10. File Systems

Basic Functions of File Management

- Present logical (abstract) view of files and directories
  - Hide complexity of hardware devices
    - Abstraction: files, directories
    - Collections/stream of logical blocks are a lower-level abstraction, subject of next chapter
- Facilitate efficient use of storage devices
  - Optimize access, e.g., to disk
- Support sharing
  - Files persist even when owner/creator is not currently active (unlike main memory)
  - Key issue: Provide protection (control access)

Hierarchical Model of FS

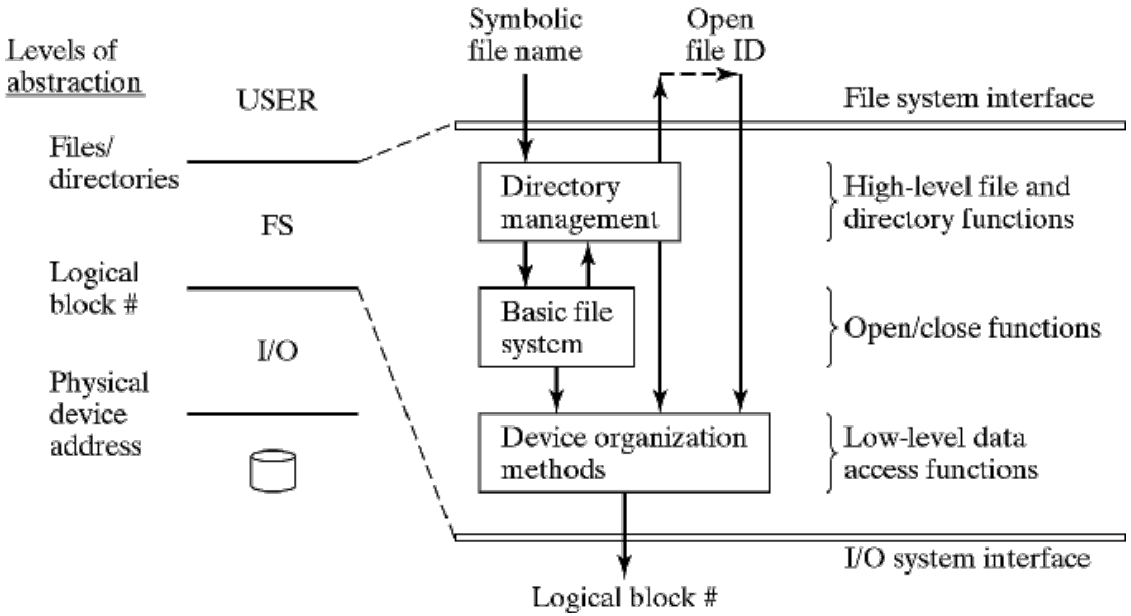


Figure 10-1

Abstract user interface:
Present convenient view

Directory management:
Map logical name to unique Id, file descriptor

Basic file system:
Open/close files

Physical device organization methods:
Map file data to disk blocks

User View of Files

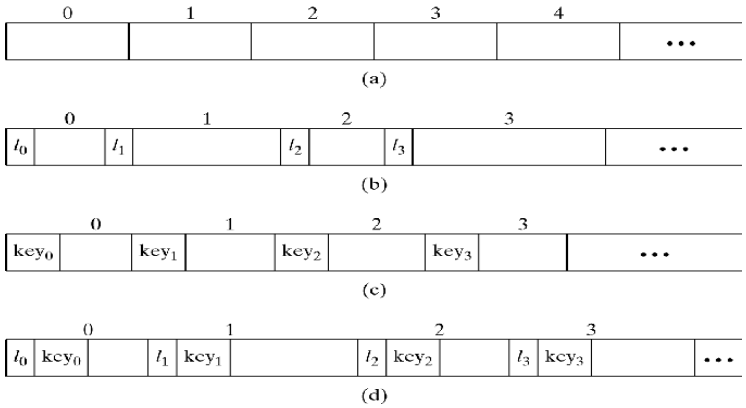
- File name and type
- File organization
- Other attributes
- Operations on files

User View of Files

- File name and type
  - Valid name
    - Number of characters
    - Lower ***vs*** upper case
  - Extension
    - Tied to type of file
    - Used by applications
  - File type recorded in header
    - Cannot be changed (even when extension changes)
    - Basic types: text, object, load file; directory
    - Application-specific types, e.g., .doc, .ps, .html

User View of Files

- Logical file organization
  - Fixed-size or variable-size records
  - Addressed
    - Implicitly (sequential access to next record)
    - Explicitly by position (record#) or key



a) Fixed Length Record

b) Variable Length Record

c) Fixed Length with Key

d) Variable Length with Key

Figure 10-2

  - Memory mapped files
    - Read virtual memory instead of read(i,buf,n)
    - Map file contents 0:(n–1) to va:(va+n–1)

Other File Attributes

- Ownership
- File Size
- File Use
  - Time of creation, last access, last modification
- File Disposition
  - Permanent or Temporary
- Protection
  - Who can access and what type of access
- Location
  - Blocks on device where file is stored
    - Important for performance
    - Not of interest to most users

Operations on Files

- Create/Delete
  - Create/delete file descriptor
  - Modify directory
- Open/Close
  - Modify open file table (“OFT”)
- Read/Write (sequential or direct)
  - Modify file descriptor
  - Transfer data between disk and memory
- Seek/Rewind
  - Modify open file table

File Directories

- Heirarchical directory organization
- Operations on directories
- Implementation of directories

File Directories

- Tree-structured
  - Simple search, insert, delete operations
  - Sharing is asymmetric (only one parent)

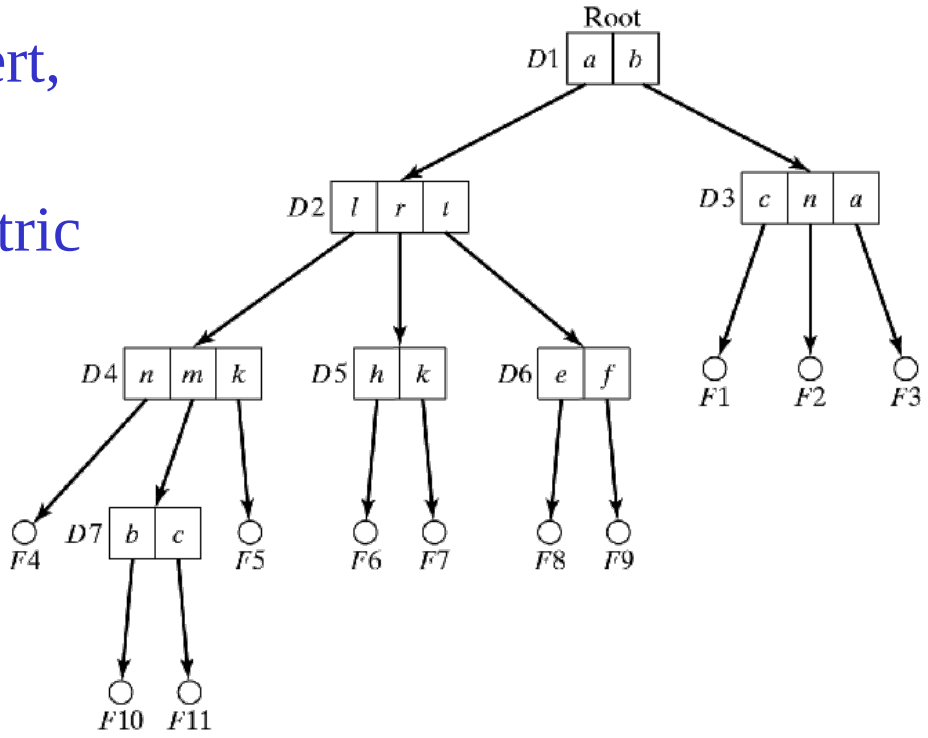


Figure 10-3

File Directories

- DAG-structured
  - Sharing is symmetric, but …

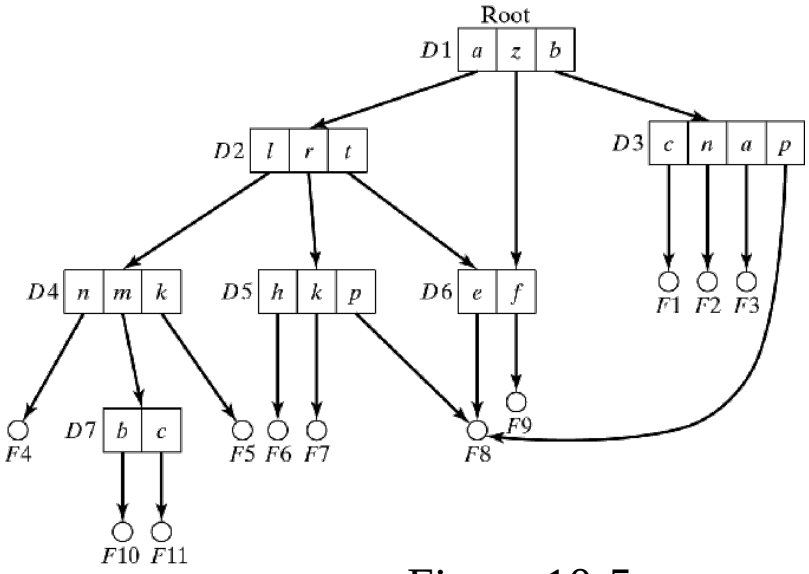


Figure 10-5

  - What are semantics of delete?
    - Any parent can remove file.
    - Only last parent can remove it.
      Need reference count

File Directories

- DAG-structured
  - Must prevent cycles

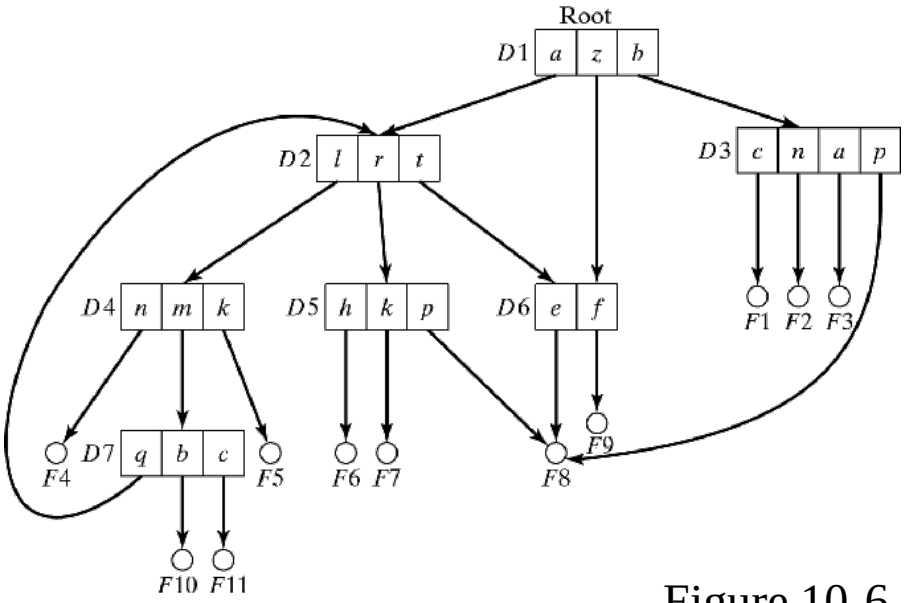


Figure 10-6

  - If cycles are allowed:
    - Search is difficult (infinite loops)
    - Deletion needs garbage collection (reference count not enough)

File Directories

- Symbolic links
  - Compromise to allow sharing but avoid cycles

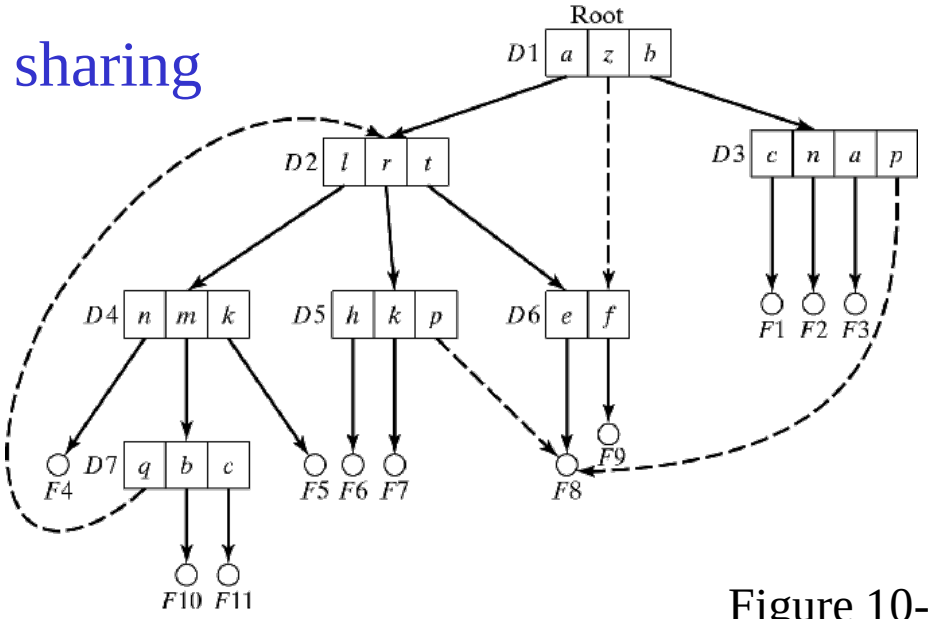


Figure 10-7

  - For read/write access:
    Symbolic link is the same as actual link
  - For deletion: Only symbolic link is deleted

File Directories

- File naming: Path names
  - Concatenated local names with delimiter:
    (`.` or `/` or `\`)
  - *Absolute* path name: start with root
    (`/`)
  - *Relative* path name: Start with current directory
    (`.`)
  - Notation to move “upward”
    (`..`)

Operations on File Directories

- Create/delete
- List
  - sorting, wild cards, recursion, information displayed
- Change (current, working, default) directory
  - path name, home directory (default)
- Move
- Rename
- Change protection
- Create/delete link (symbolic)
- Find/search routines

Implementation of Directories

- What information to keep in each entry
  - Only symbolic name and pointer to descriptor
    - Needs an extra disk access to descriptor
  - All descriptive information
    - Directory can become very large
- How to organize entries within directory
  - Fixed-size array of slots or a linked list
    - Easy insertion/deletion
    - Search is sequential
  - Hash table (how big should it be?)
  - B-tree (balanced, but sequential access can be slow)
  - B^+-tree (balanced and with good sequential access)

Basic File System

- Open/Close files
  - Retrieve and set up descriptive information for efficient access
- File descriptor (*i-node* in Unix)
  - Owner id
  - File type
  - Protection information
  - Mapping to physical disk blocks
  - Time of creation, last use, last modification
  - Reference counter

Basic File System

- *Open File Table (OFT)* keeps track of currently open files
- *Open* command:
  - Verify access rights
  - Allocate OFT entry
  - Allocate read/write buffers
  - Fill in OFT entry
    - Initialization (e.g., current position)
    - Information from descriptor (e.g. file length, disk location)
    - Pointers to allocated buffers
  - Return OFT index

Basic File System

- *Close* command:
  - Flush modified buffers to disk
  - Release buffers
  - Update file descriptor
    - file length, disk location, usage information
  - Free OFT entry

Basic File System

- Example: Unix
- Unbuffered access

  fd=open(name,rw,…)
  stat=read(fd,mem,n)
  stat=write(fd,mem,n)
- Buffered access

  fp=fopen(name,rwa)
  c=readc(fp) // read one character

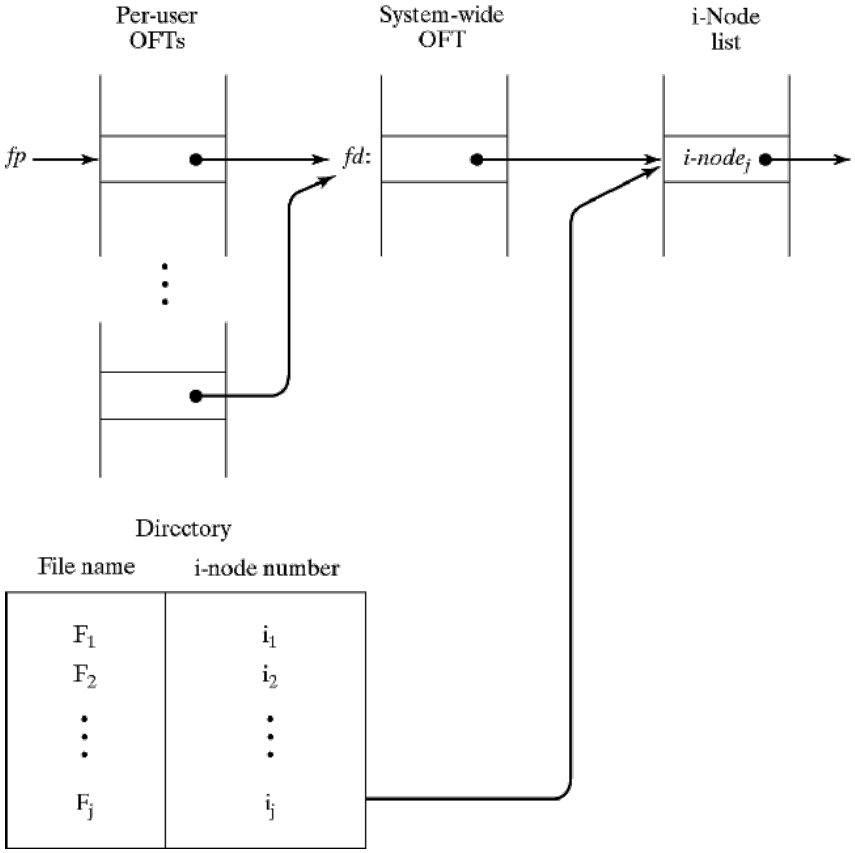


Figure 10-11

Physical Organization Methods

- Contiguous organization
  - Simple implementation
  - Fast sequential access (minimal arm movement)
  - Insert/delete is difficult
  - How much space to allocate initially
  - External fragmentation

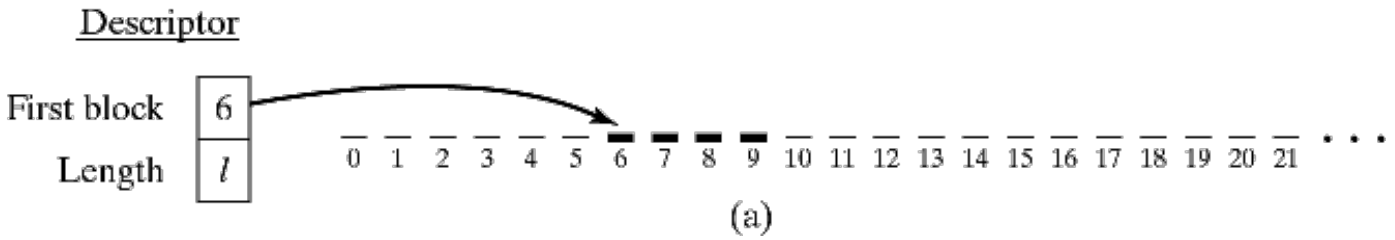


Figure 10-12a

Physical Organization Methods

- Linked Organization
  - Simple insert/delete, no external fragmentation
  - Sequential access less efficient (seek latency)
  - Direct access not possible
  - Poor reliability (when chain breaks)

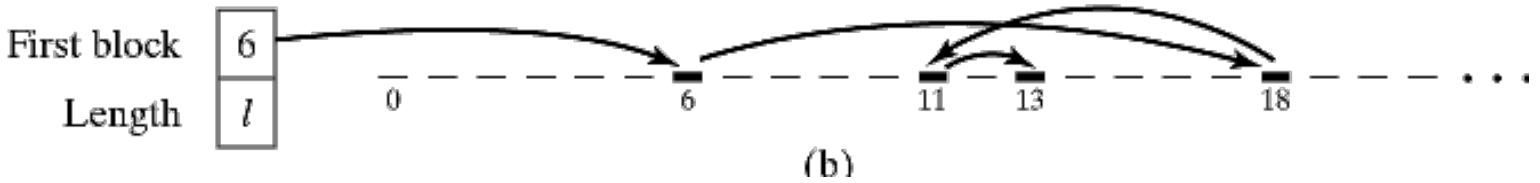


Figure 10-12b

Physical Organization Methods

- Linked Variation 1: Keep pointers segregated
  - May be cached

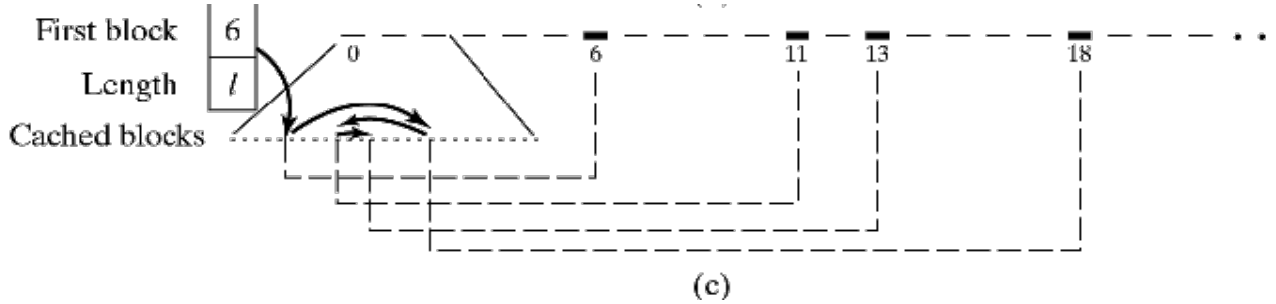


Figure 10-12c

- Linked Variation 2: Link sequences of adjacent blocks, rather than individual blocks

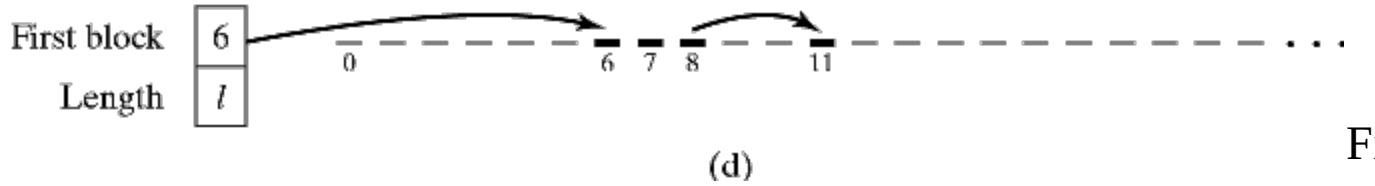


Figure 10-12d

Physical Organization Methods

- Indexed Organization
  - Index table: sequential list of records
  - Simplest implementation: keep index list in descriptor

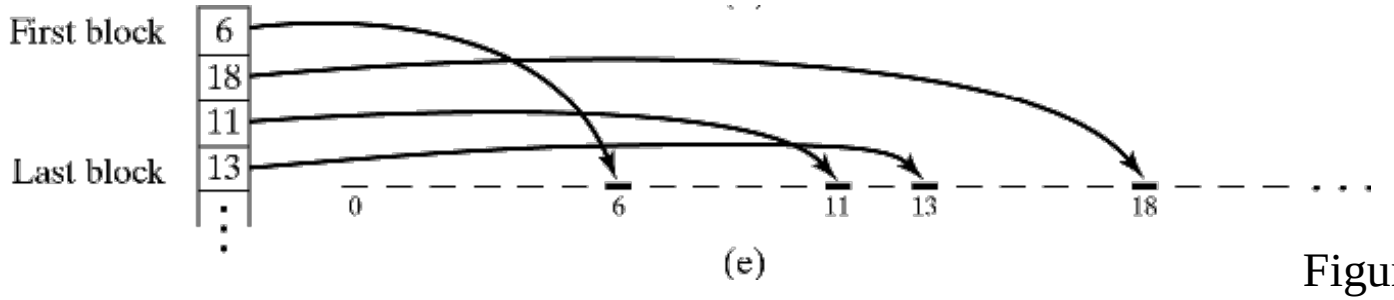


Figure 10-12e

  - Insert/delete is easy
  - Sequential and direct access is efficient
  - Drawback: file size limited by number of index entries

Physical Organization Methods

- Variations of indexing
  - Multi-level index hierarchy
    - Primary index points to secondary indices
    - Problem: number of disk accesses increases with depth of hierarchy
  - Incremental indexing
    - Fixed number of entries at top-level index
    - When insufficient, allocate additional index levels
    - Example: Unix -- 3-level expansion (see next slide)

Physical Organization Methods

- Incremental indexing
  - Example: Unix
    3-level expansion

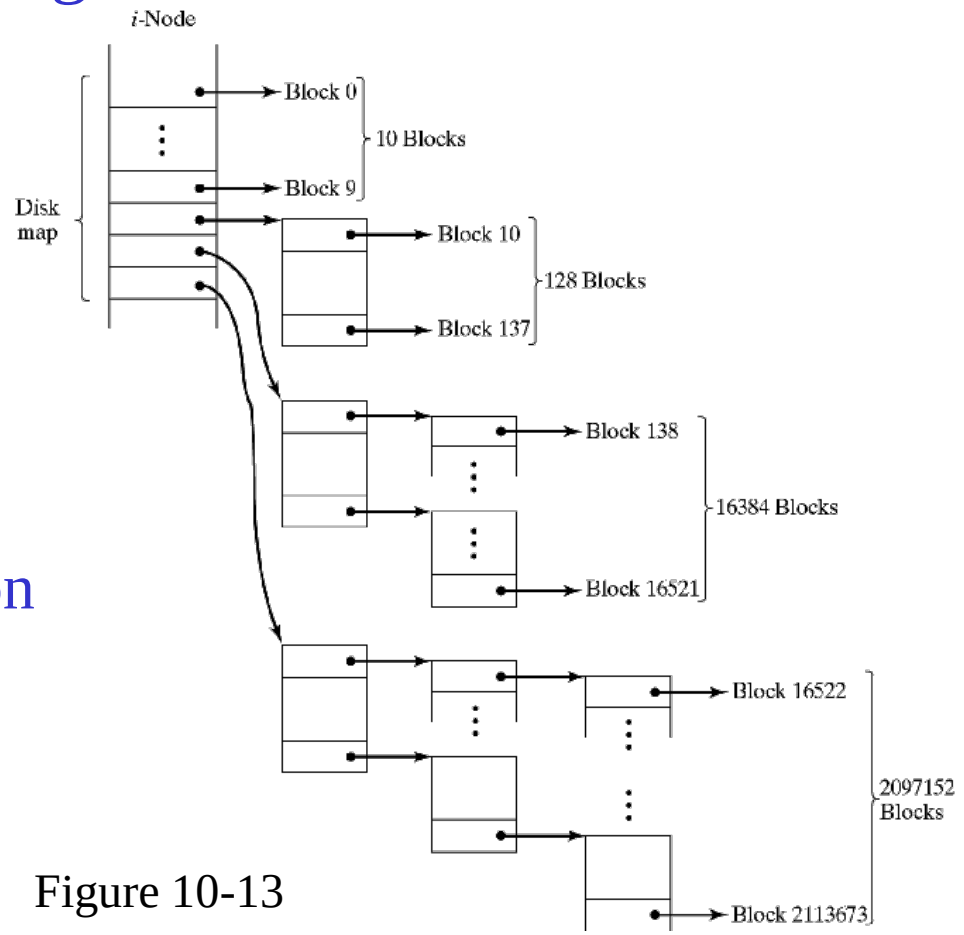


Figure 10-13

Free Storage Space Management

- Similar to main memory management
- Linked list organization
  - Linking individual blocks -- inefficient:
    - No block clustering to
      minimize seek operations
    - Groups of blocks are
      allocated/released one at a time
  - Linking groups of consecutive blocks
- Bit map organization
  - Analogous to main memory

Distributed File Systems

- Present a single view of all files across multiple computers
  - Shared directory structure
  - Shared files
- Implementation
  - Basic architecture
  - Caching
  - Servers: Stateless vs. Stateful
  - File replication

Distributed File Systems

- Directory structures differentiated by:
  - Global *vs* Local naming:
    - Single global structure or different for each user?
  - Location transparency:
    - Does the path name reveal anything about machine or server?
  - Location independence
    - When a file moves between machines, does its path name change?

Global Directory Structure

- Combine local directory structures under a new common root

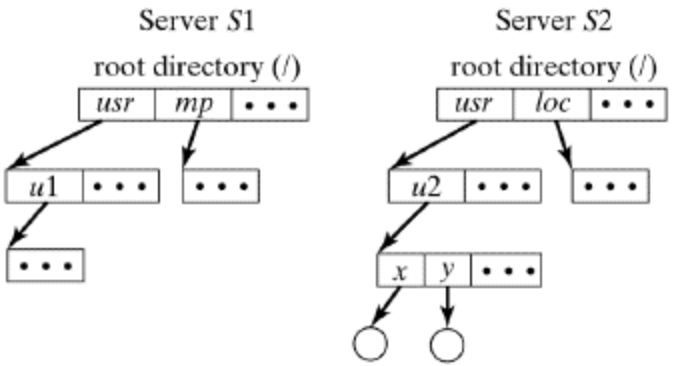


Figure 10-14a

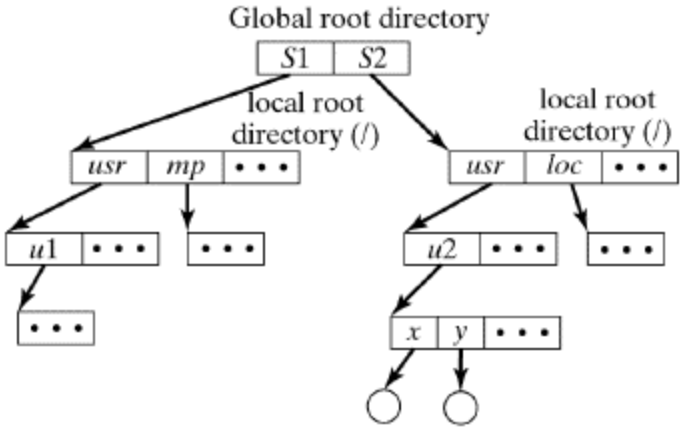


Figure 10-14b

Global Directory Structure

- Problem with "Combine under new common root:"
  - Using **/** for new root invalidates existing local names
- Solution (Unix United):
  - Use **/** for local root
  - Use **..** to move to new root
  - Example: reach **u1** from **u2**: can use either

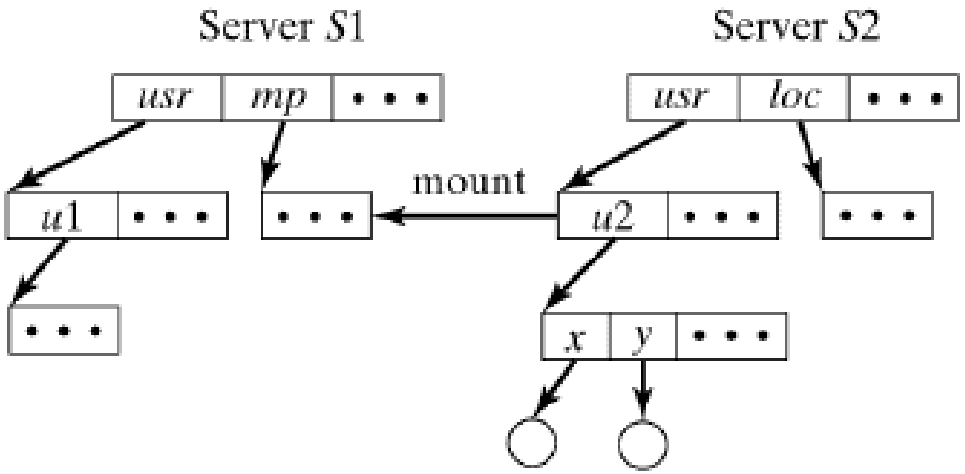
    ../../../S1/usr/u1

    or

    /../S1/usr/u1
  - Names are *not* location transparent

Local Directory Structures

- Mounting
  - Subtree on one machine is *mounted* over/in-the-place-of a directory on another machine (called the *mount point*)
  - Original contents of mount point are invisible during mount (so usually an empty directory is chosen)
  - Structure changes dynamically
  - Each user has own view of FS



On S1: **`/mp`**
On S2: **`/usr`**

On S1: **`/mp/u2/x`**
On S2: **`/usr/u2/x`**

Figure 10-14c

Shared Directory Substructure

- Each machine has local file system
- One subtree is shared by all machines

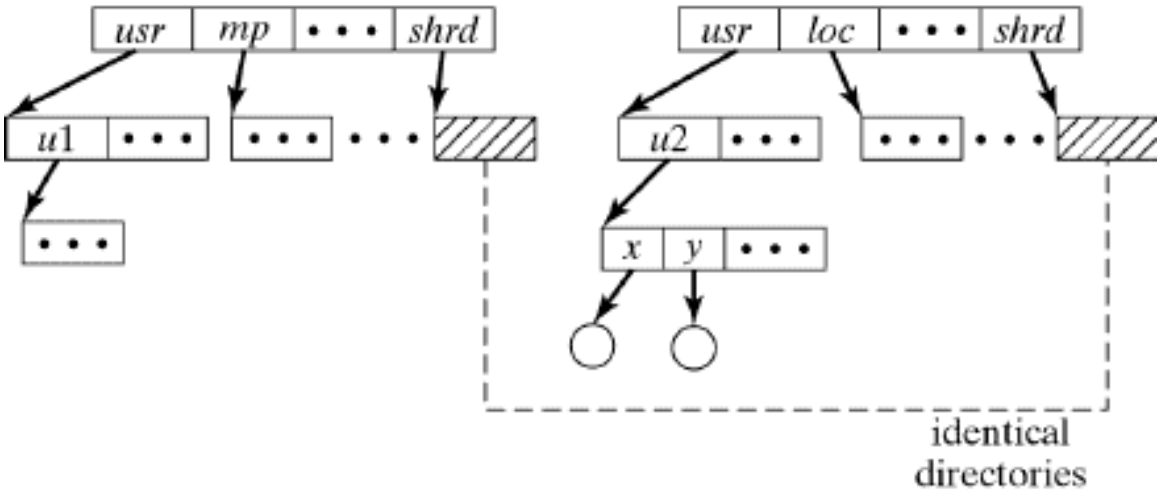


Figure 10-14d

Semantics of File Sharing

- Unix semantics
  - All updates are immediately visible
  - Generates a lot of network traffic
- Session semantics
  - Updates visible when file closes
  - Simultaneous updates are unpredictable (lost)
- Transaction semantics
  - Updates visible at end of transaction
- Immutable-files semantics
  - Updates create a new version of file
  - Now the problem is one of version management

Implementing DFS

- Basic Architecture
  - Client/Server Virtual file system (cf., Sun's NFS):
    - If file is local, access local file system
    - If file is remote, communicate with remote server

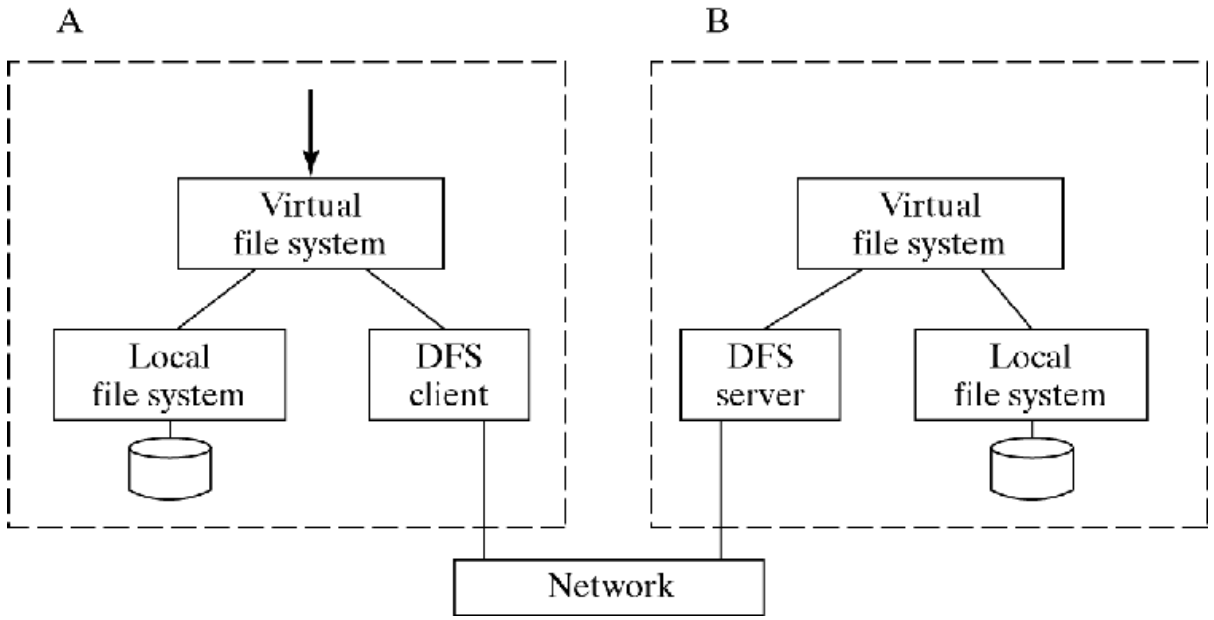


Figure 10-15

Implementing DFS

- Caching reduces
  - Network delay
  - Disk access delay
- Server caching - simple
  - No disk access on subsequent access
  - No cache coherence problems
  - But network delay still exists
- Client caching - more complicated
  - When to update file on server?
  - When/how to inform other processes when files is updated on server?

Implementing DFS

- When to update file on server?
  - Write-through
    - Allows Unix semantics but overhead is significant
  - Delayed writing
    - Requires weaker semantics
      - Session semantics: only propagate update when file is closed
      - Transaction semantics: only propagate updates at end of transactions
- How to propagate changes to other caches?
  - Server initiates/informs other processes
    - Violates client/server relationship
  - Clients check periodically
    - Checking before each access defeats purpose of caching
    - Checking less frequently requires weaker semantics
      - Session semantics: only check when opening the file

Implementing DFS

- Stateless vs. Stateful Server
- Stateful = Maintain state of open files
- Client passes commands & data between user process & server

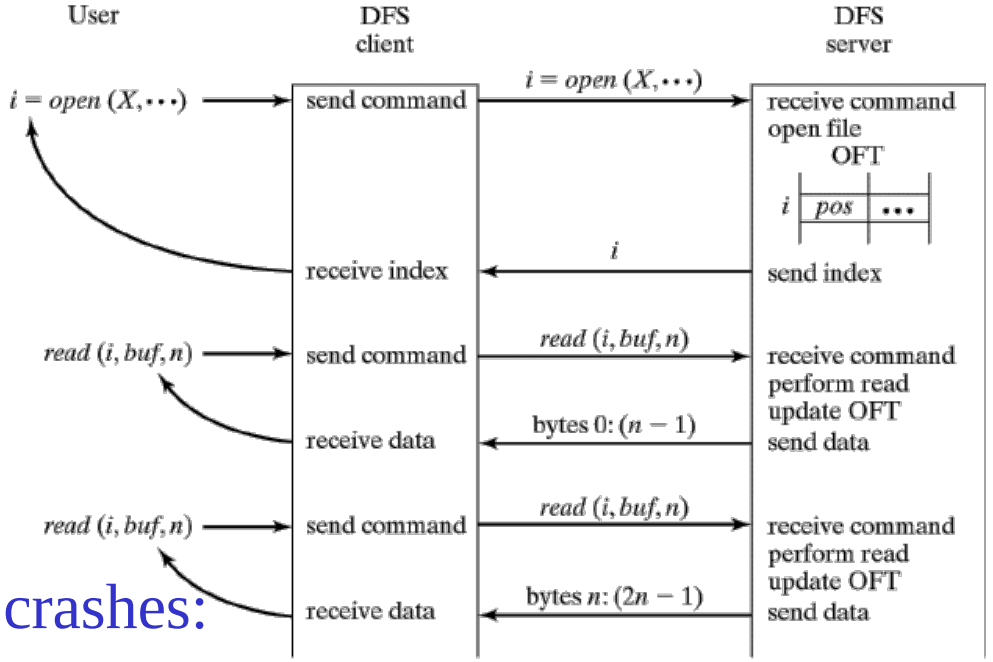


Figure 10-16a

- Problem when server crashes:
  - State of open files is lost
  - Client must restore state when server recovers

Implementing DFS

- Stateless Server (e.g., NFS) = Client maintains state of open files
- (Most) commands are *idempotent* (can be repeated). (File deletion and renaming aren't)

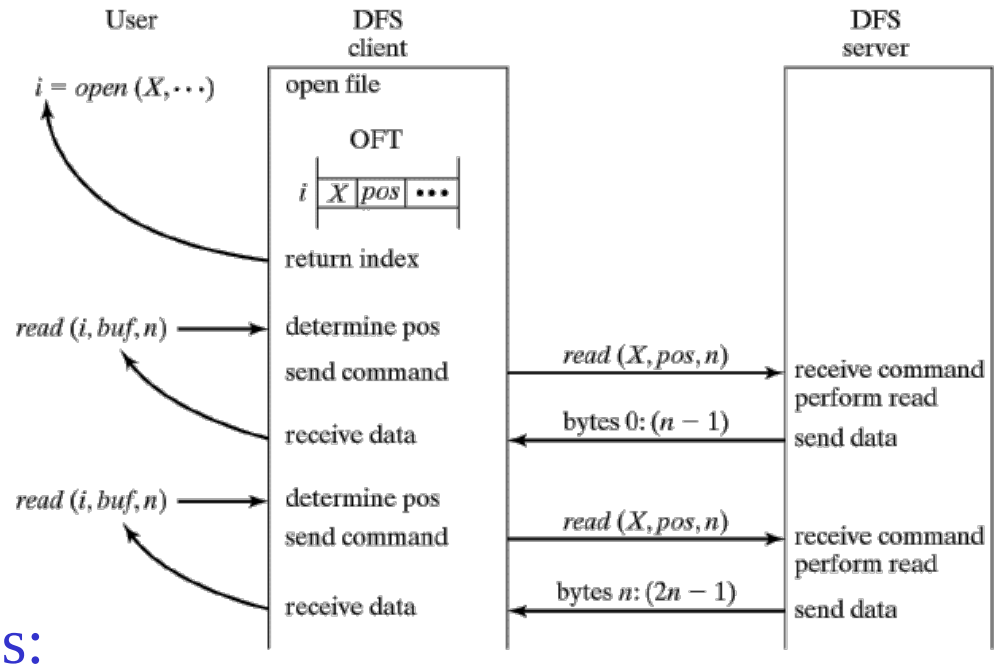


Figure 10-16b

- When server crashes:
  - Client waits until server recovers
  - Client reissues read/write commands

Implementing DFS

- File replication improves
  - Availability
    - Multiple copies available
  - Reliability
    - Multiple copies help in recovery
  - Performance
    - Multiple copies remove bottlenecks and reduce network latency
  - Scalability
    - Multiple copies reduce bottlenecks

Implementing DFS

- Problem: File copies must be consistent
- Replication protocols
  - Read-Any/Write-All
    - Problem: What if a server is temporarily unavailable?
  - Quorum-Based Read/Write
    - N copies; r = read quorum; w = write quorum
    - r+w > N and w > N/2
    - Any read sees at least one current copy
    - No disjoint writes

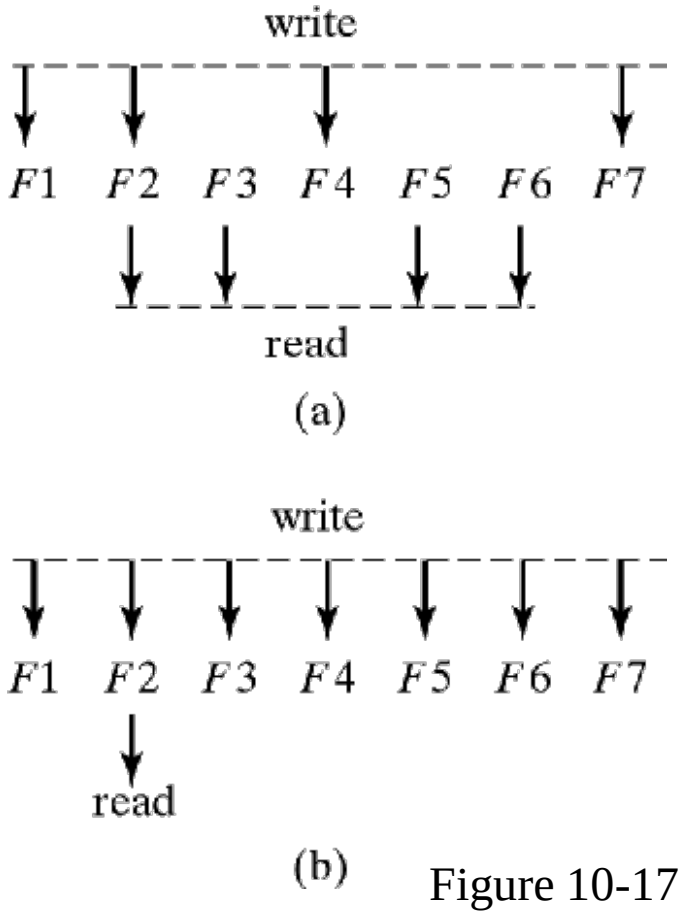


Figure 10-17