subdirectory contains files and subdirectories, and forms a **tree**.
- Directories are special files.



Acyclic-Graph Directory: 1/2

- This type of directories allows a file/directory to be shared by multiple directories.
- This is different from two copies of the same file or directory.
- An acyclic-graph directory is more flexible than a simple tree structure. However, it is more complex.



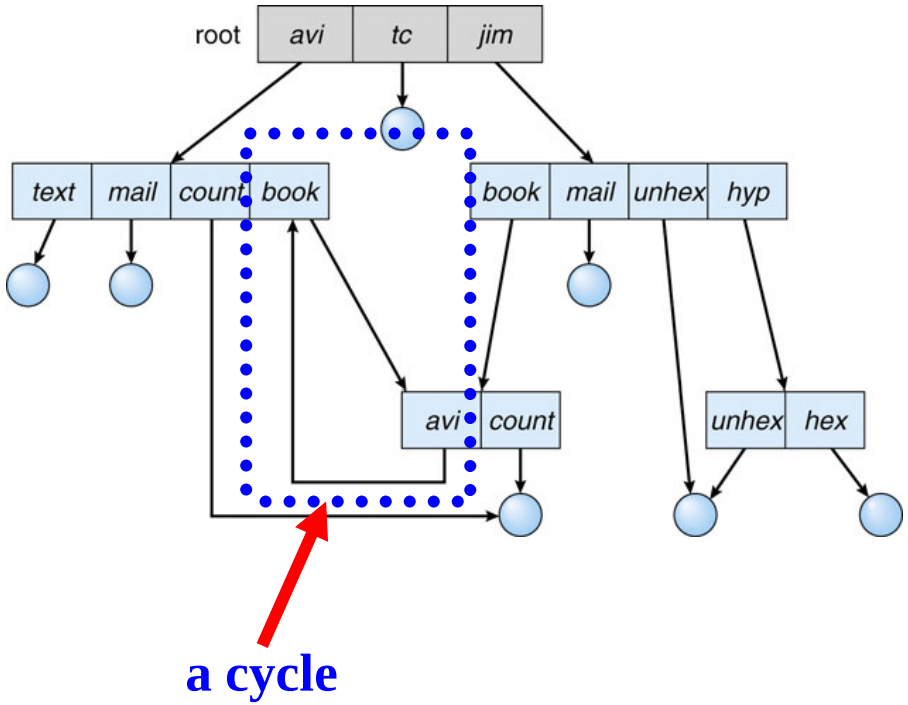
file `count` is shared by directories `dict` and `spell`

Acyclic-Graph Directory: 2/2

- **Since a file have multiple absolute path names, how do we calculate file system statistics or do backup? Would the same file be counted multiple times?**
- **How do we delete a file?**
  - **If sharing is implemented with symbolic links, we only delete the link if we have a list of links to the file. The file is removed when the list is empty.**
  - **Or, we remove the file and keep the links. When the file is accessed again, a message is given and the link is removed.**
  - **Or, we can maintain a reference count for each shared file. The file is removed when the count is zero.**

General Graph Directory: 1/2

- **It is easy to traverse the directories of a tree or an acyclic directory system.**
- **However, if links are added arbitrarily, the directory graph becomes arbitrary and may contain cycles.**
- ***How do we search for a file?***



General Graph Directory: 2/2

- **How do we delete a file? We can use reference count!**
  - **In a cycle, due to self-reference, the reference count may be non-zero even when it is no longer possible to refer to a file or directory.**
  - **Thus, garbage collection may needed. A garbage collector traverses the directory and marks files and directories that can be accessed.**
  - **A second round removes those inaccessible items.**
- **To avoid this time-consuming task, a system can check if a cycle may occur when a link is made. How? You should know!**

File Sharing

- **When a file is shared by multiple users, how can we ensure its consistency?**
- **If multiple users are writing to the file, should all of the writers be allowed to write?**
- **Or, should the operating system protect the user actions from each other?**
- **This is the file consistency semantics.**

File Consistency Semantics

- **Consistency semantics is a characterization of the system that specifies the semantics of multiple users accessing a *shared* file *simultaneously*.**
- **Consistency semantics is an important criterion for evaluating any file system that supports file sharing.**
- **There are three commonly used semantics**
  - **Unix semantics**
  - **Session Semantics**
  - **Immutable-Shared-Files Semantics**
- **A file session consists all file accesses between `open()` and `close()`.**

Unix Semantics

- **Writes to an open file by a user are visible immediately to other users who have the file open at the same time.**
- **All users share the file pointer. Thus, advancing the file pointer by one user affects all sharing users.**
- **A file has a single image that interleaves all accesses, regardless of their origin.**
- **File access contention may cause delays.**

Session Semantics

- Writes to an open file by a user are not visible immediately to other users who have the same file open simultaneously.
- Once a file is closed, the changes made to it are visible only in sessions started later.
- Already-open instances of the file are not affected by these changes.
  - A file may be associated temporarily with several and possible different images at the same time.
  - Multiple users are allowed to perform both read and write concurrently on their image of the file without delay.
- The Andrew File System (AFS) uses this semantics.

Immutable-Shared-Files Semantics

- **Once a file is declared as shared by its creator, it cannot be modified.**
- **An immutable file has two important properties:**
  - **Its name may not be used**
  - **Its content may not be altered**
- **Thus, the name of an immutable file indicates that the contents of the file is fixed – a constant rather than a variable.**
- **The implementation of these semantics in a distributed system is simple, since sharing is disciplined (*i.e.*, read-only).**

File Protection

- **We can keep files safe from physical damage (*i.e.*, reliability) and improper access (*i.e.*, protection).**
- ***Reliability* is generally provided by backup.**
- **The need for *file protection* is a direct result of the ability to access files.**
- **Access control may be a complete protection by denying access. Or, the access may be controlled.**

File Protection: Types of Access

- **Access control may be implemented by limiting the types of file access that can be made.**
- **The types of access may be**
  - **Read: read from the file**
  - **Write: write or rewrite the file**
  - **Execute: load the file into memory and execute it**
  - **Append: write new info at the end of a file**
  - **Delete: delete a file**
  - **List: list the name and attributes of the file**

File Protection: Access Control: 1/4

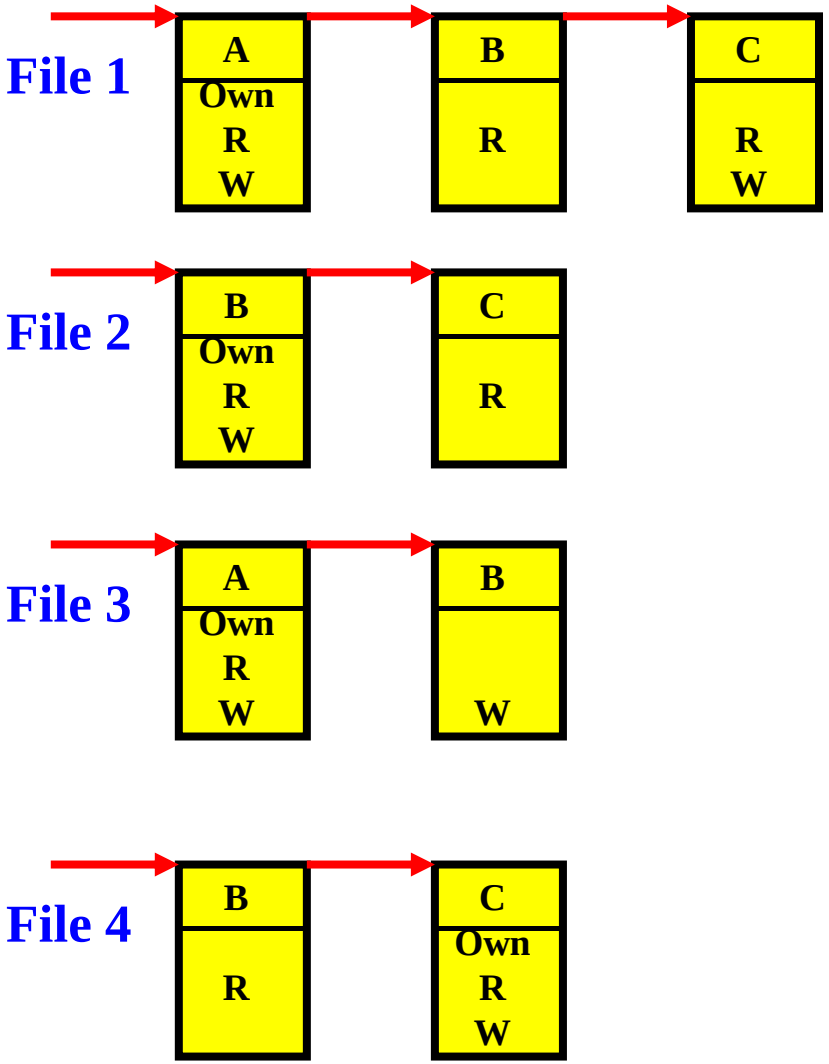
- **The most commonly used approach is to make the access dependent on the identity of the user.**
- **Each file and directory is associated with an access matrix specifying the user name and the types of permitted access.**
- **When a user makes a request to access a file or a directory, his/her identity is compared against the information stored in the access matrix.**

File Protection: Access Control: 2/4

Access Matrix

	File 1	File 2	File 3	File 4	Account 1	Account 2
User A	Own R W		Own R W		Inquiry Credit	
User B	R	Own R W	W	R	Inquiry debit	Inquiry Credit
User C	R W	R		Own R W		Inquiry debit

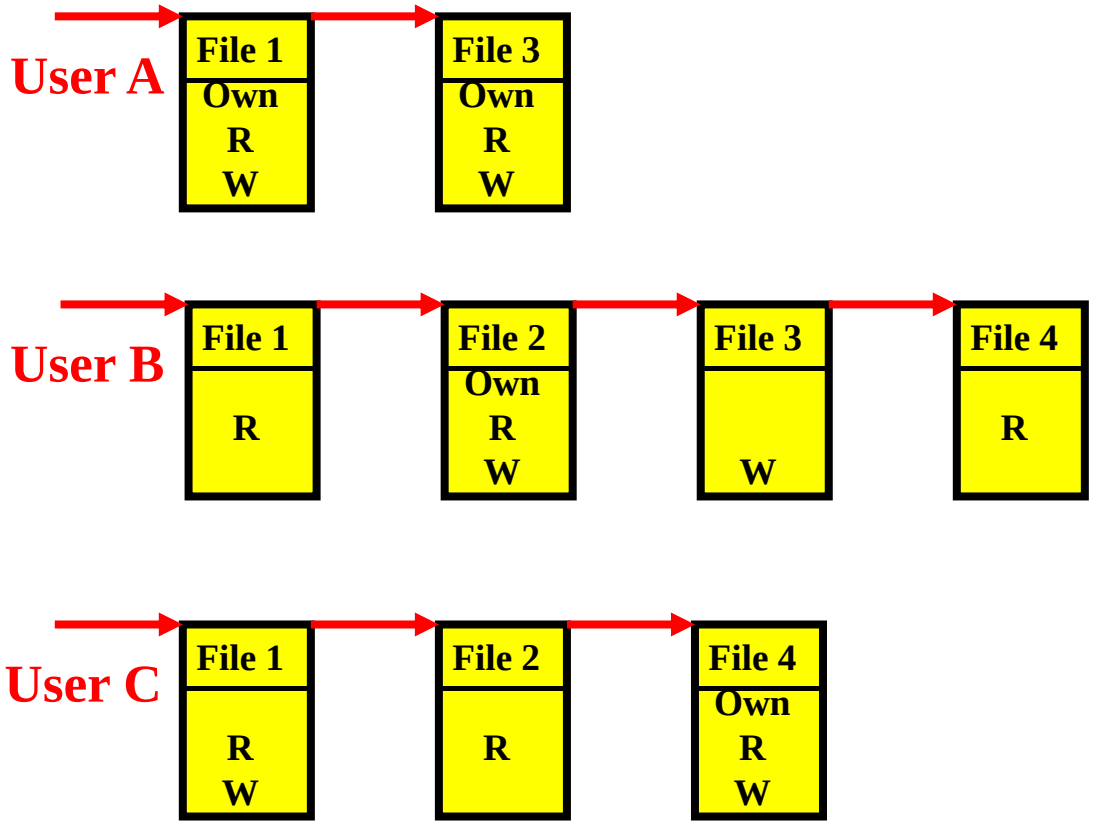
File Protection: Access Control: 3/4



Access-control Lists

- In practice, the access matrix is sparse.
- The matrix can be decomposed into columns (files), yielding access-control lists (ACL)
- However, this list can be very long!

File Protection: Access Control: 4/4



Capability Lists

- **Decomposition by rows (users) yields capability tickets.**
- **Each user has a number of tickets for file/directory access.**
- **These tickets may be authorized to loan or be given to other users.**
- **All tickets may be held and managed by the OS for better protection.**

The End