

Chapter 11: File System Implementation

- File-System Structure
- File-System Implementation
- Directory Implementation
- Allocation Methods
- Free-Space Management
- Efficiency and Performance
- Recovery
- Log-Structured File Systems
- NFS
- Example: WAFL File System

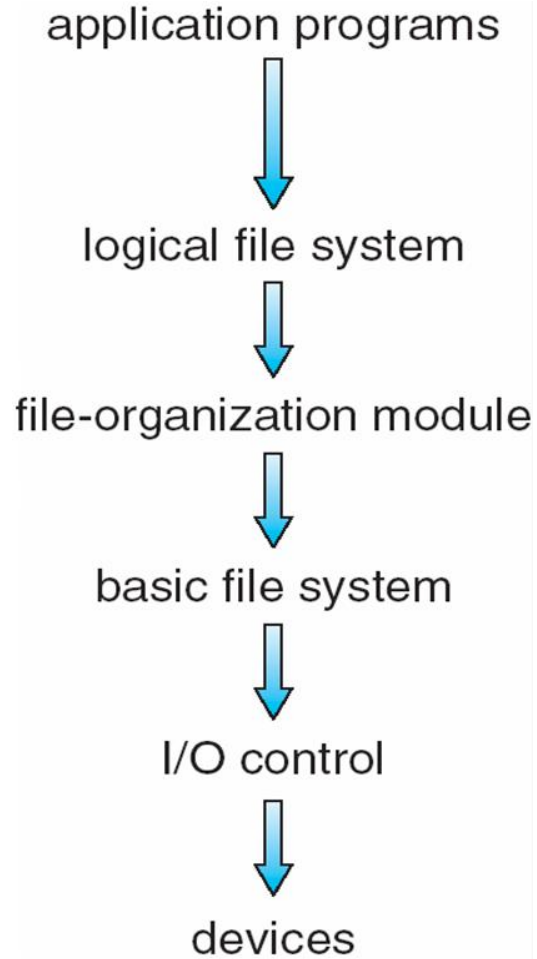
Objectives

- To describe the details of implementing local file systems and directory structures
- To describe the implementation of remote file systems
- To discuss block allocation and free-block algorithms and trade-offs

File-System Structure

- File structure
 - Logical storage unit
 - Collection of related information
- File system resides on secondary storage (disks)
- File system organized into layers
- **File control block** – storage structure consisting of information about a file

Layered File System



A Typical File Control Block

file permissions

file dates (create, access, write)

file owner, group, ACL

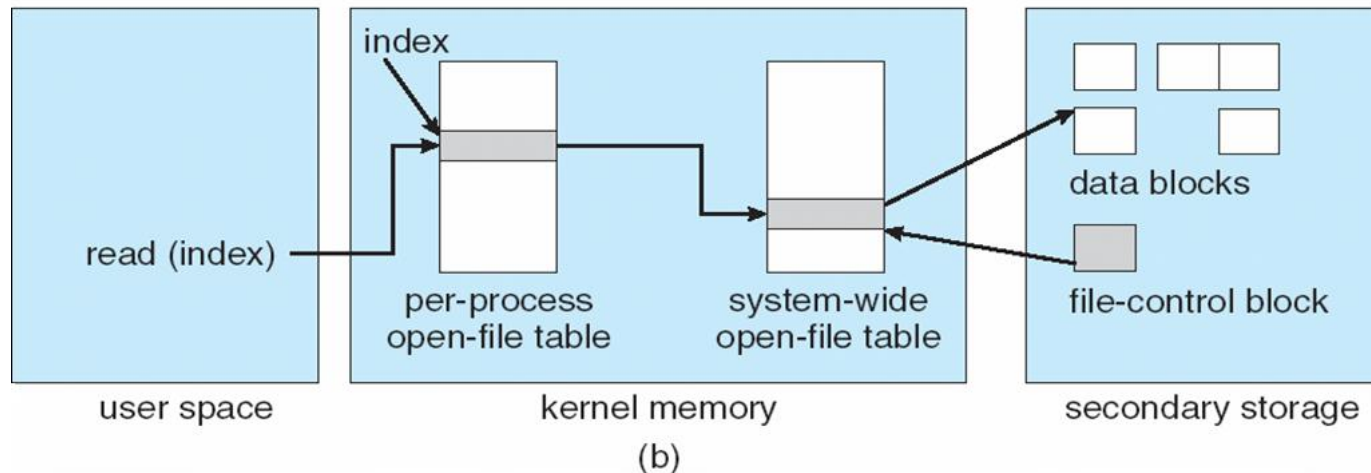
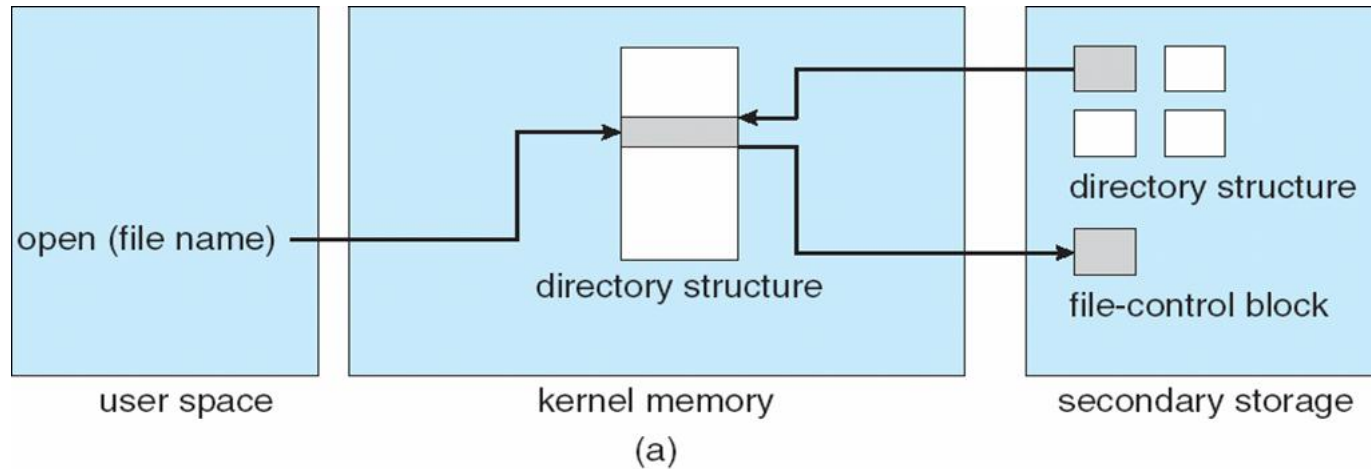
file size

file data blocks or pointers to file data blocks

In-Memory File System Structures

- The following figure illustrates the necessary file system structures provided by the operating systems.
- Figure 12-3(a) refers to opening a file.
- Figure 12-3(b) refers to reading a file.

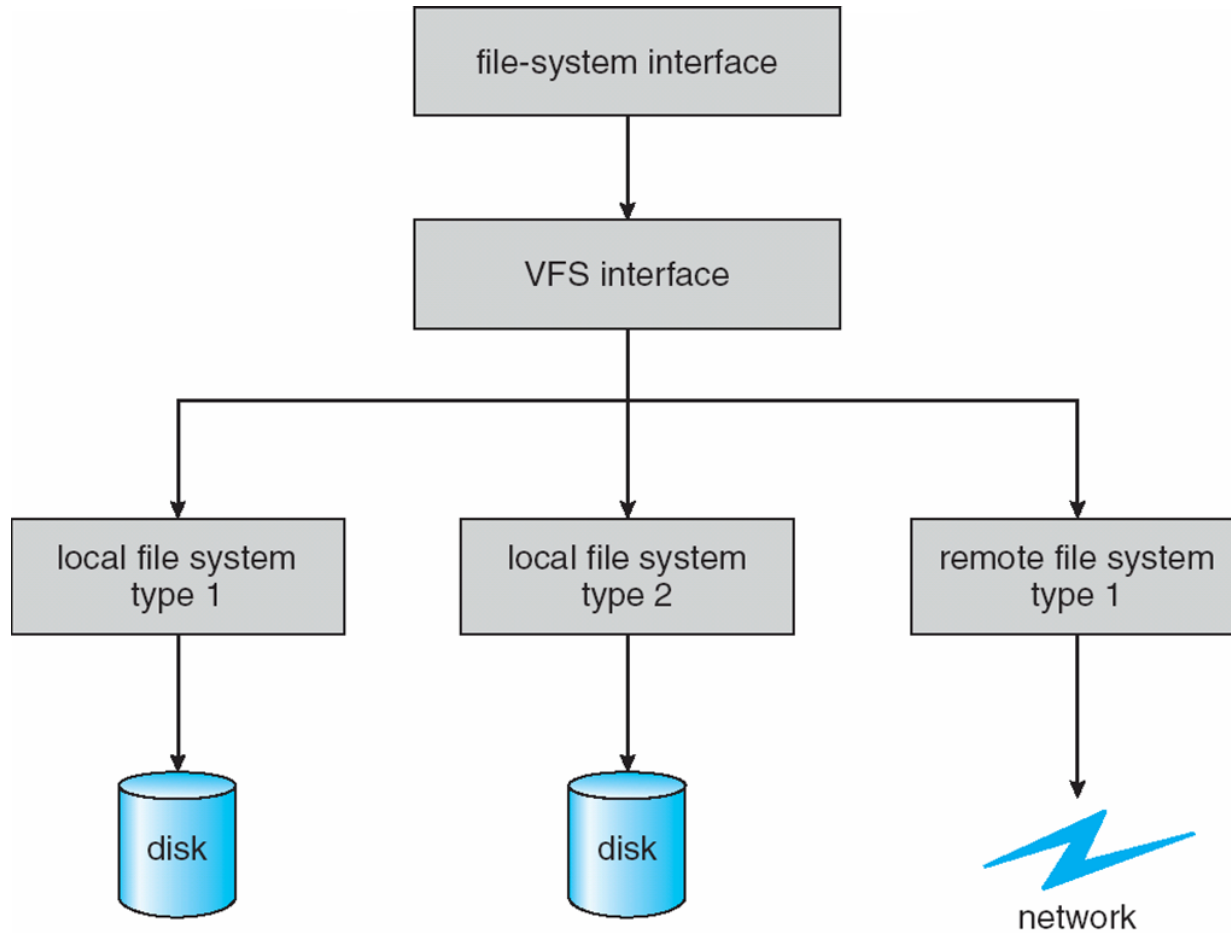
In-Memory File System Structures



Virtual File Systems

- Virtual File Systems (VFS) provide an object-oriented way of implementing file systems.
- VFS allows the same system call interface (the API) to be used for different types of file systems.
- The API is to the VFS interface, rather than any specific type of file system.

Schematic View of Virtual File System



Directory Implementation

- **Linear list** of file names with pointer to the data blocks.
 - simple to program
 - time-consuming to execute
- **Hash Table** – linear list with hash data structure.
 - decreases directory search time
 - **collisions** – situations where two file names hash to the same location
 - fixed size

Allocation Methods

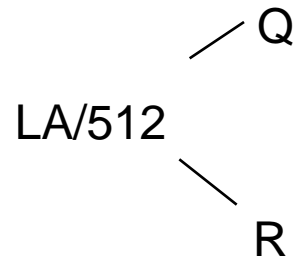
- An allocation method refers to how disk blocks are allocated for files:
- **Contiguous allocation**
- **Linked allocation**
- **Indexed allocation**

Contiguous Allocation

- Each file occupies a set of contiguous blocks on the disk
- Simple – only starting location (block #) and length (number of blocks) are required
- Random access
- Wasteful of space (dynamic storage-allocation problem)
- Files cannot grow

Contiguous Allocation

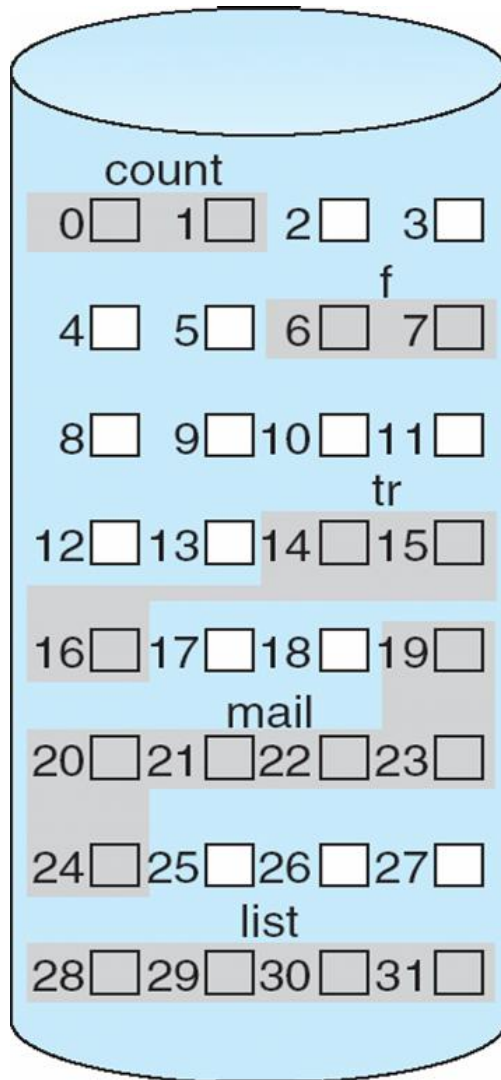
- Mapping from logical to physical



Block to be accessed = ! + starting address

Displacement into block = R

Contiguous Allocation of Disk Space



directory

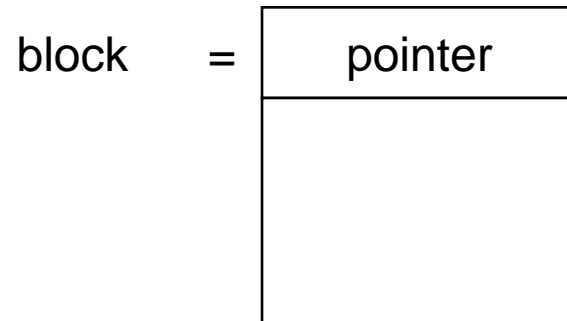
file	start	length
count	0	2
tr	14	3
mail	19	6
list	28	4
f	6	2

Extent-Based Systems

- Many newer file systems (I.e. Veritas File System) use a modified contiguous allocation scheme
- Extent-based file systems allocate disk blocks in **extents**
- An **extent** is a contiguous block of disks
 - Extents are allocated for file allocation
 - A file consists of one or more extents.

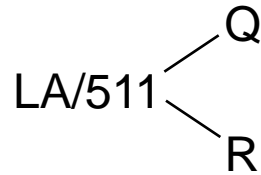
Linked Allocation

- Each file is a linked list of disk blocks: blocks may be scattered anywhere on the disk.



Linked Allocation (Cont.)

- Simple – need only starting address
- Free-space management system – no waste of space
- No random access
- Mapping

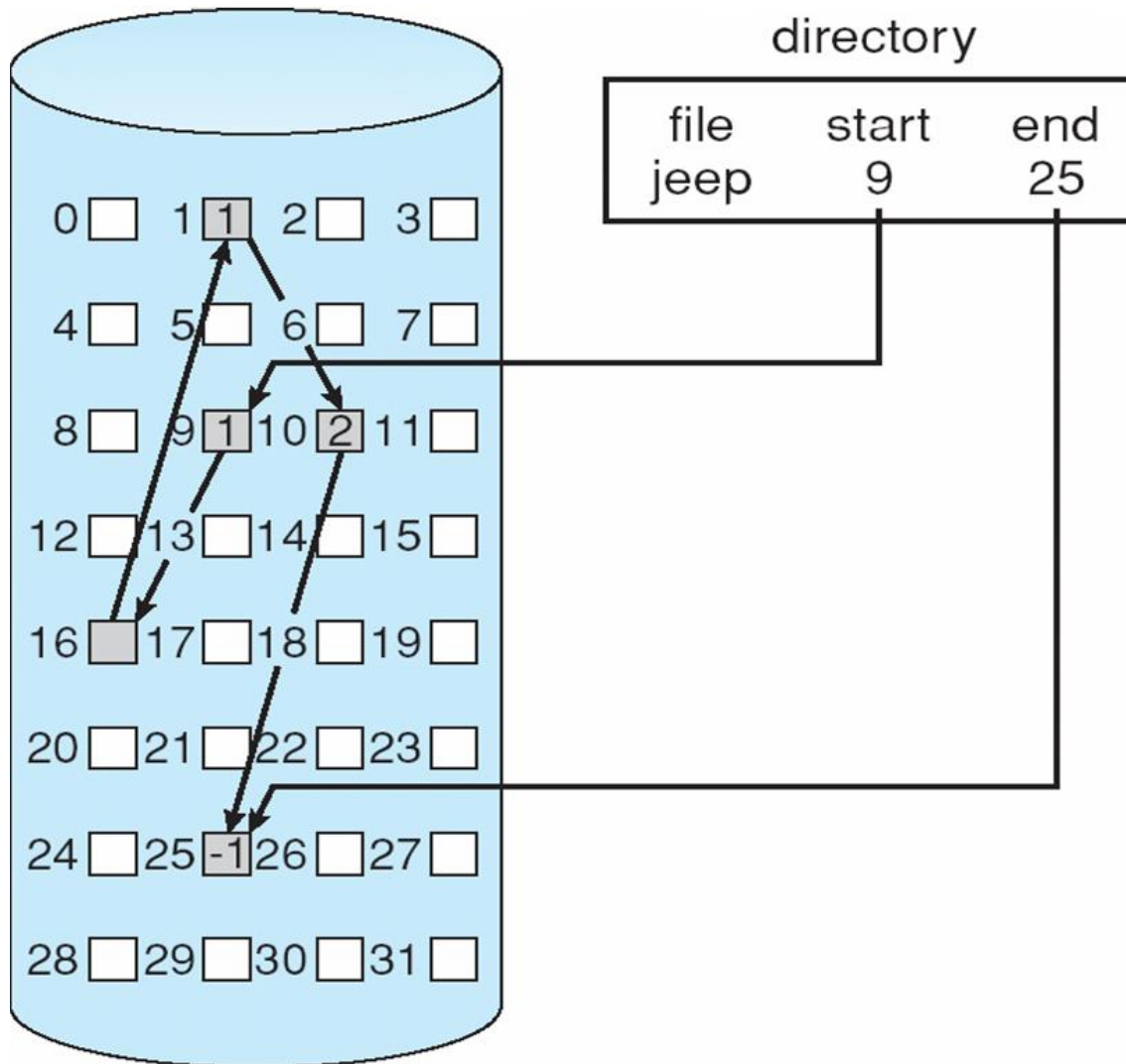


Block to be accessed is the Qth block in the linked chain of blocks representing the file.

Displacement into block = $R + 1$

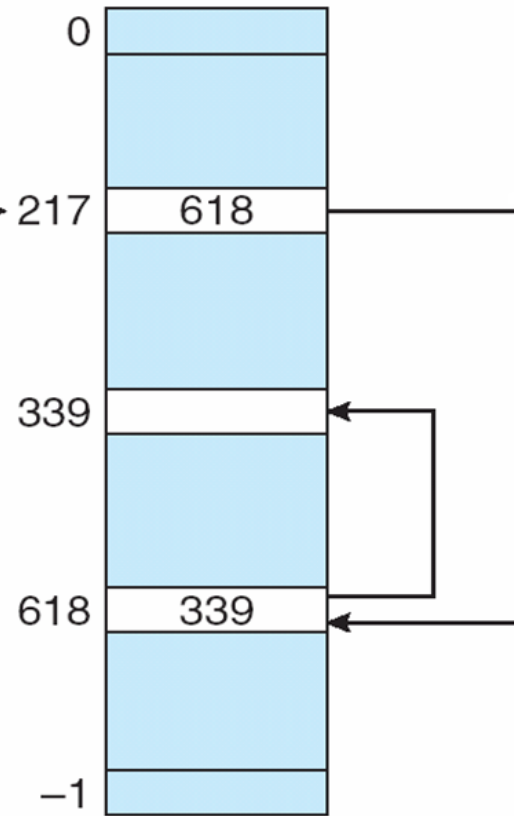
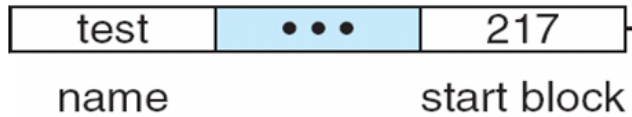
File-allocation table (FAT) – disk-space allocation used by MS-DOS and OS/2.

Linked Allocation



File-Allocation Table

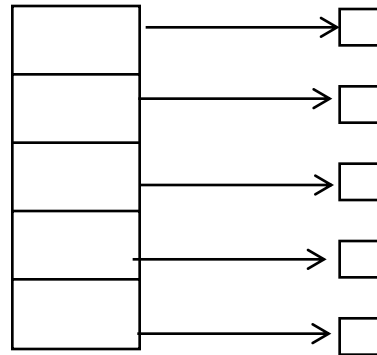
directory entry



FAT

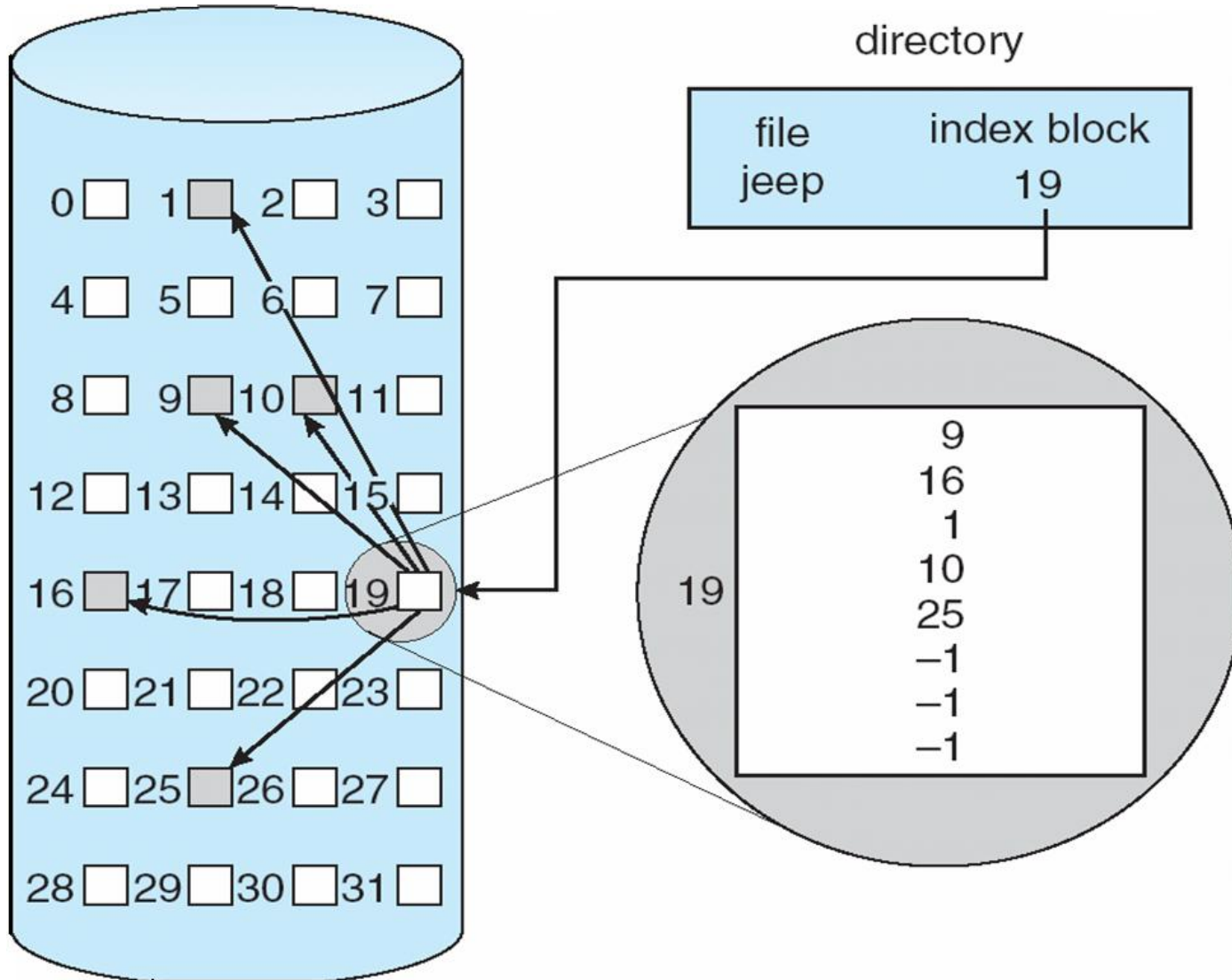
Indexed Allocation

- Brings all pointers together into the *index block*.
- Logical view.



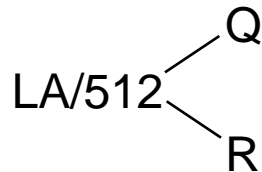
index table

Example of Indexed Allocation



Indexed Allocation (Cont.)

- Need index table
- Random access
- Dynamic access without external fragmentation, but have overhead of index block.
- Mapping from logical to physical in a file of maximum size of 256K words and block size of 512 words. We need only 1 block for index table.



Q = displacement into index table

R = displacement into block

Indexed Allocation – Mapping (Cont.)

- Mapping from logical to physical in a file of unbounded length (block size of 512 words).
- Linked scheme – Link blocks of index table (no limit on size).

$$LA / (512 \times 511) \begin{cases} Q_1 \\ R_1 \end{cases}$$

Q_1 = block of index table

R_1 is used as follows:

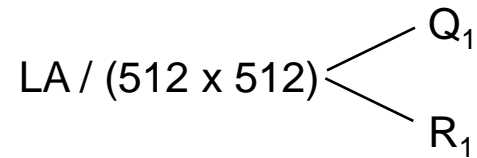
$$R_1 / 512 \begin{cases} Q_2 \\ R_2 \end{cases}$$

Q_2 = displacement into block of index table

R_2 displacement into block of file:

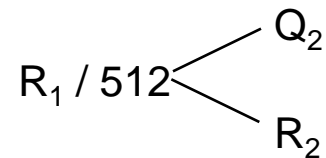
Indexed Allocation – Mapping (Cont.)

- Two-level index (maximum file size is 512^3)



Q_1 = displacement into outer-index

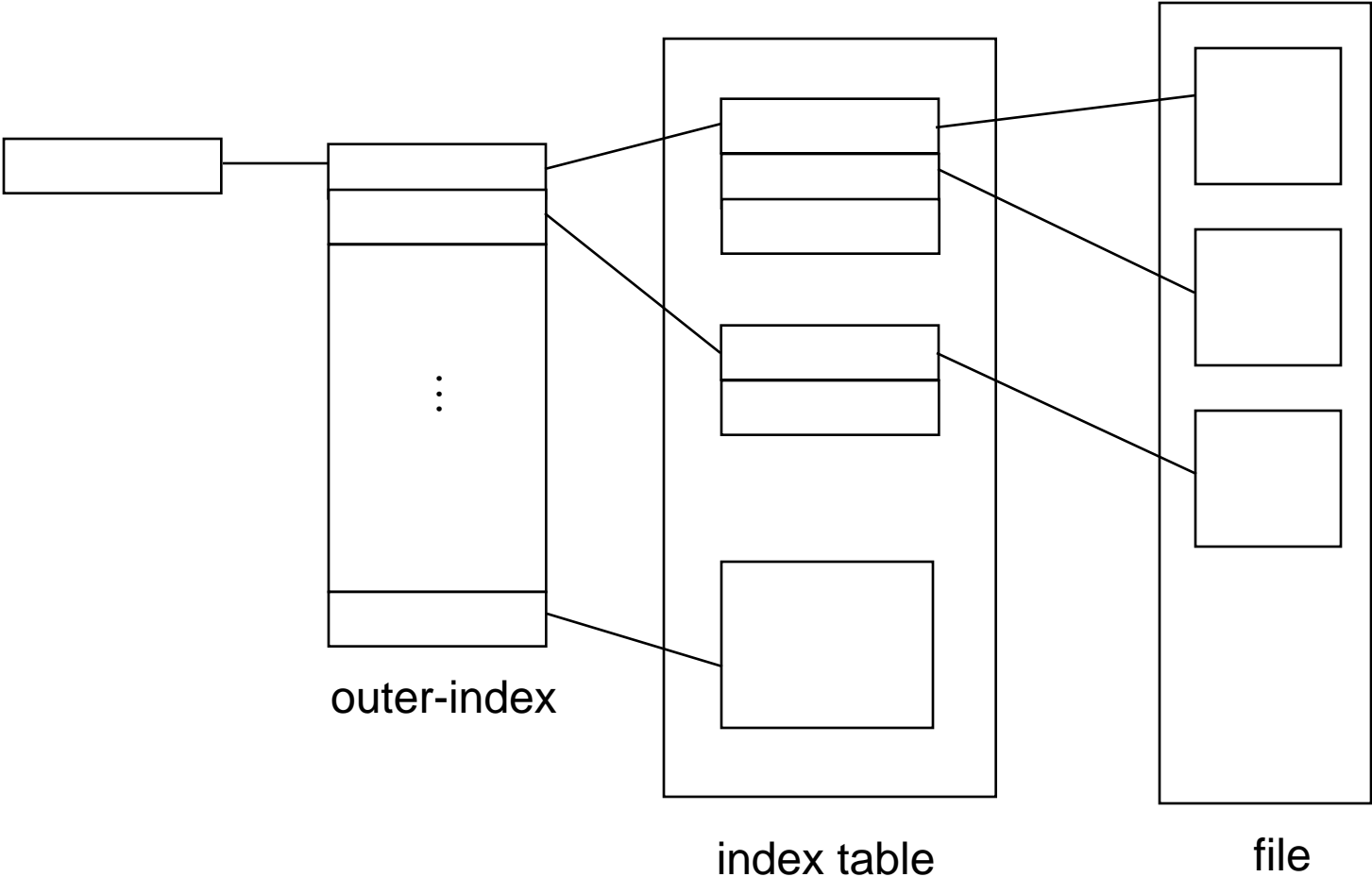
R_1 is used as follows:



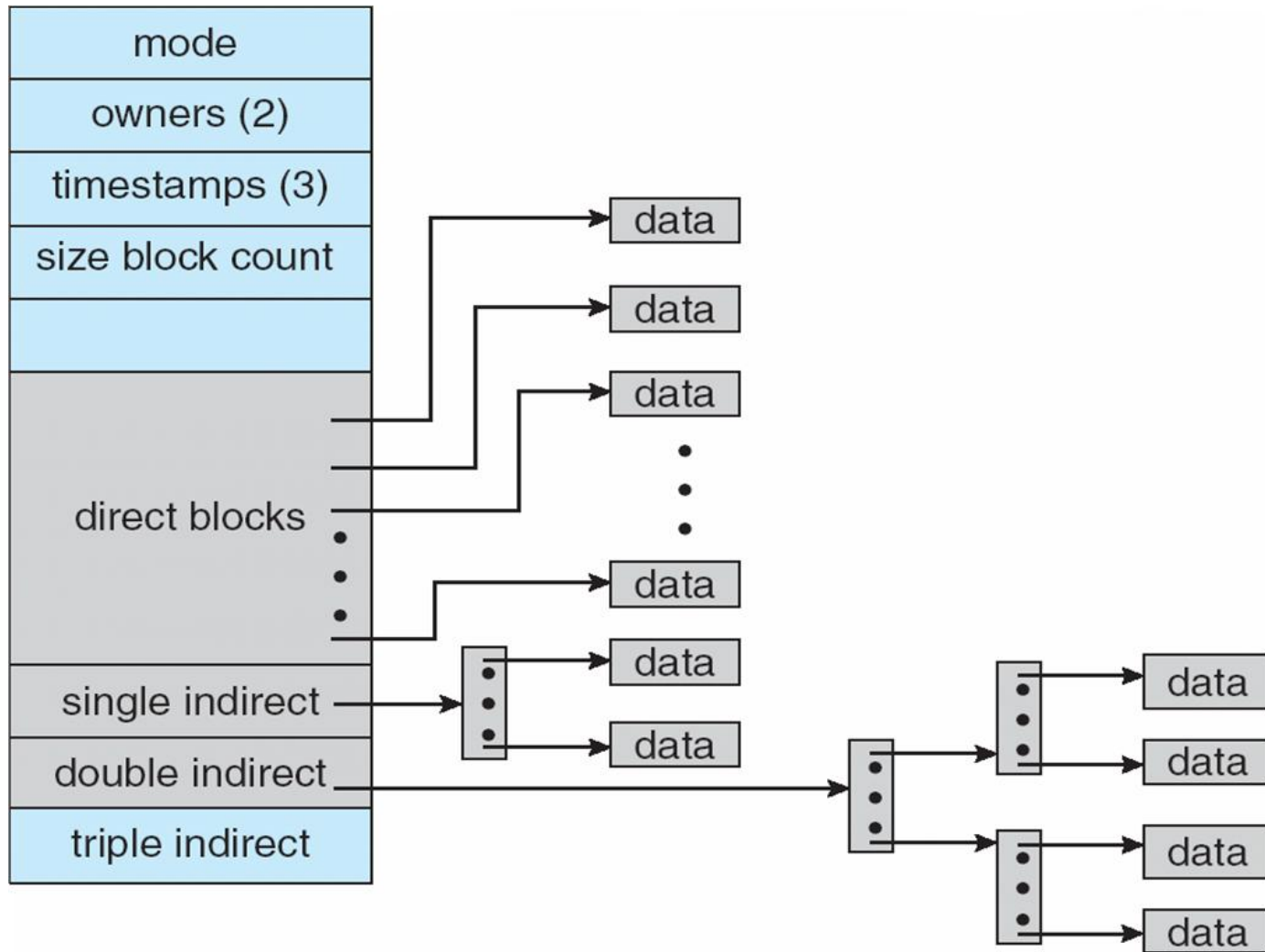
Q_2 = displacement into block of index table

R_2 displacement into block of file:

Indexed Allocation – Mapping (Cont.)

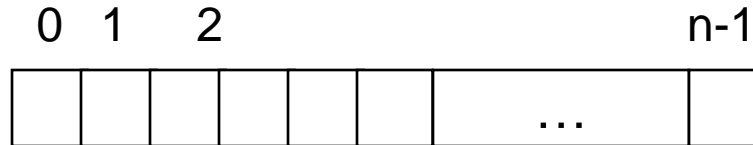


Combined Scheme: UNIX (4K bytes per block)



Free-Space Management

- Bit vector (n blocks)



$$\text{bit}[i] = \begin{cases} 0 \Rightarrow \text{block}[i] \text{ free} \\ 1 \Rightarrow \text{block}[i] \text{ occupied} \end{cases}$$

Block number calculation

(number of bits per word) *
(number of 0-value words) +
offset of first 1 bit

Free-Space Management (Cont.)

- Bit map requires extra space

- Example:

block size = 2^{12} bytes

disk size = 2^{30} bytes (1 gigabyte)

$n = 2^{30}/2^{12} = 2^{18}$ bits (or 32K bytes)

- Easy to get contiguous files
- Linked list (free list)
 - Cannot get contiguous space easily
 - No waste of space
- Grouping
- Counting

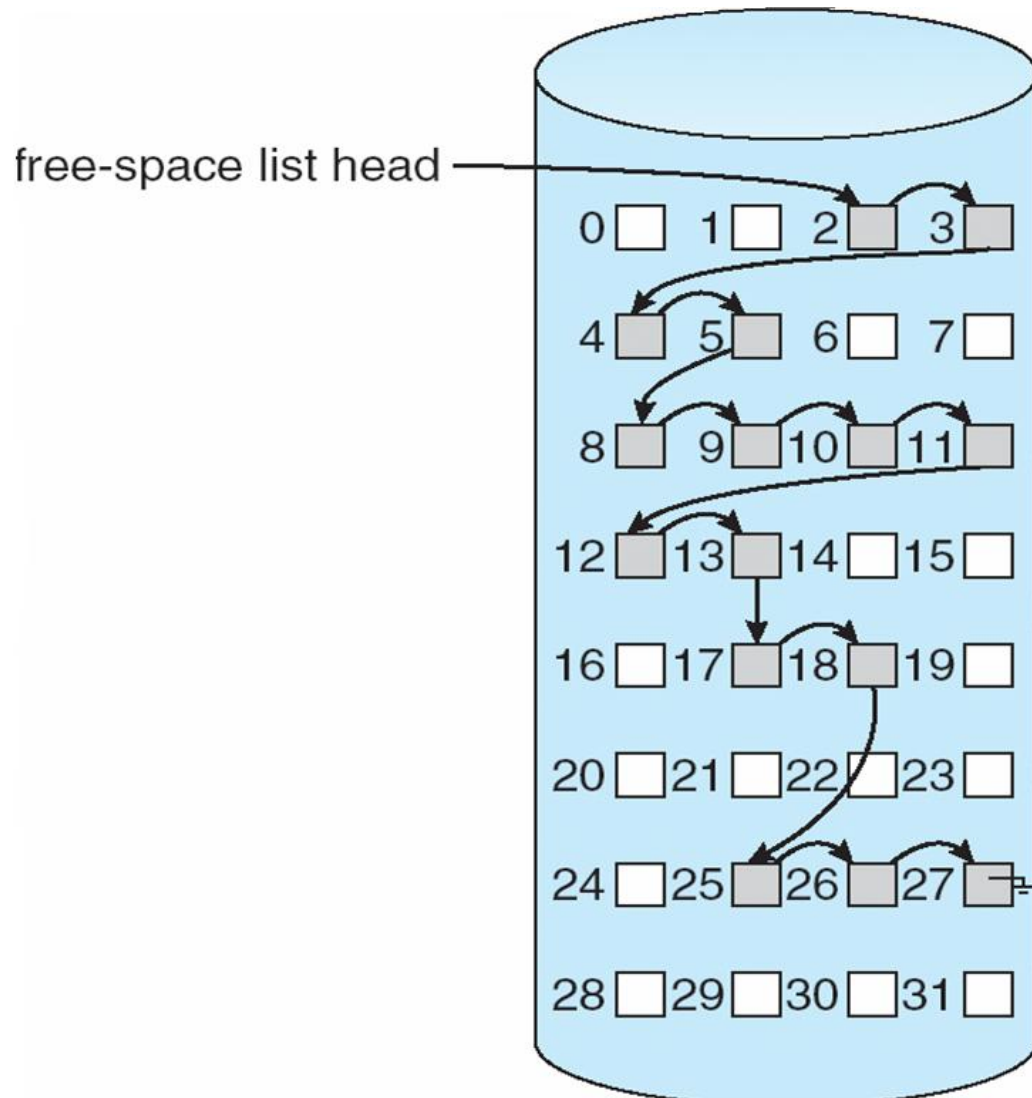
Free-Space Management (Cont.)

- Need to protect:
 - Pointer to free list
 - Bit map
 - ▶ Must be kept on disk
 - ▶ Copy in memory and disk may differ
 - ▶ Cannot allow for block[*i*] to have a situation where bit[*i*] = 1 in memory and bit[*i*] = 0 on disk
 - Solution:
 - ▶ Set bit[*i*] = 1 in disk
 - ▶ Allocate block[*i*]
 - ▶ Set bit[*i*] = 1 in memory

Directory Implementation

- Linear list of file names with pointer to the data blocks
 - simple to program
 - time-consuming to execute
- Hash Table – linear list with hash data structure
 - decreases directory search time
 - **collisions** – situations where two file names hash to the same location
 - fixed size

Linked Free Space List on Disk



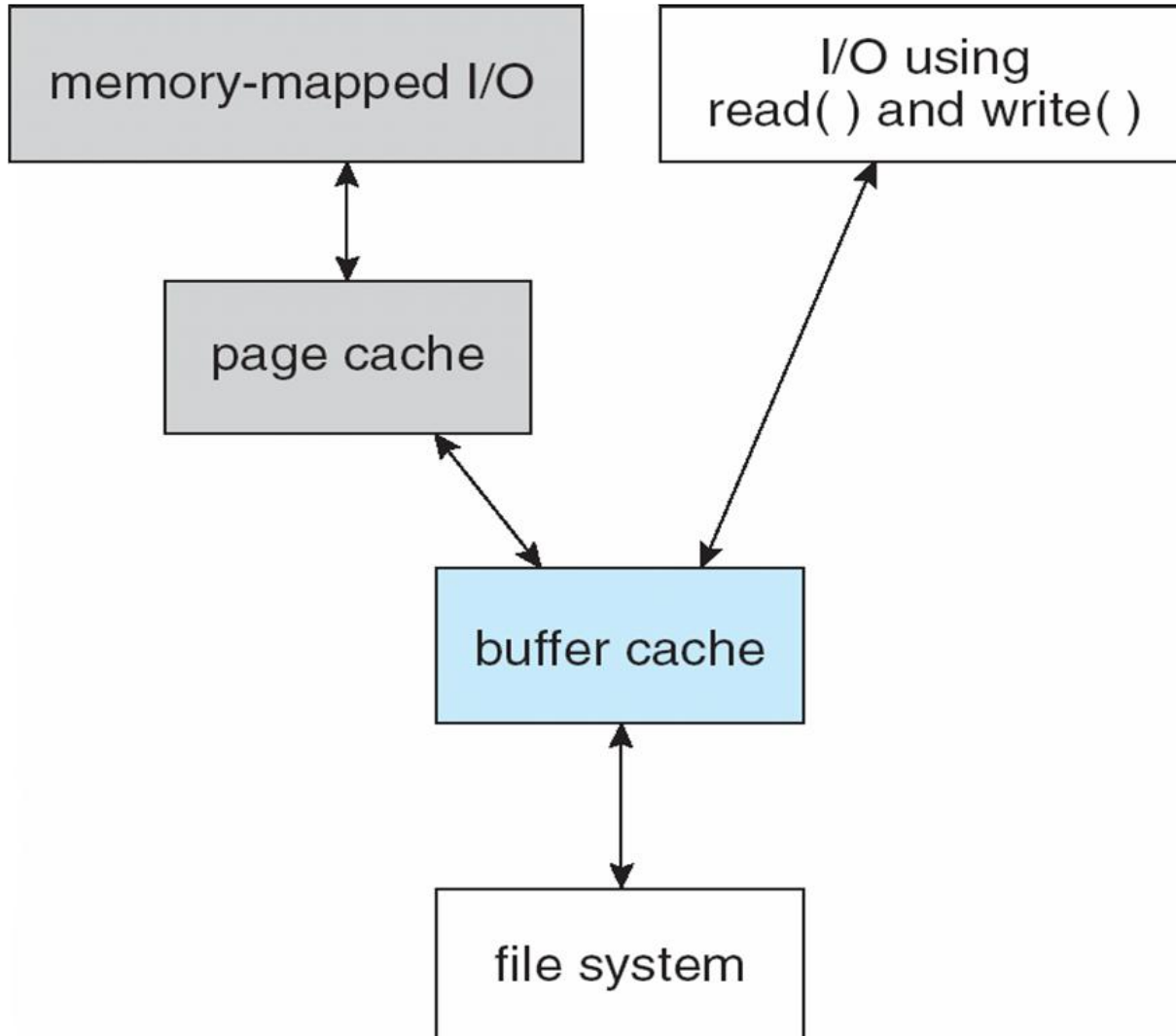
Efficiency and Performance

- Efficiency dependent on:
 - disk allocation and directory algorithms
 - types of data kept in file's directory entry
- Performance
 - disk cache – separate section of main memory for frequently used blocks
 - free-behind and read-ahead – techniques to optimize sequential access
 - improve PC performance by dedicating section of memory as virtual disk, or RAM disk

Page Cache

- A **page cache** caches pages rather than disk blocks using virtual memory techniques
- Memory-mapped I/O uses a page cache
- Routine I/O through the file system uses the buffer (disk) cache
- This leads to the following figure

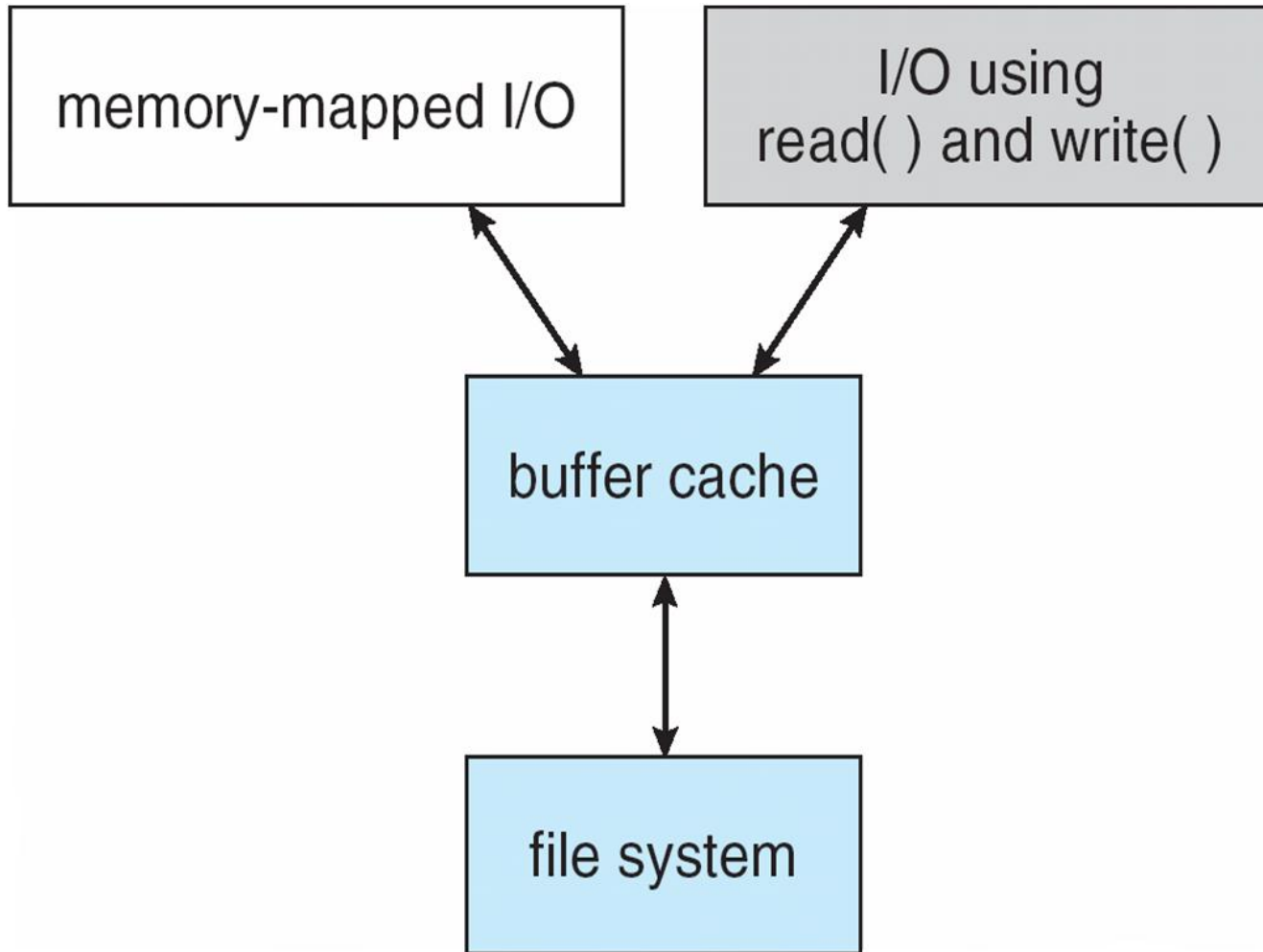
I/O Without a Unified Buffer Cache



Unified Buffer Cache

- A unified buffer cache uses the same page cache to cache both memory-mapped pages and ordinary file system I/O

I/O Using a Unified Buffer Cache



Recovery

- Consistency checking – compares data in directory structure with data blocks on disk, and tries to fix inconsistencies
- Use system programs to **back up** data from disk to another storage device (floppy disk, magnetic tape, other magnetic disk, optical)
- Recover lost file or disk by **restoring** data from backup

Log Structured File Systems

- **Log structured** (or journaling) file systems record each update to the file system as a **transaction**
- All transactions are written to a **log**
 - A transaction is considered **committed** once it is written to the log
 - However, the file system may not yet be updated
- The transactions in the log are asynchronously written to the file system
 - When the file system is modified, the transaction is removed from the log
- If the file system crashes, all remaining transactions in the log must still be performed

The Sun Network File System (NFS)

- An implementation and a specification of a software system for accessing remote files across LANs (or WANs)
- The implementation is part of the Solaris and SunOS operating systems running on Sun workstations using an unreliable datagram protocol (UDP/IP protocol and Ethernet)

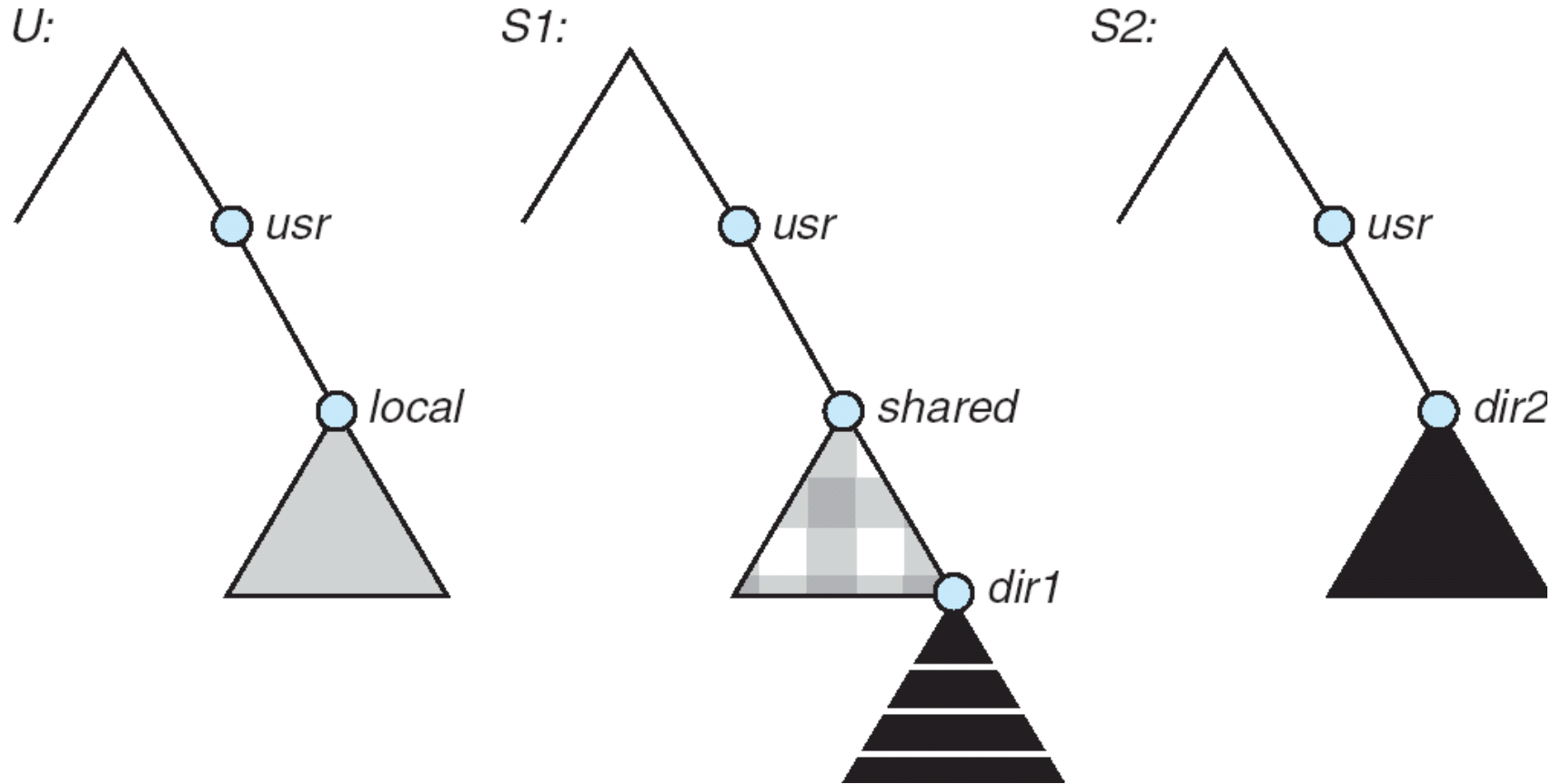
NFS (Cont.)

- Interconnected workstations viewed as a set of independent machines with independent file systems, which allows sharing among these file systems in a transparent manner
 - A remote directory is mounted over a local file system directory
 - ▶ The mounted directory looks like an integral subtree of the local file system, replacing the subtree descending from the local directory
 - Specification of the remote directory for the mount operation is nontransparent; the host name of the remote directory has to be provided
 - ▶ Files in the remote directory can then be accessed in a transparent manner
 - Subject to access-rights accreditation, potentially any file system (or directory within a file system), can be mounted remotely on top of any local directory

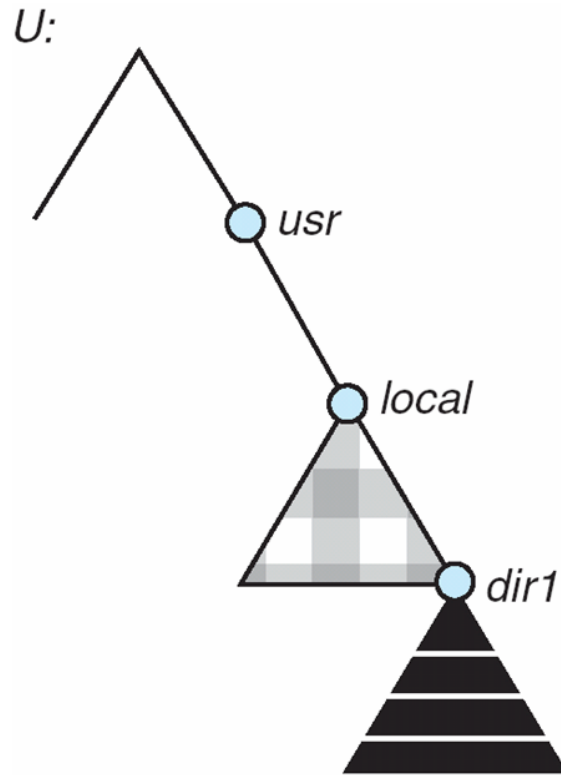
NFS (Cont.)

- NFS is designed to operate in a heterogeneous environment of different machines, operating systems, and network architectures; the NFS specifications independent of these media
- This independence is achieved through the use of RPC primitives built on top of an External Data Representation (XDR) protocol used between two implementation-independent interfaces
- The NFS specification distinguishes between the services provided by a mount mechanism and the actual remote-file-access services

Three Independent File Systems

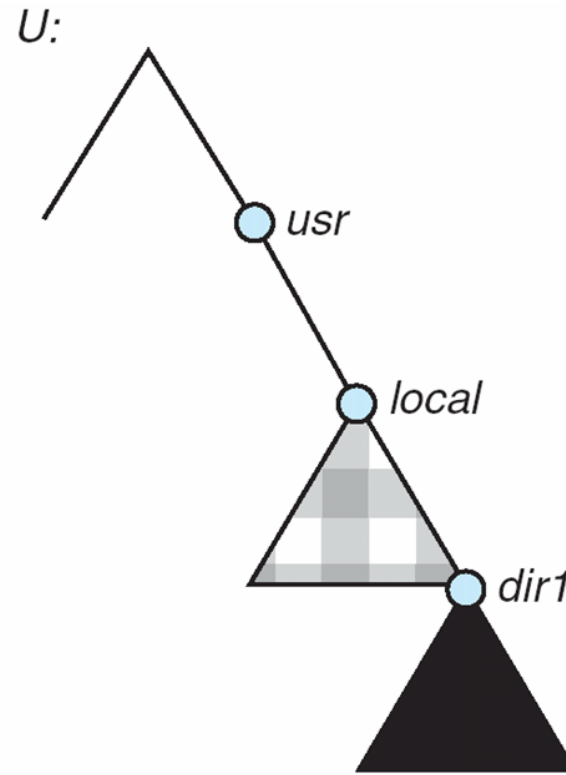


Mounting in NFS



(a)

Mounts



(b)

Cascading mounts

NFS Mount Protocol

- Establishes initial logical connection between server and client
- Mount operation includes name of remote directory to be mounted and name of server machine storing it
 - Mount request is mapped to corresponding RPC and forwarded to mount server running on server machine
 - Export list – specifies local file systems that server exports for mounting, along with names of machines that are permitted to mount them
- Following a mount request that conforms to its export list, the server returns a file handle—a key for further accesses
- File handle – a file-system identifier, and an inode number to identify the mounted directory within the exported file system
- The mount operation changes only the user's view and does not affect the server side

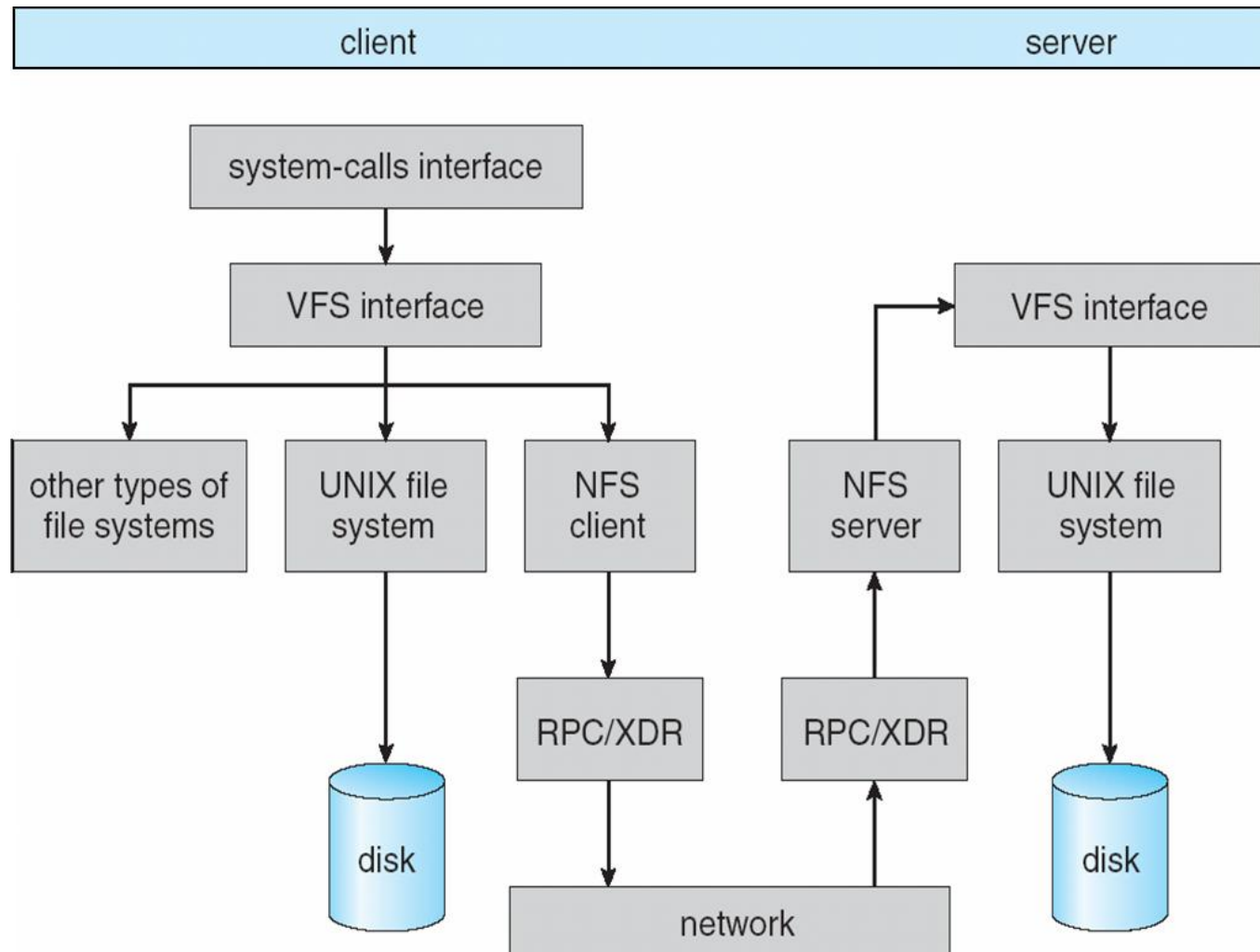
NFS Protocol

- Provides a set of remote procedure calls for remote file operations. The procedures support the following operations:
 - searching for a file within a directory
 - reading a set of directory entries
 - manipulating links and directories
 - accessing file attributes
 - reading and writing files
- NFS servers are **stateless**; each request has to provide a full set of arguments
(NFS V4 is just coming available – very different, stateful)
- Modified data must be committed to the server's disk before results are returned to the client (lose advantages of caching)
- The NFS protocol does not provide concurrency-control mechanisms

Three Major Layers of NFS Architecture

- UNIX file-system interface (based on the **open**, **read**, **write**, and **close** calls, and **file descriptors**)
- *Virtual File System* (VFS) layer – distinguishes local files from remote ones, and local files are further distinguished according to their file-system types
 - The VFS activates file-system-specific operations to handle local requests according to their file-system types
 - Calls the NFS protocol procedures for remote requests
- NFS service layer – bottom layer of the architecture
 - Implements the NFS protocol

Schematic View of NFS Architecture



NFS Path-Name Translation

- Performed by breaking the path into component names and performing a separate NFS lookup call for every pair of component name and directory vnode
- To make lookup faster, a directory name lookup cache on the client's side holds the vnodes for remote directory names

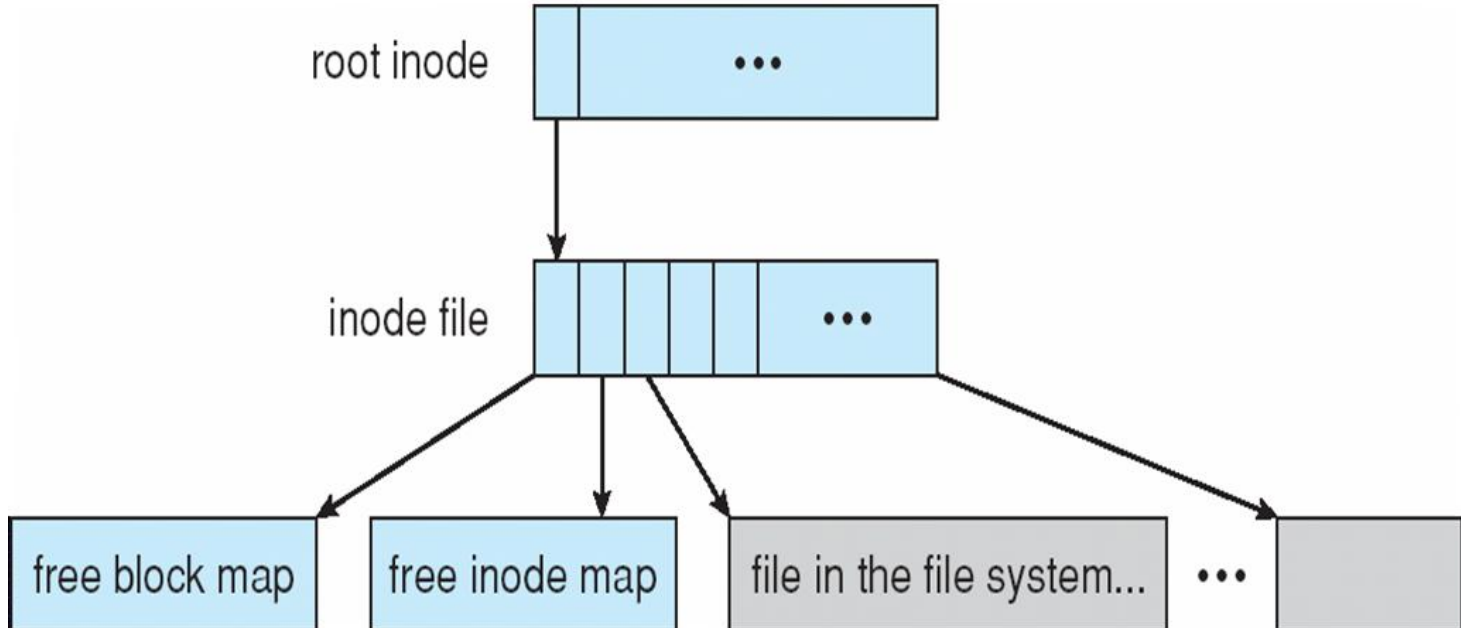
NFS Remote Operations

- Nearly one-to-one correspondence between regular UNIX system calls and the NFS protocol RPCs (except opening and closing files)
- NFS adheres to the remote-service paradigm, but employs buffering and caching techniques for the sake of performance
- File-blocks cache – when a file is opened, the kernel checks with the remote server whether to fetch or revalidate the cached attributes
 - Cached file blocks are used only if the corresponding cached attributes are up to date
- File-attribute cache – the attribute cache is updated whenever new attributes arrive from the server
- Clients do not free delayed-write blocks until the server confirms that the data have been written to disk

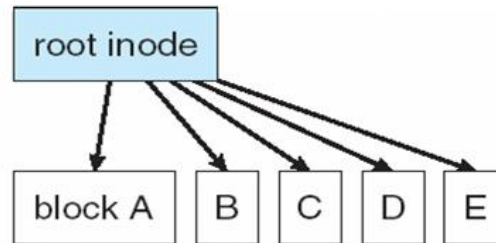
Example: WAFL File System

- Used on Network Appliance “Filers” – distributed file system appliances
- “Write-anywhere file layout”
- Serves up NFS, CIFS, http, ftp
- Random I/O optimized, write optimized
 - NVRAM for write caching
- Similar to Berkeley Fast File System, with extensive modifications

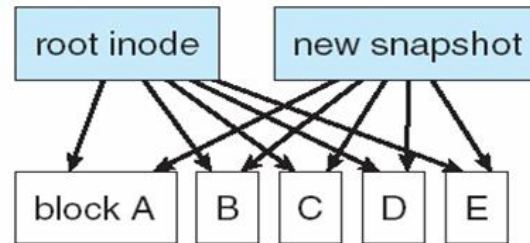
The WAFL File Layout



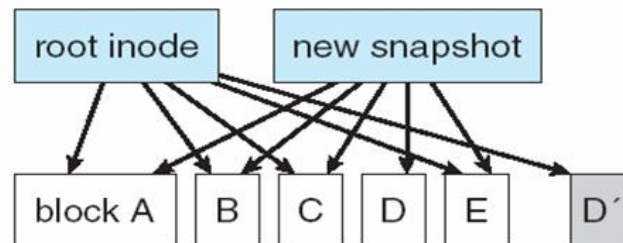
Snapshots in WAFL



(a) Before a snapshot.



(b) After a snapshot, before any blocks change.



(c) After block D has changed to D'.

11.02

file permissions

file dates (create, access, write)

file owner, group, ACL

file size

file data blocks or pointers to file data blocks

End of Chapter 11