操作系统原理及应用

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Chapter 11 File System Implementation

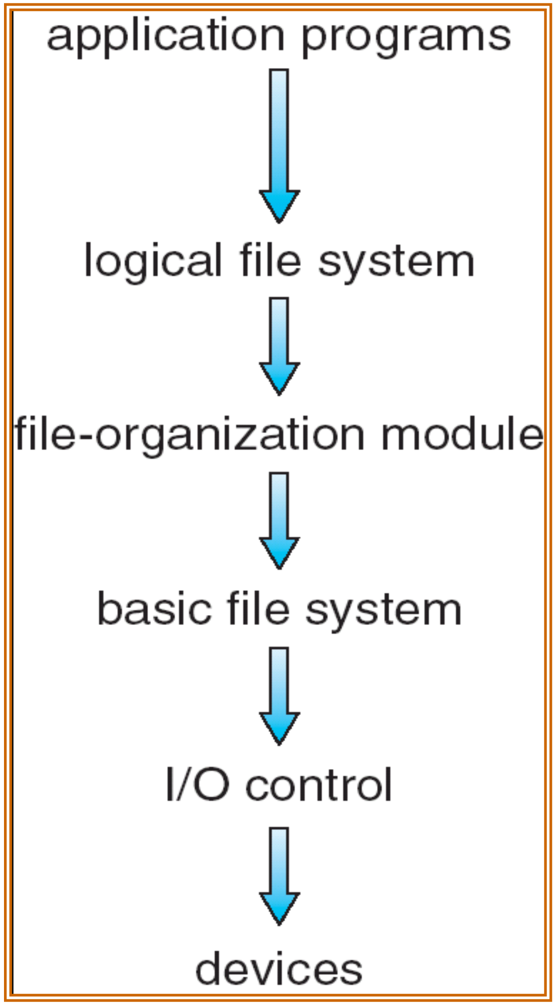
Outline

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

File-System Structure

- File structure
  - Logical storage unit
  - Collection of related information
- File system resides on secondary storage (disks)
- File system organized into layers

Layered File System



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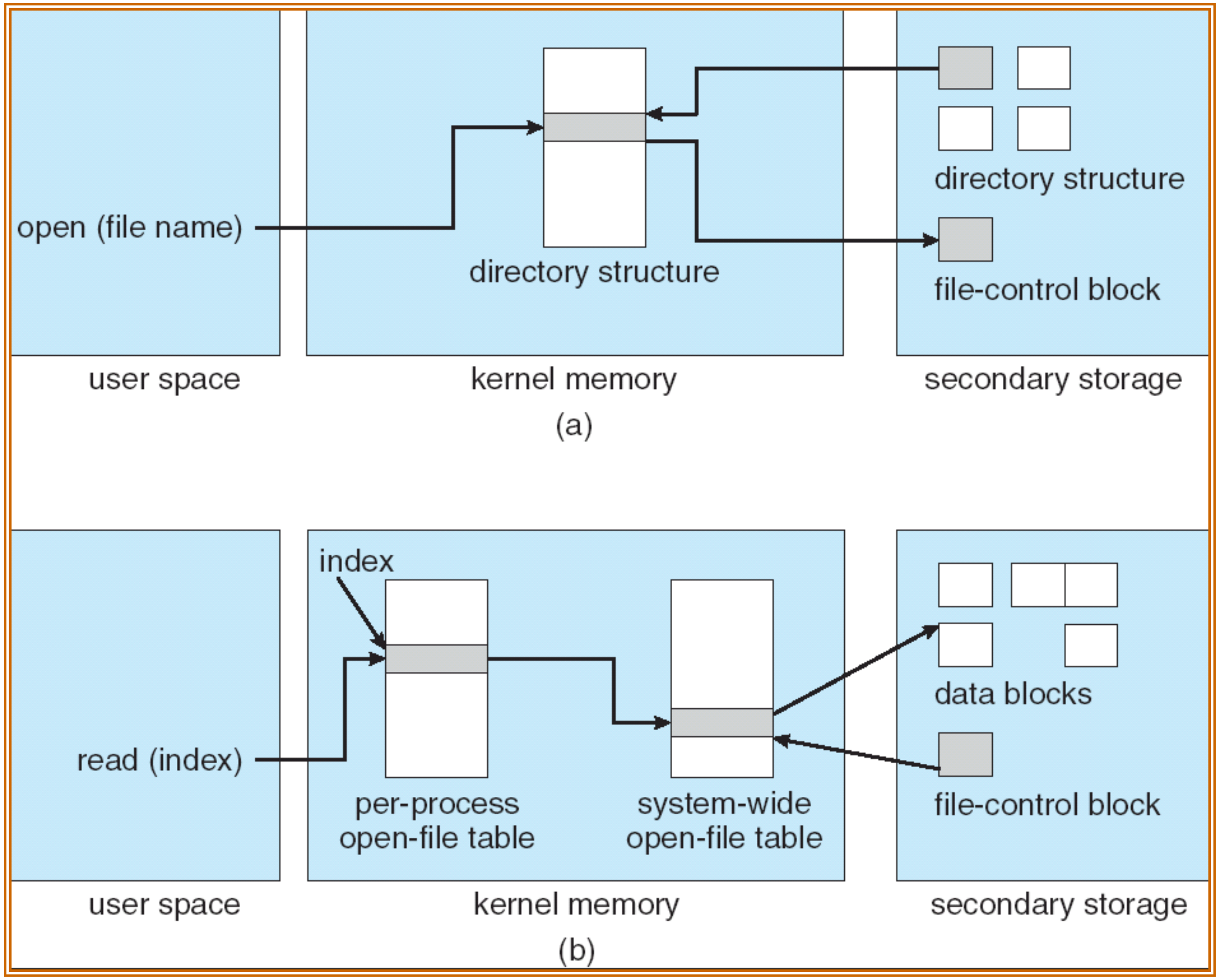
A Typical File Control Block

- **File control block – storage structure consisting of information about a file.**

file permissions
file dates (create, access, write)
file owner, group, ACL
file size
file data blocks or pointers to file data blocks

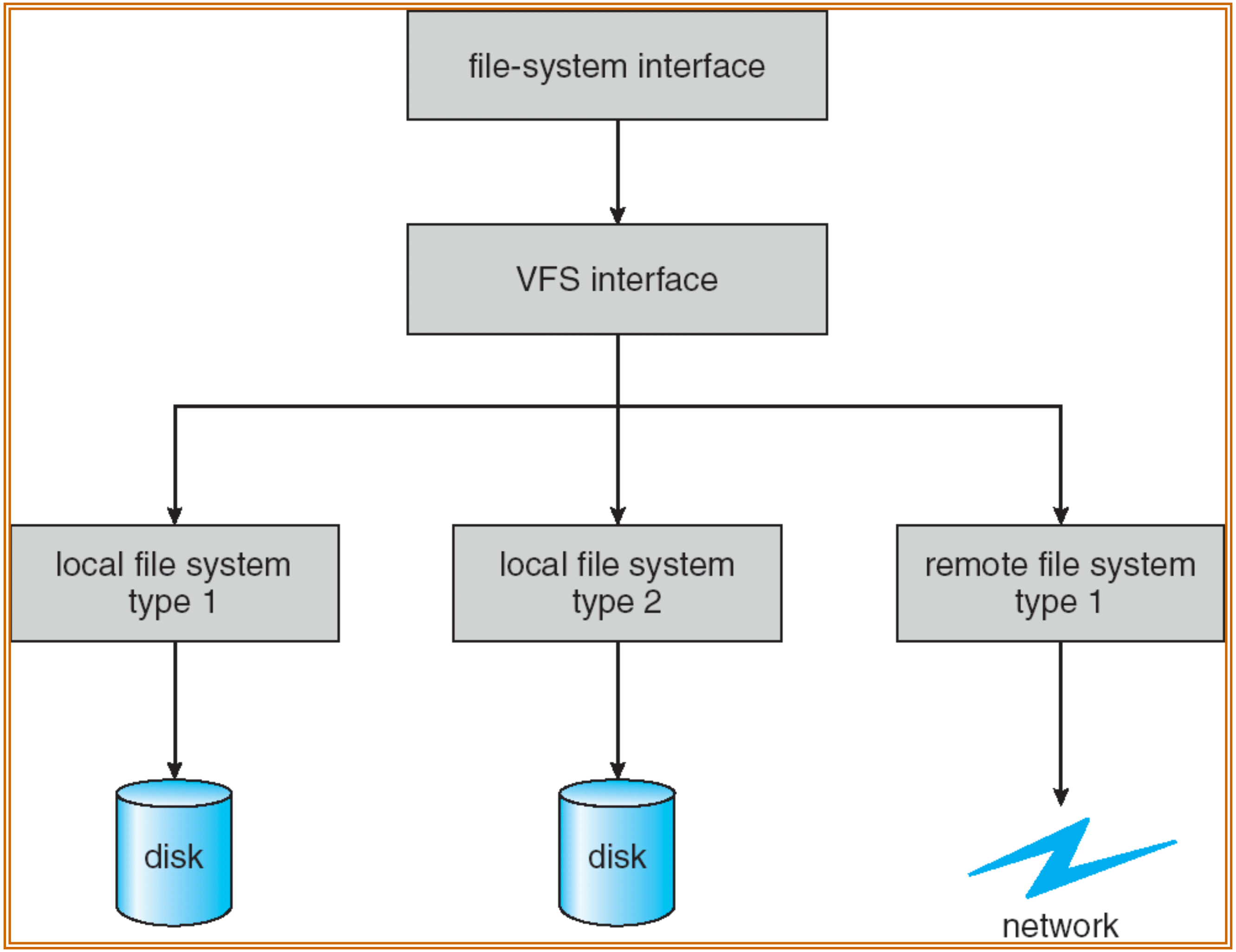
In-Memory File System Structures



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



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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**

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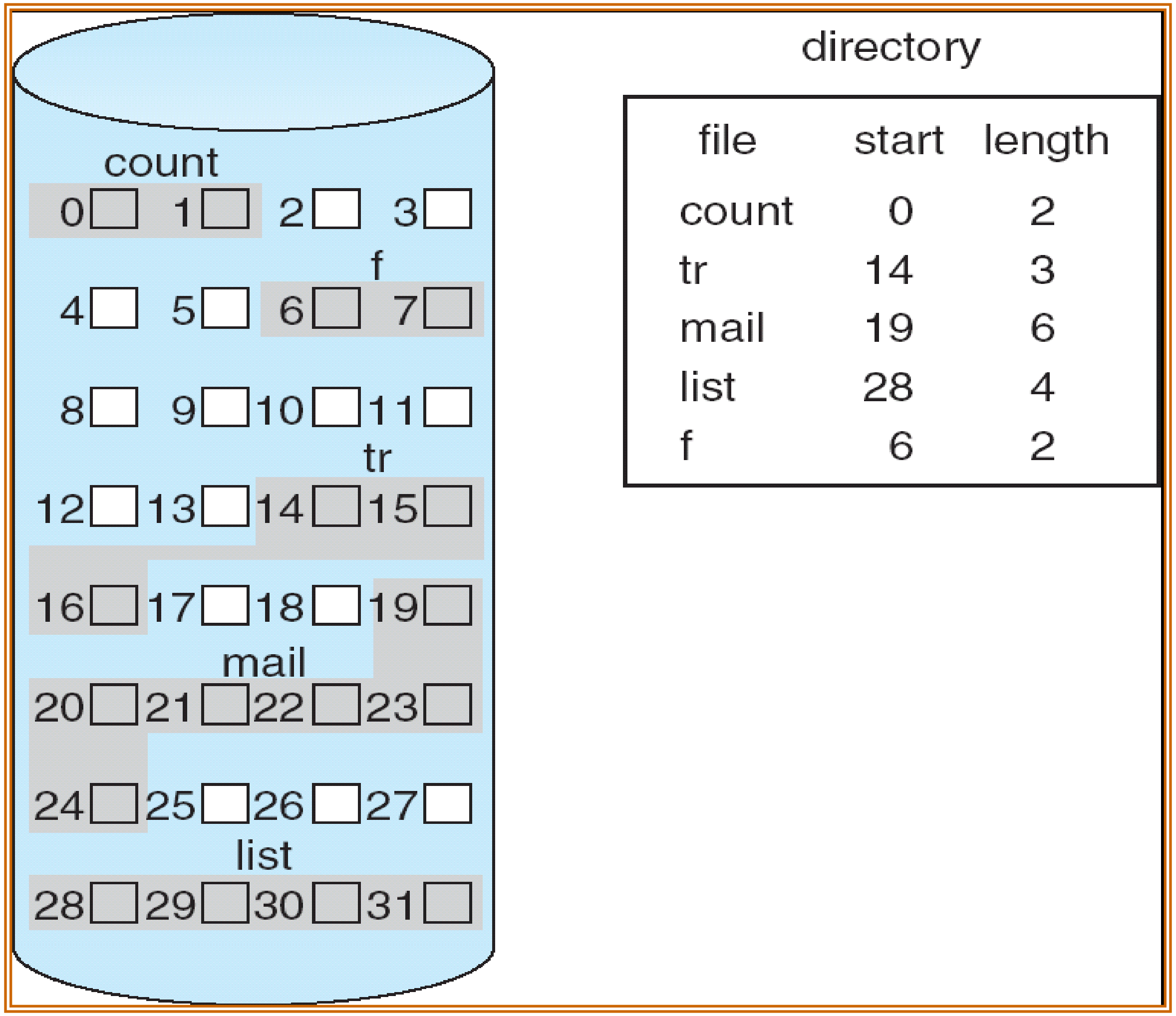
Allocation Methods

- 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 (Sequential + Direct)
- Wasteful of space (dynamic storage-allocation problem).
- Files cannot grow.

Contiguous Allocation of Disk Space



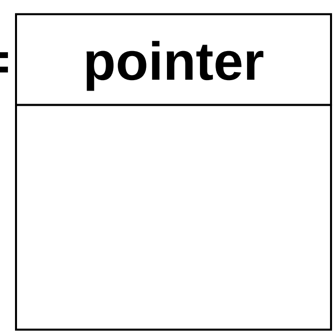
Extent-Based Systems

- 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.**

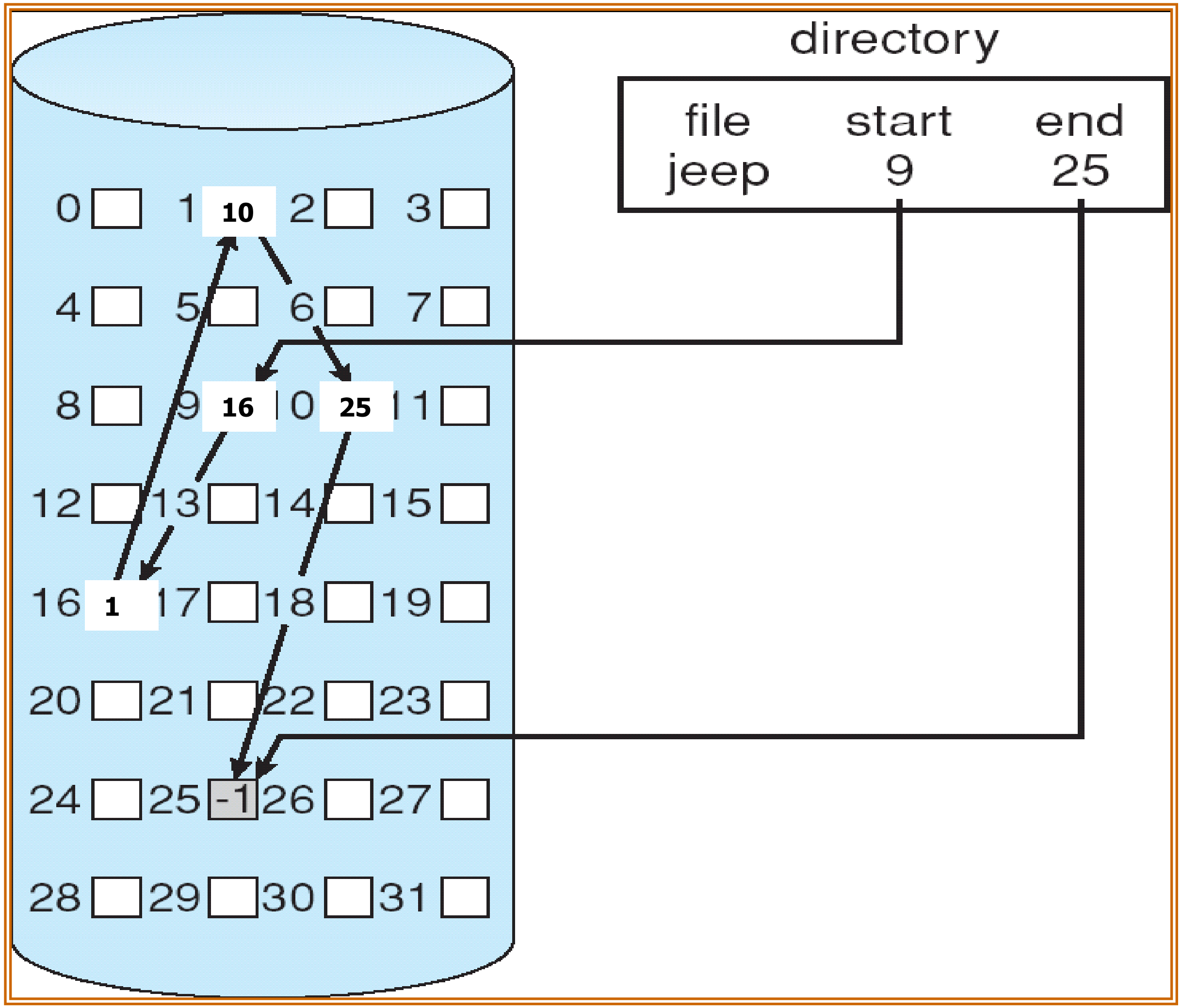
block =



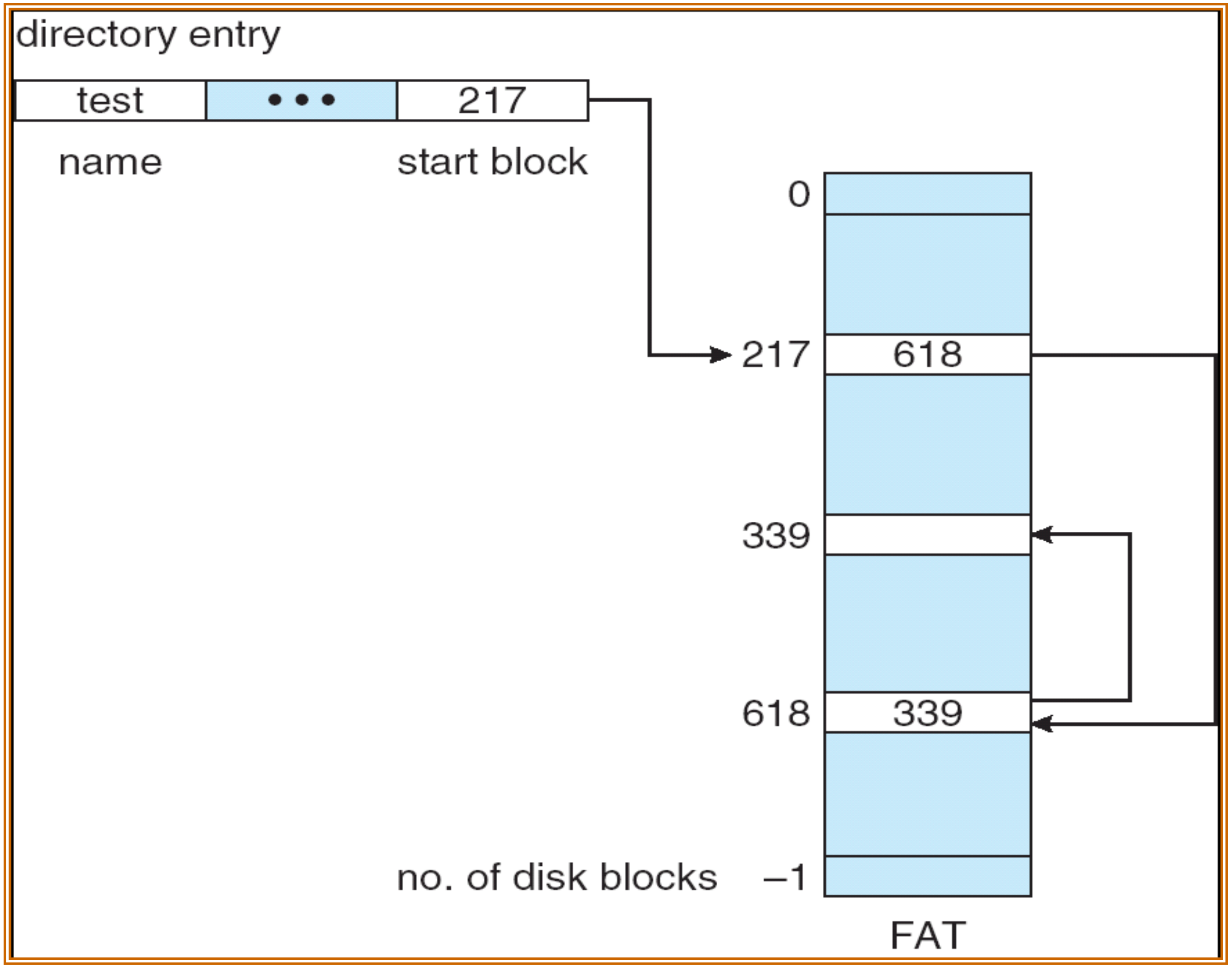
Linked Allocation

- Simple – need only starting address and end address
- Free-space management system – no waste of space
- Files can grow
- No random access
- Each block contains a pointer, wasting space
- Blocks scatter everywhere and a large number of disk seeks may be necessary
- Reliability: what if a pointer is lost or damaged?

Linked Allocation

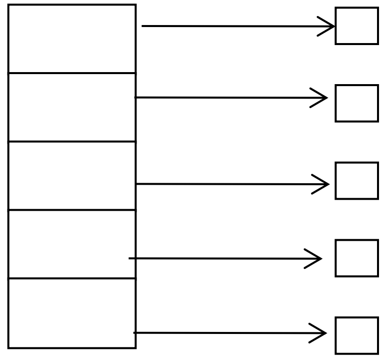


File-Allocation Table



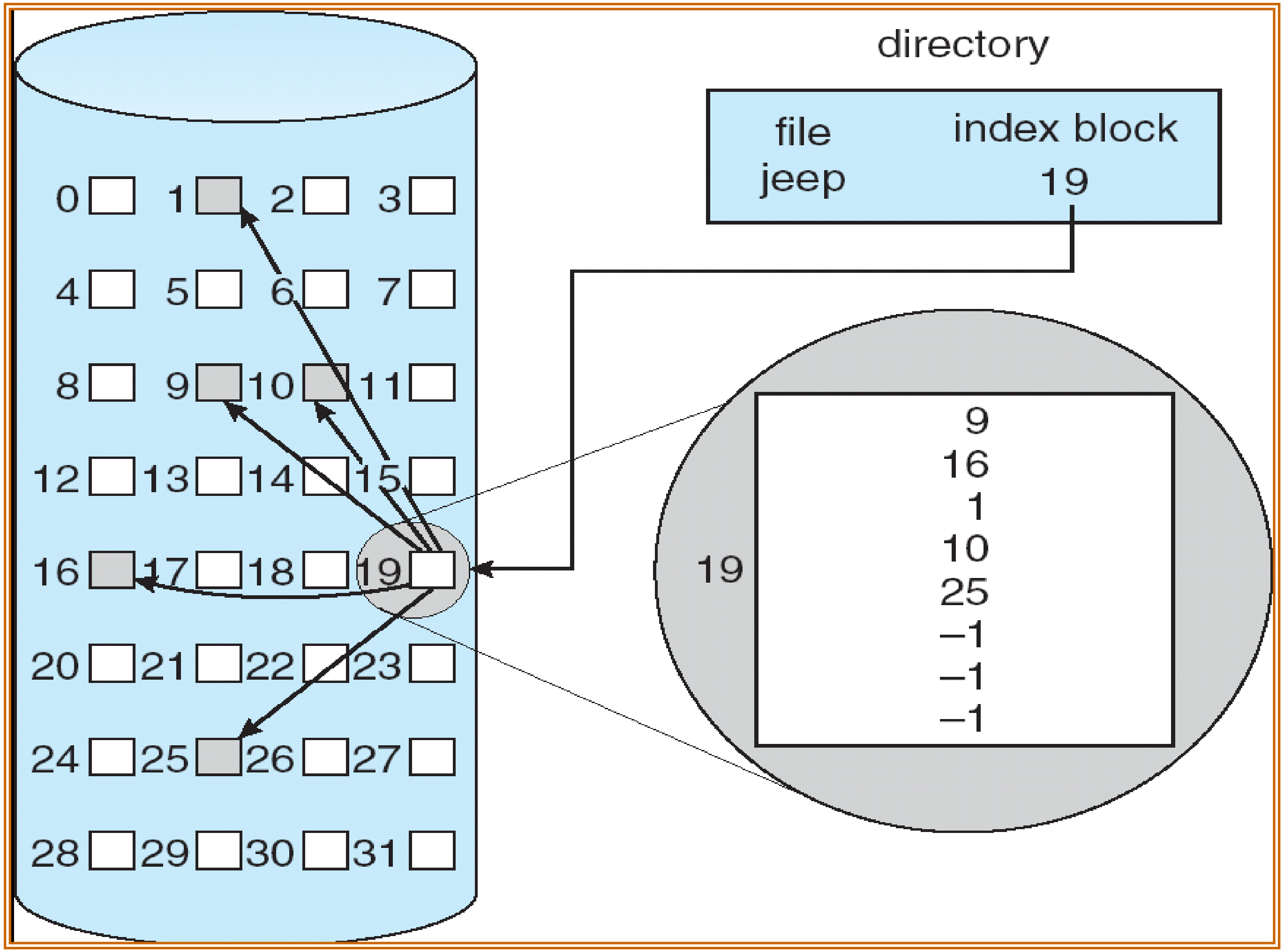
Indexed Allocation

- Brings all pointers together into the *index block*.
- A file's directory entry contains a pointer to its index. Hence, the index block of an indexed allocation plays the same role as the page table.
- Logical view.



index table

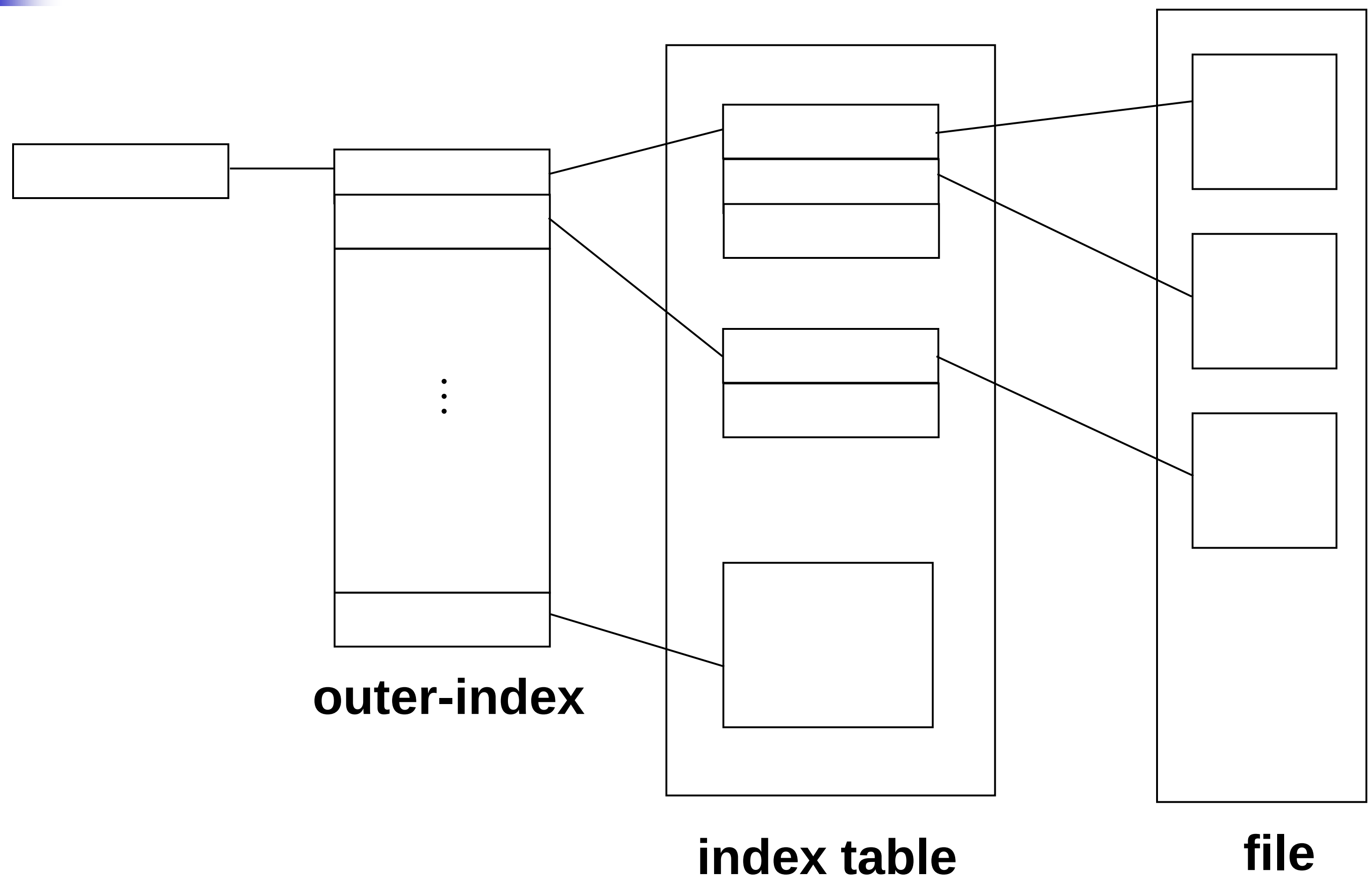
Example of Indexed Allocation



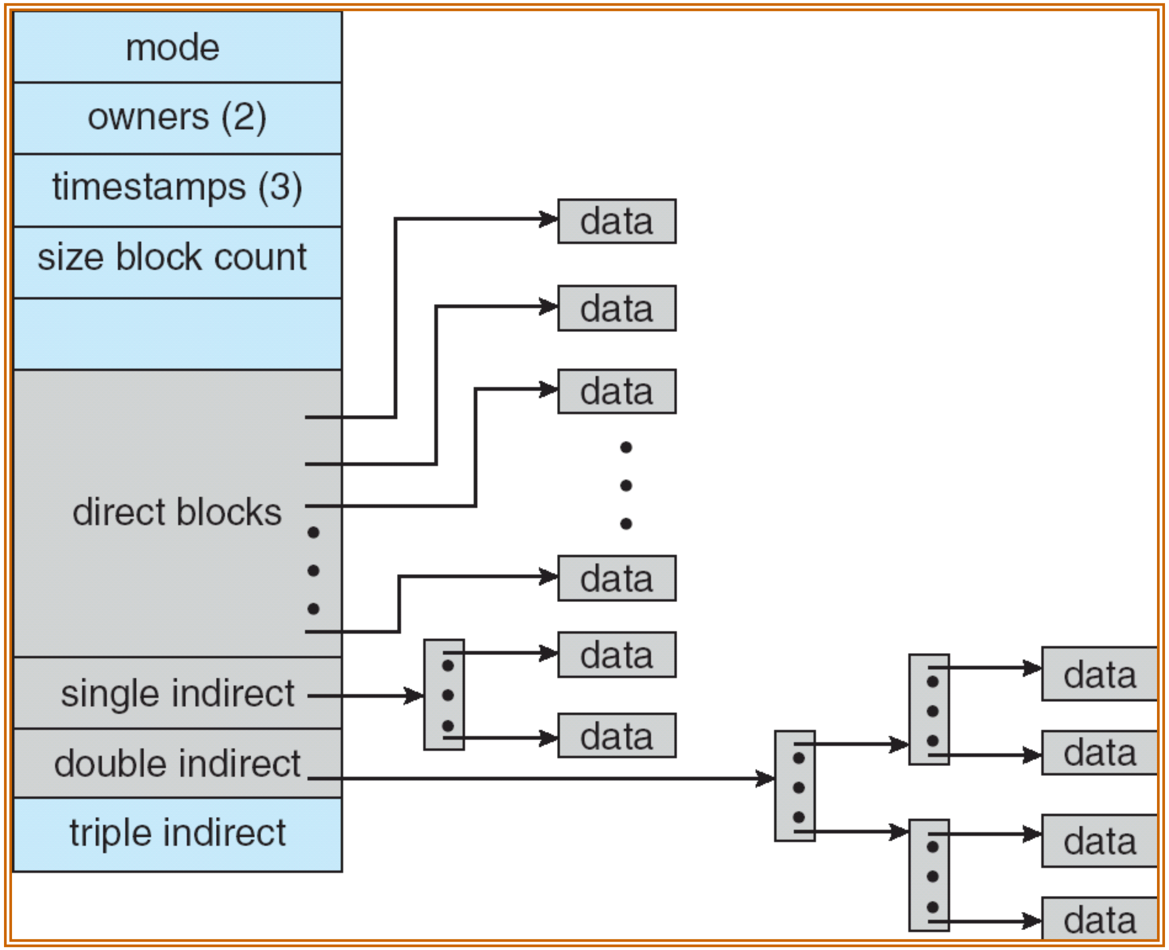
Indexed Allocation

- Random access
- The indexed allocation suffers from wasted space.The index block may not be fully used (i.e., internal fragmentation).
- The number of entries of an index table determines the size of a file. To overcome this problem, we can have
  - multiple index blocks, chain them into a linked-list
  - multiple index blocks, but make them a tree just like the indexed access method (Multilevel)
  - A combination of both

Indexed Allocation



Combined Scheme: UNIX (4K bytes per block)



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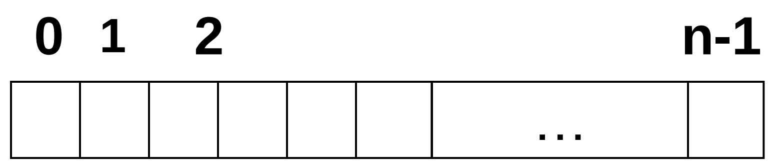
Free-Space Management

- How do we keep track free blocks on a disk?
- A free-space list is maintained. When a new block is requested, we search this list to find one.
- The following are commonly used techniques
  - Bit Vector
  - Linked List
  - Linked List + Grouping
  - Linked List+Address+Count

Bit vector

- **Bit vector (*n* blocks)**



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

Block number calculation

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

Bit vector

- Bit map requires extra space.
  Example:

  block size = 2^{12} bytes (4K byte)

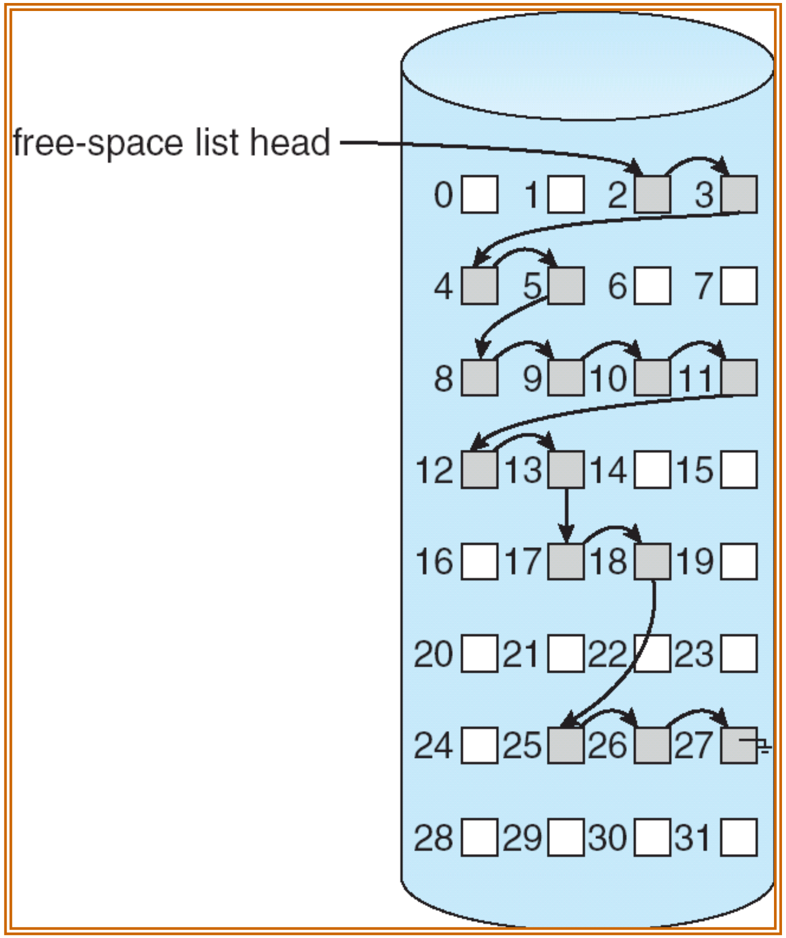
  disk size = 2^{30} bytes (1 gigabyte)

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

- Easy to get contiguous files

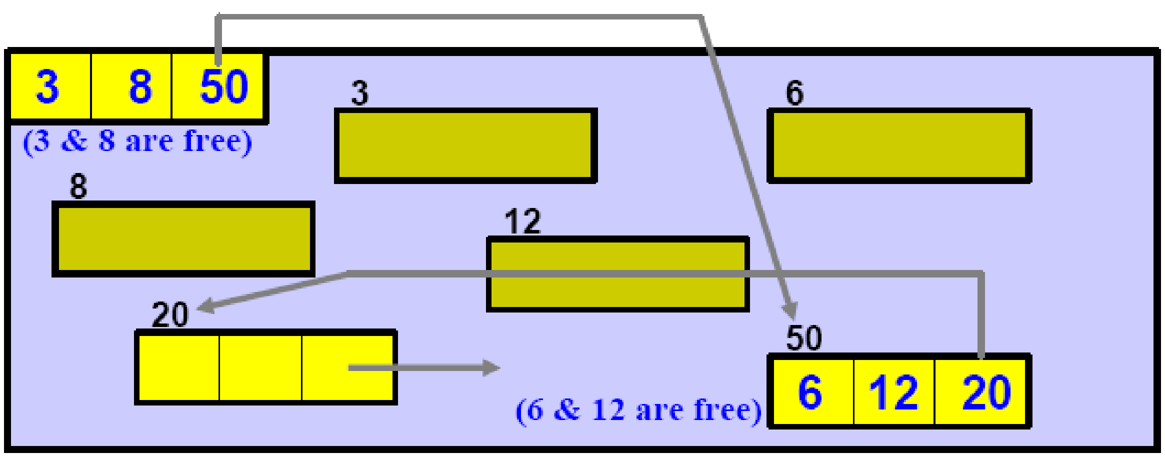
Linked List

- Linked list
  - Cannot get contiguous space easily
  - No waste of space



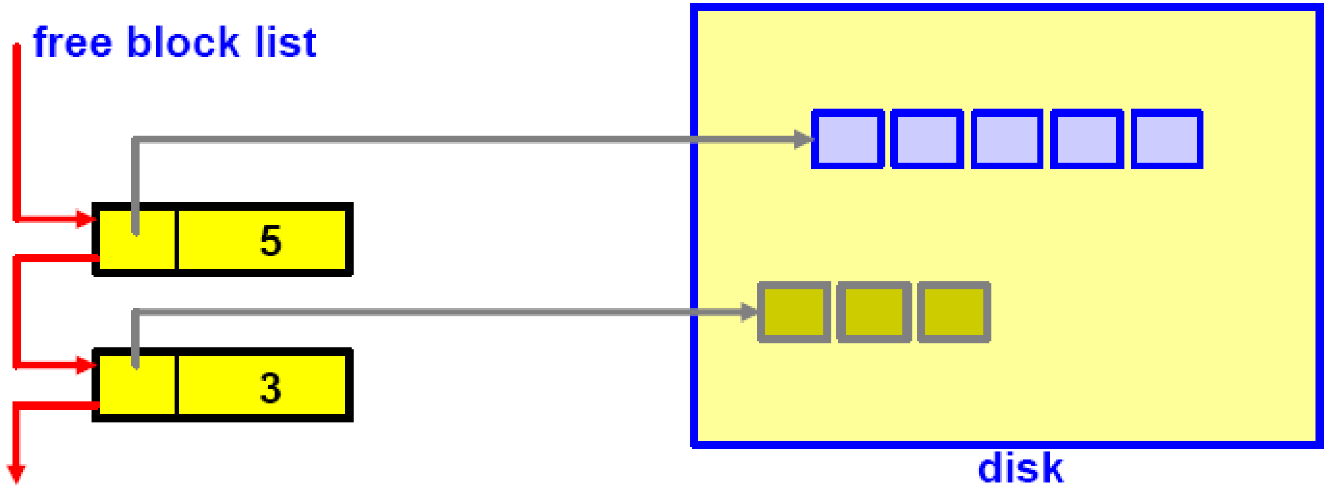
Grouping

- The first free block contains the addresses of *n* other free blocks.
- For each group, the first *n-1* blocks are actually free and the last (i.e., *n-th*) block contains the addresses of the next group.
- In this way, we can quickly locate free blocks.



Address counting

- We can make the list short with the following trick
  - Blocks are often allocated and freed in groups
  - We can store the address of the first free block and the number of the following n free blocks.



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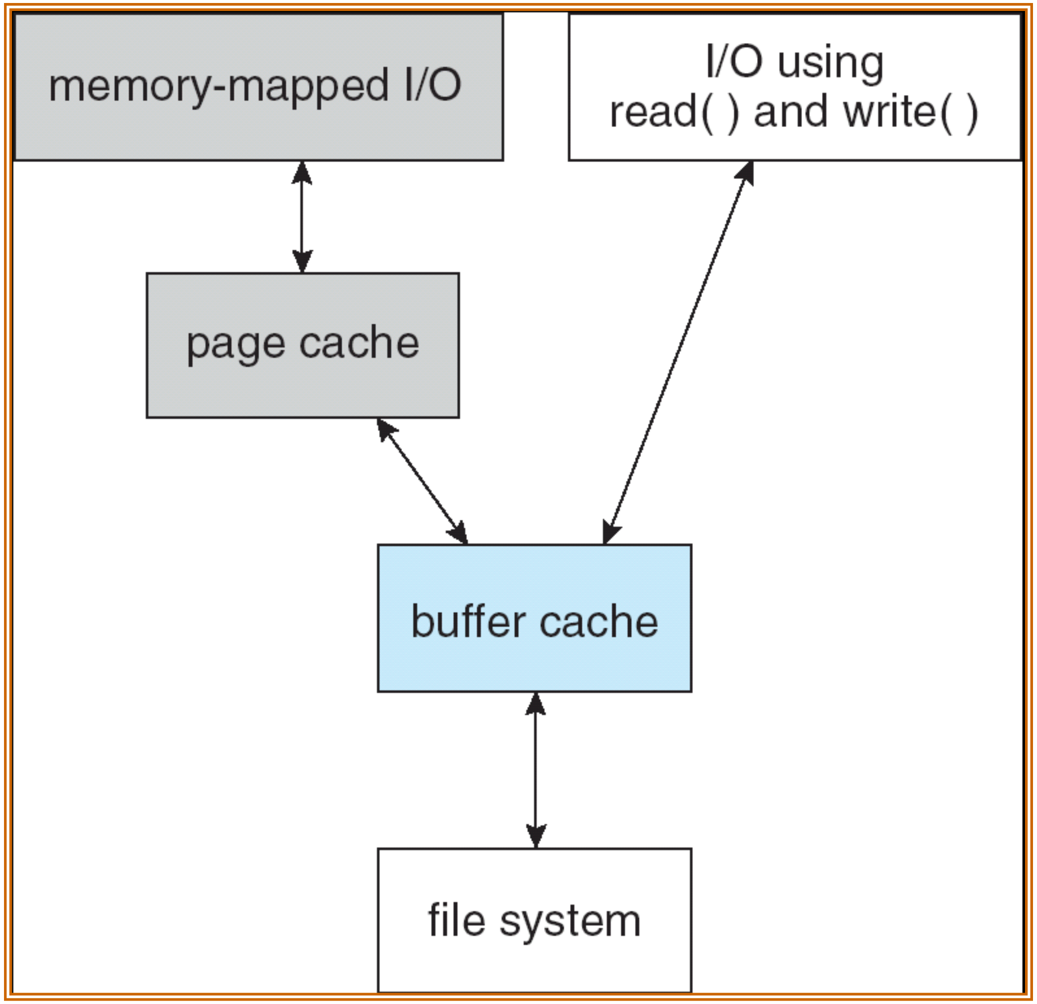
Efficiency and Performance

- Efficiency dependent on
  - disk allocation and directory management algorithms
  - types of data kept in file’s directory entry
- Performance
  - disk cache – separate section of main memory for frequently used blocks
  - free-behind (马上释放) and read-ahead (预先读取) – techniques to optimize sequential access
  - improve PC performance by dedicating section of memory as virtual disk, or RAM disk

Page Cache

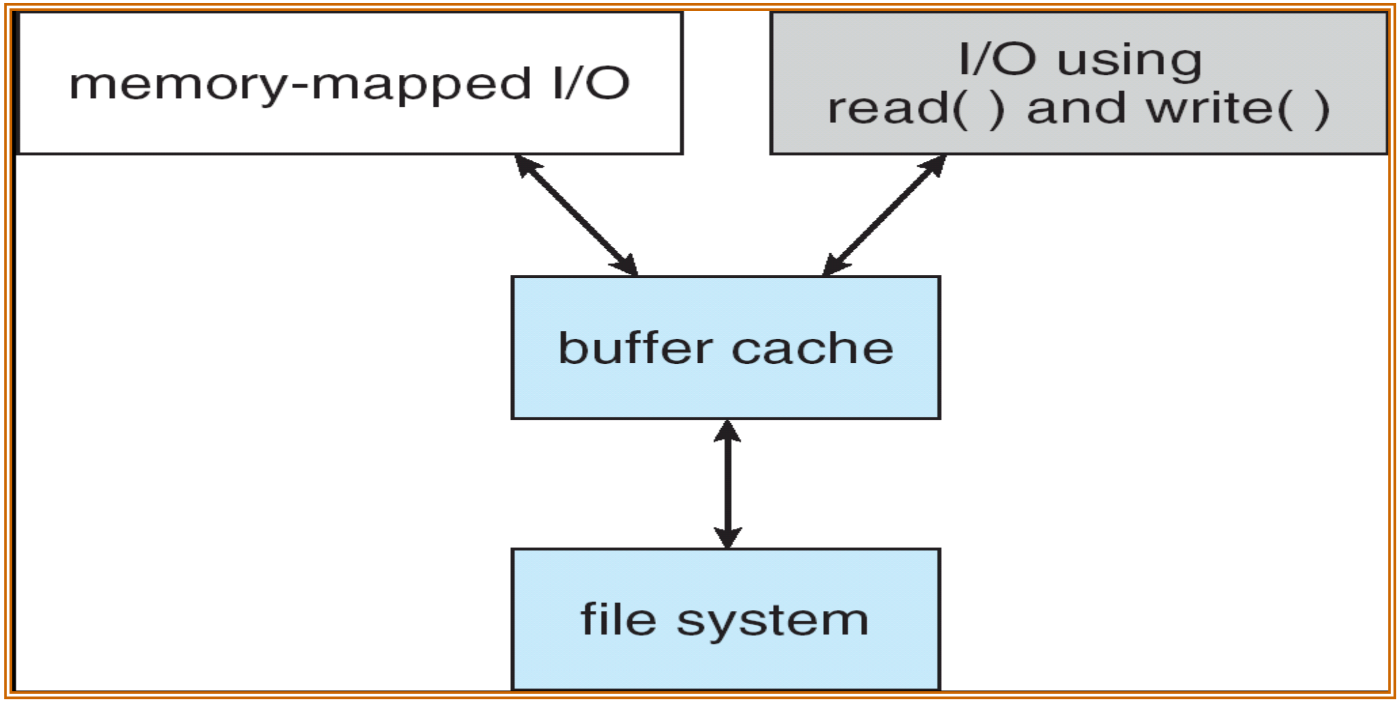
- A page cache caches pages rather than disk blocks using virtual memory techniques
- Memory-mapped I/O uses a page cache
- Routine I/O through the file system uses the buffer (disk) cache
- This leads to the following figure

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



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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**

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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

Log Structured File Systems

- 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

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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

- 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

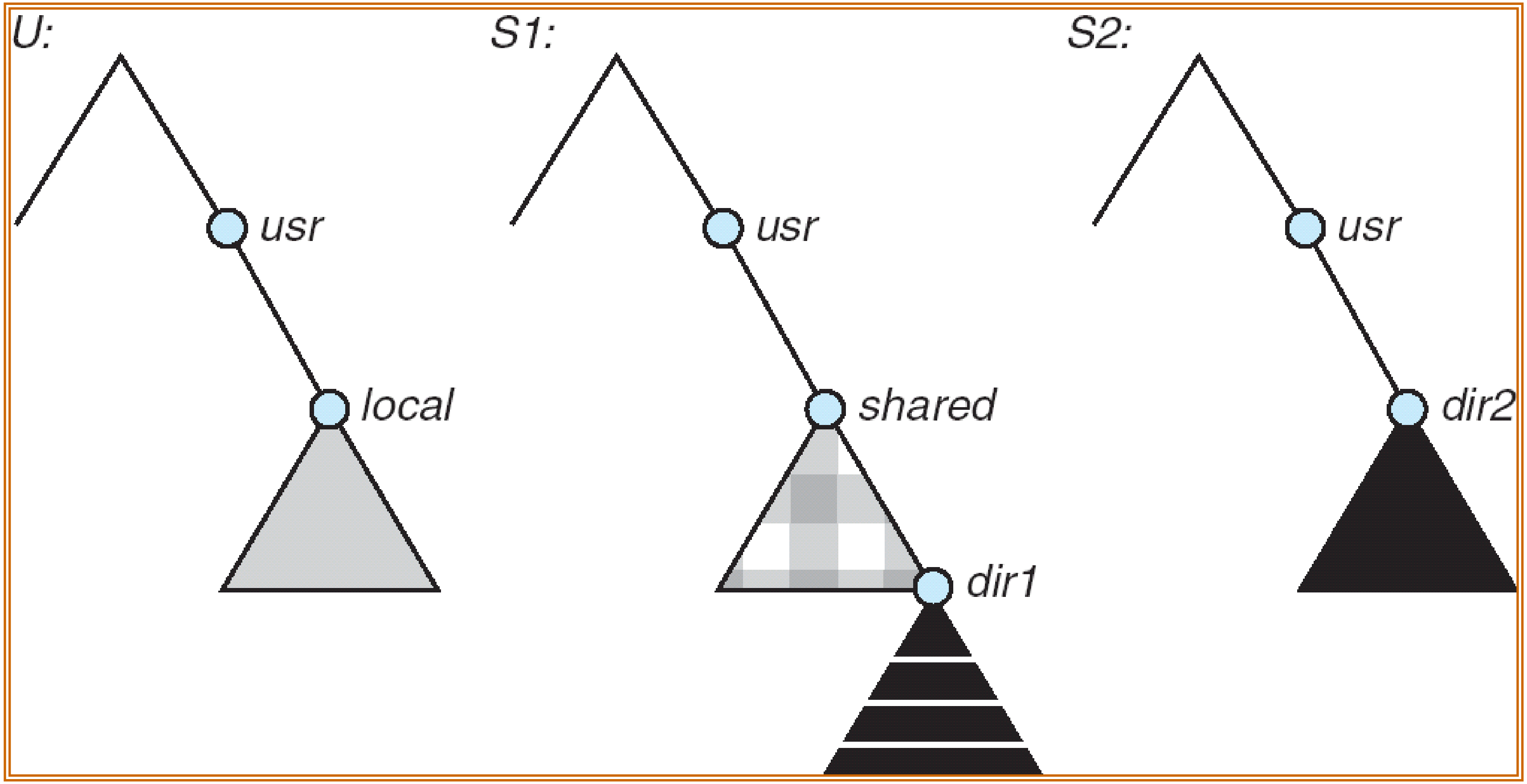
NFS

- **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**

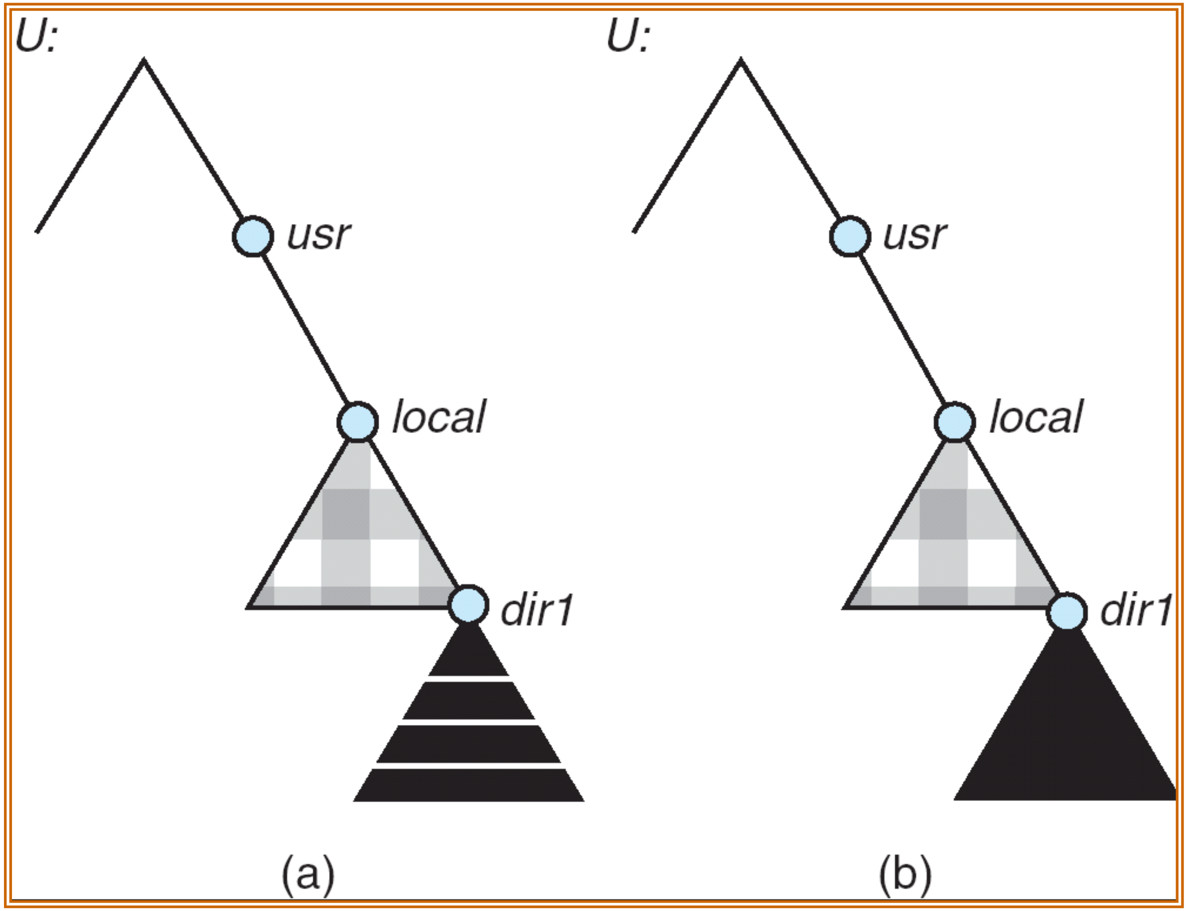
NFS

- 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



Mounts 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

NFS Mount Protocol

- 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

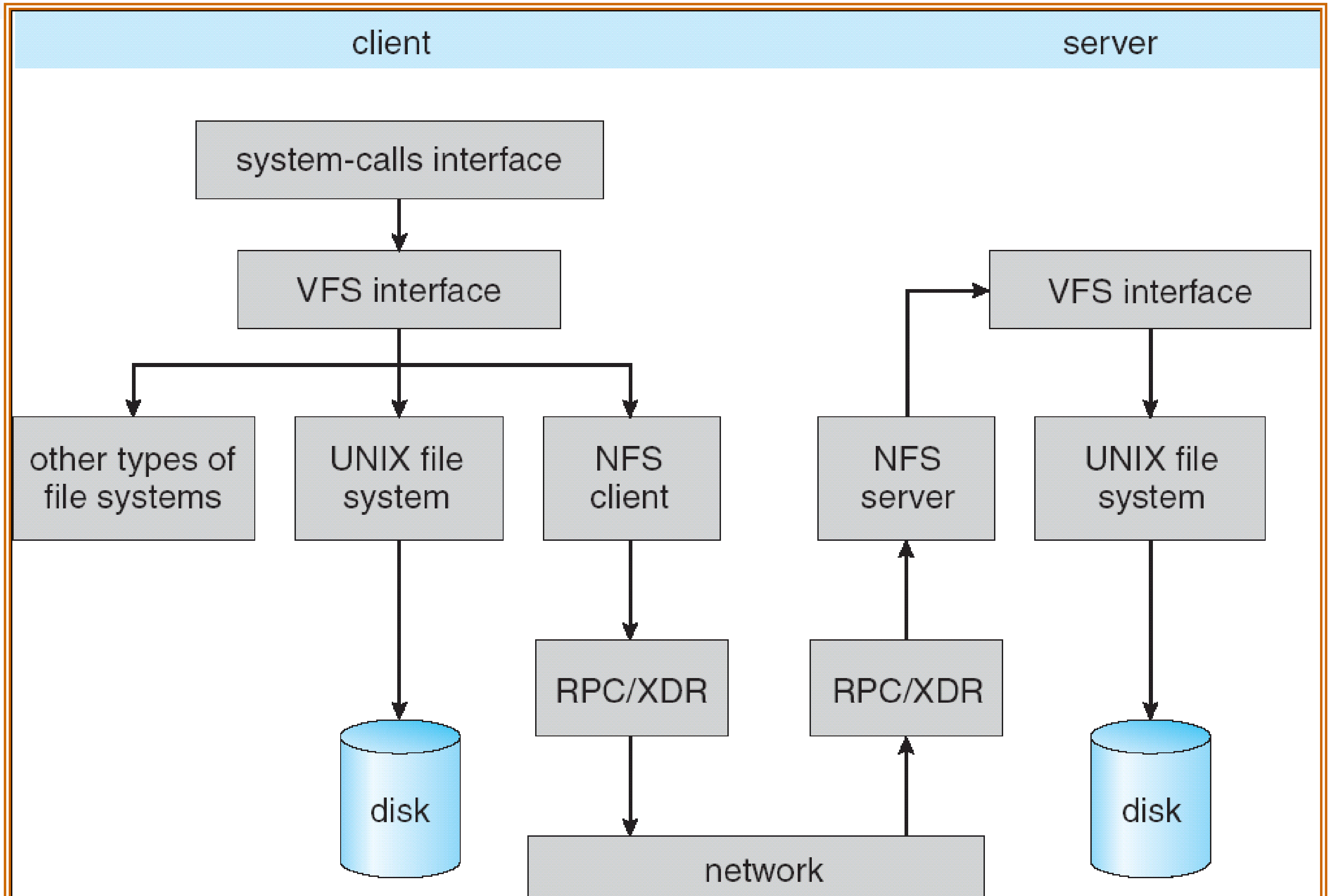
NFS Protocol

- 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**
  - **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

NFS Remote Operations

- 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