# File System: Interface and Implmentation

# Two Parts

- Filesystem Interface
  - Interface the user sees
    - Organization of the files as seen by the user
    - Operations defined on files
    - Properties that can be read/modified
- Filesystem design
  - Implementing the interface

# Filesystem Interface

# Basic Topics

- File Concept
- Access Methods
- Directory Structure
- File System Mounting
- File Sharing
- Protection

# File Concept

- Logical units of information on secondary storage
- Named collection of related info on secondary storage
- Abstracts out the secondary storage details by presenting a common logical storage view

# File Types

- Data
  - Text, binary,…
- Program
- Regular files – stores information
- Directory – stores information about file(s)
- Device files – represents different devices

# File Structure

- None - sequence of words, bytes
- Simple record structure
  - Lines
  - Fixed length
  - Variable length
- Complex Structures
  - Formatted document
  - Relocatable load file

# Important File Attributes

- Name – only information kept in human-readable form
- 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

# File Operations

- Create
- Write
- Read
- Reposition within file – 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

# Access Methods

- Sequential Access

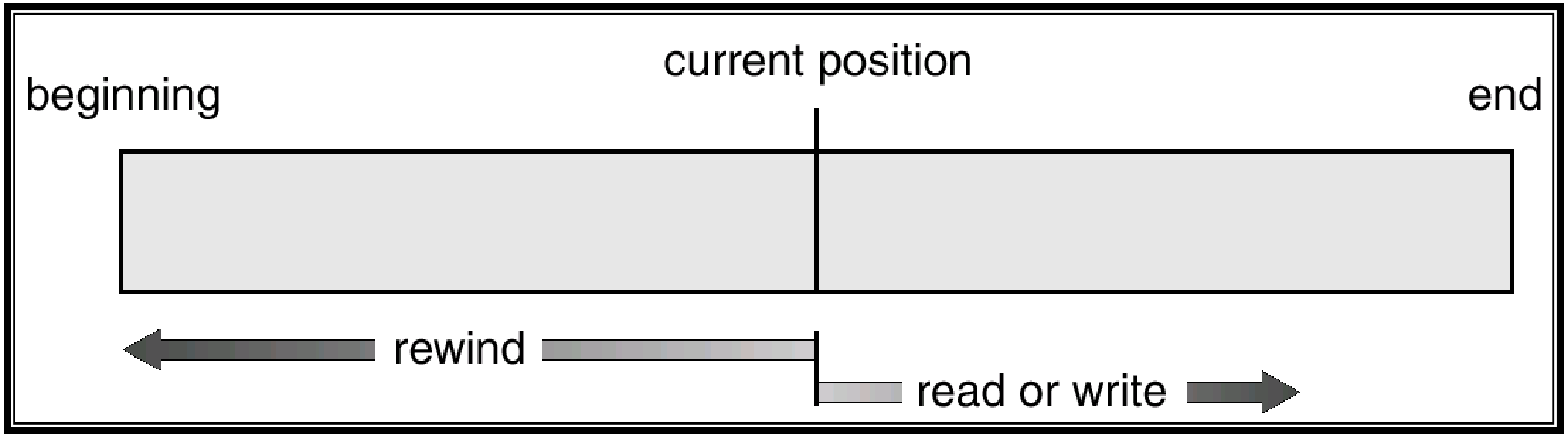
  *read next*
  *write next*
  *reset*

- Direct Access

  *read n*
  *write n*
  *position to n*
  *read next*
  *write next*

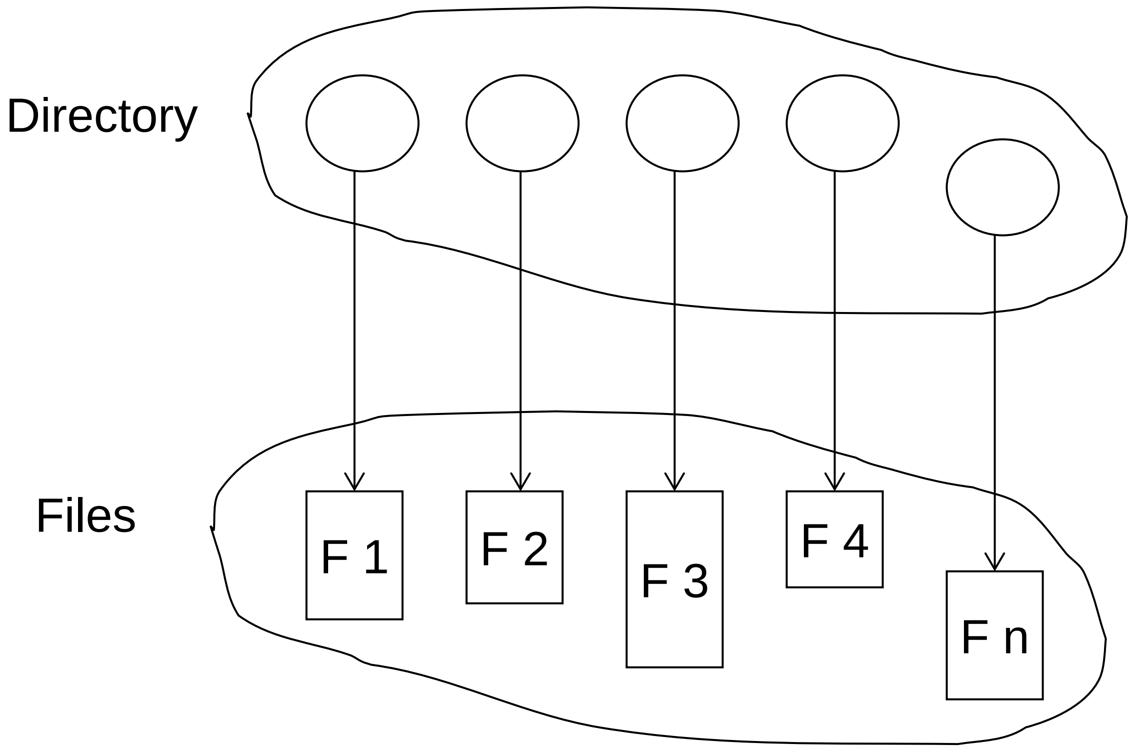
*n* = relative block number

# Sequential-access File

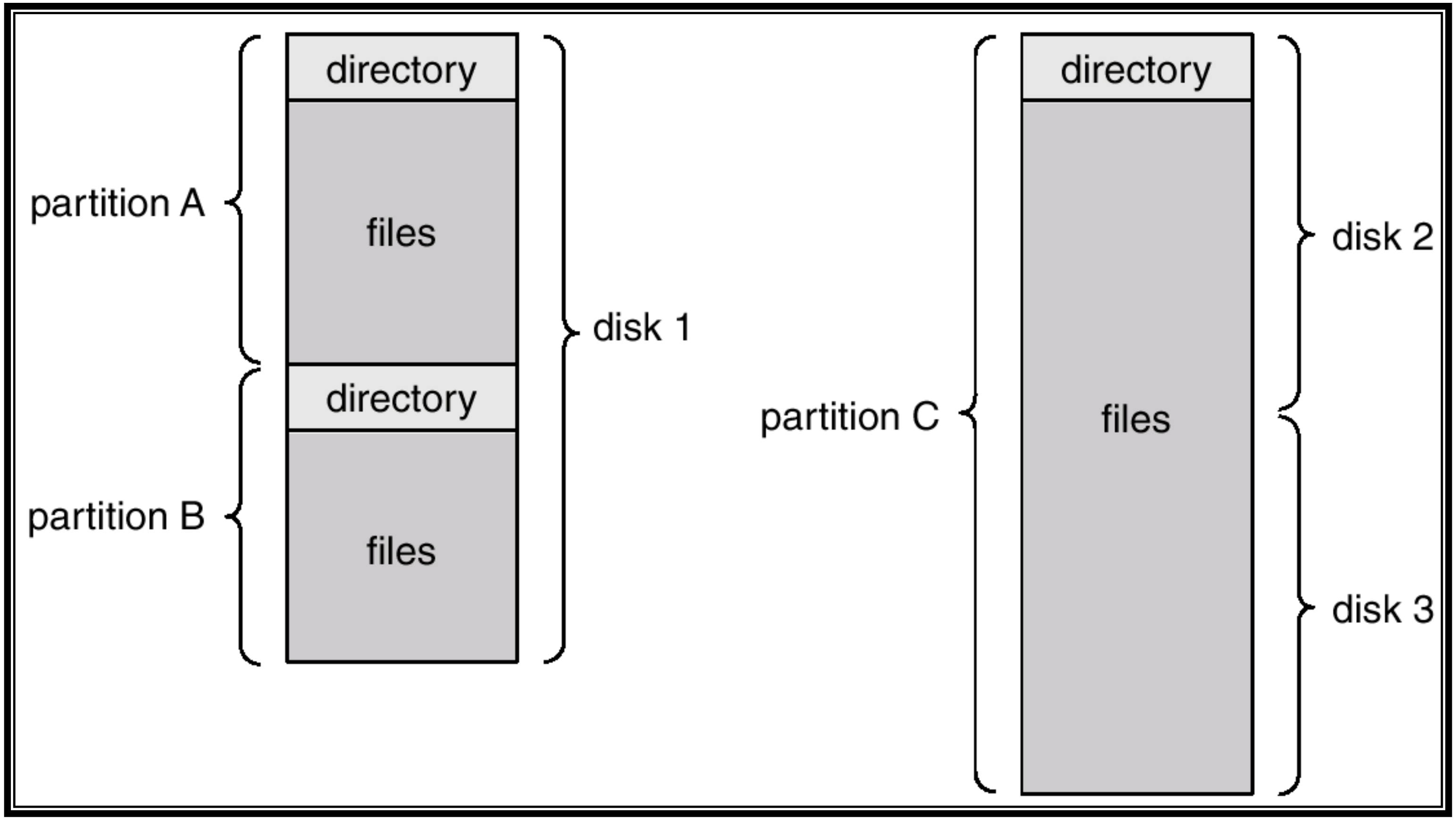


# Directory Structure

- A collection of nodes containing information about all files



# A Typical File-system Organization



# Information in a Device Directory

- Name
- Type
- Address
- Current length
- Maximum length
- Date last accessed (for archival)
- Date last updated (for dump)
- Owner ID
- Protection information

# Operations Performed on Directory

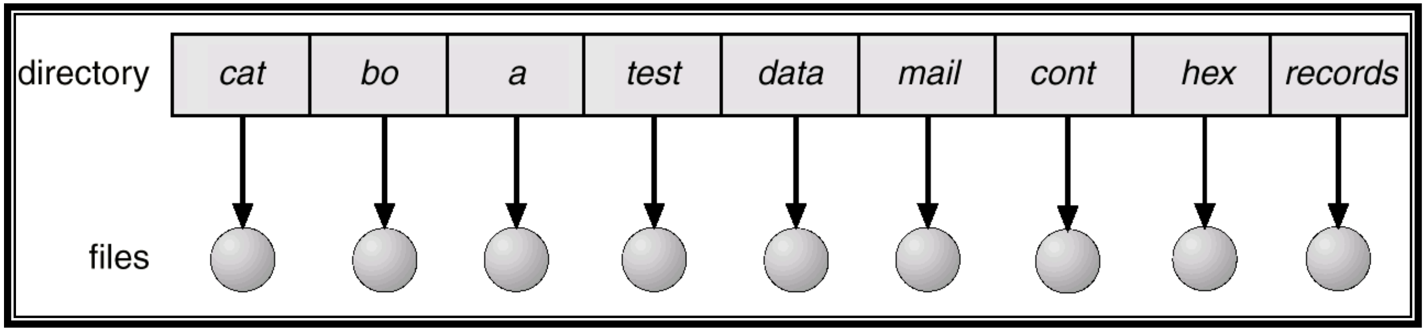
- Search for a file
- Create a file
- Delete a file
- List a directory
- Rename a file
- Traverse the file system

# 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

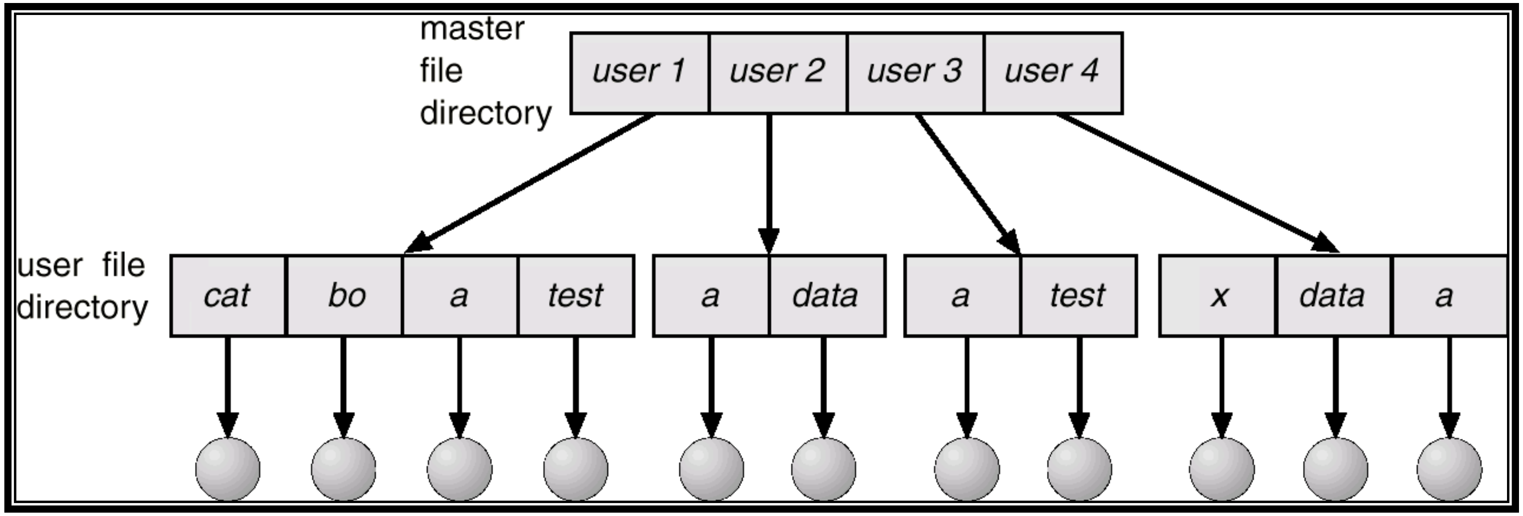
- A single directory for all users




- Problems
  - Naming problem
  - Grouping problem

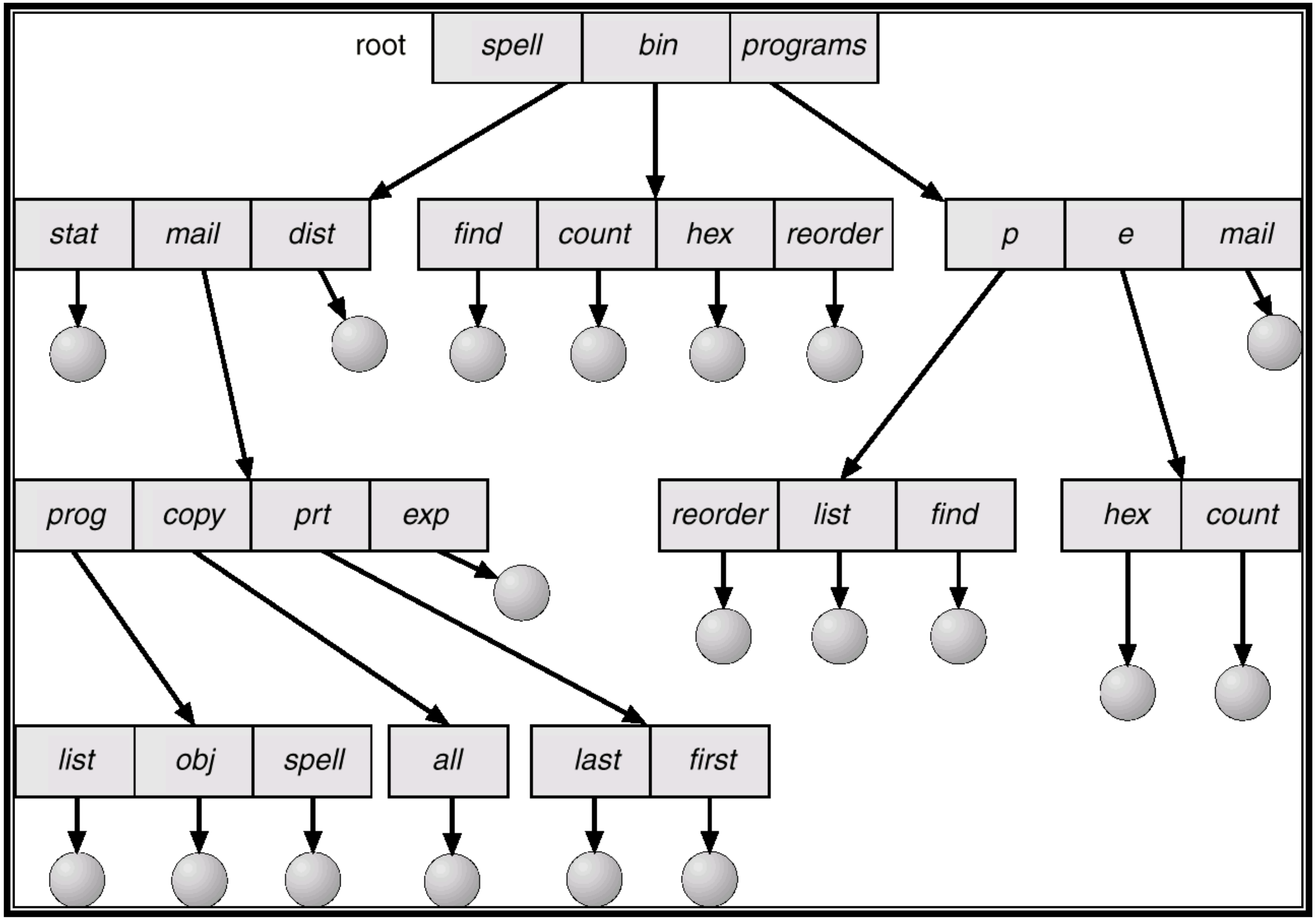
# Two-Level Directory

- 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

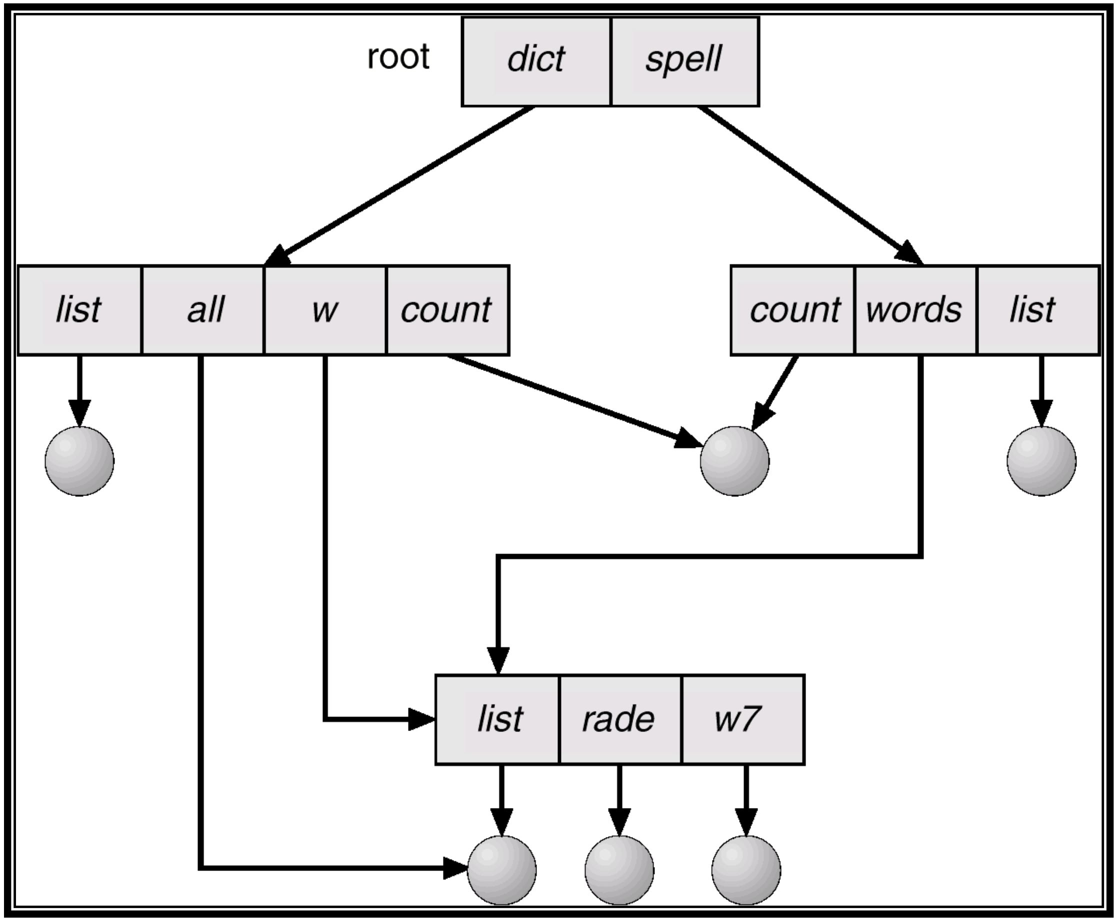
  **rm** <file-name>

- Creating a new subdirectory is done in current directory.

  **mkdir** <dir-name>

# Acyclic-Graph Directories

- Have shared subdirectories and files

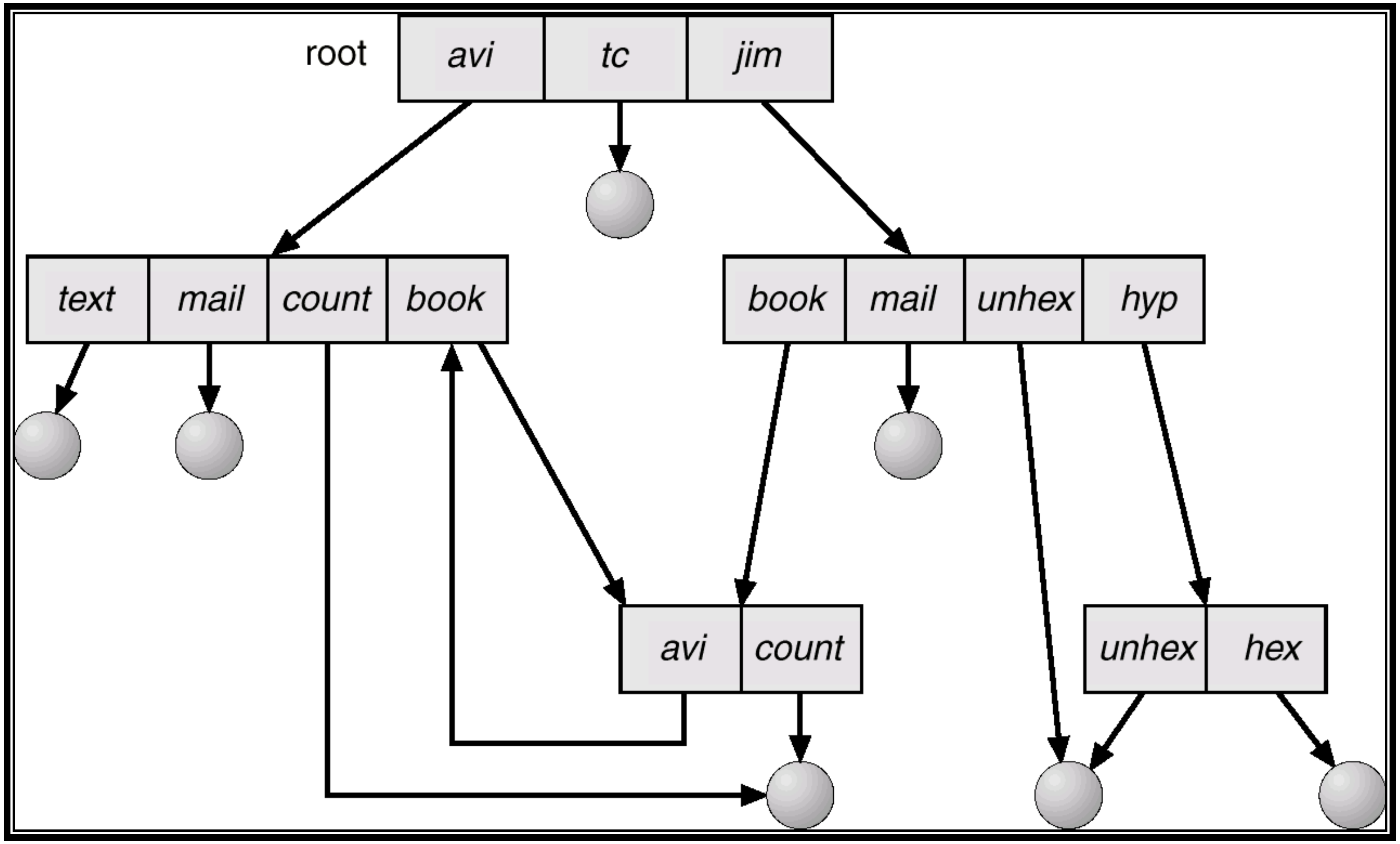


# Acyclic-Graph Directories (Cont.)

- Two different names (aliasing)
- If *dict* deletes *count* $\Rightarrow$ 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

# General Graph Directory

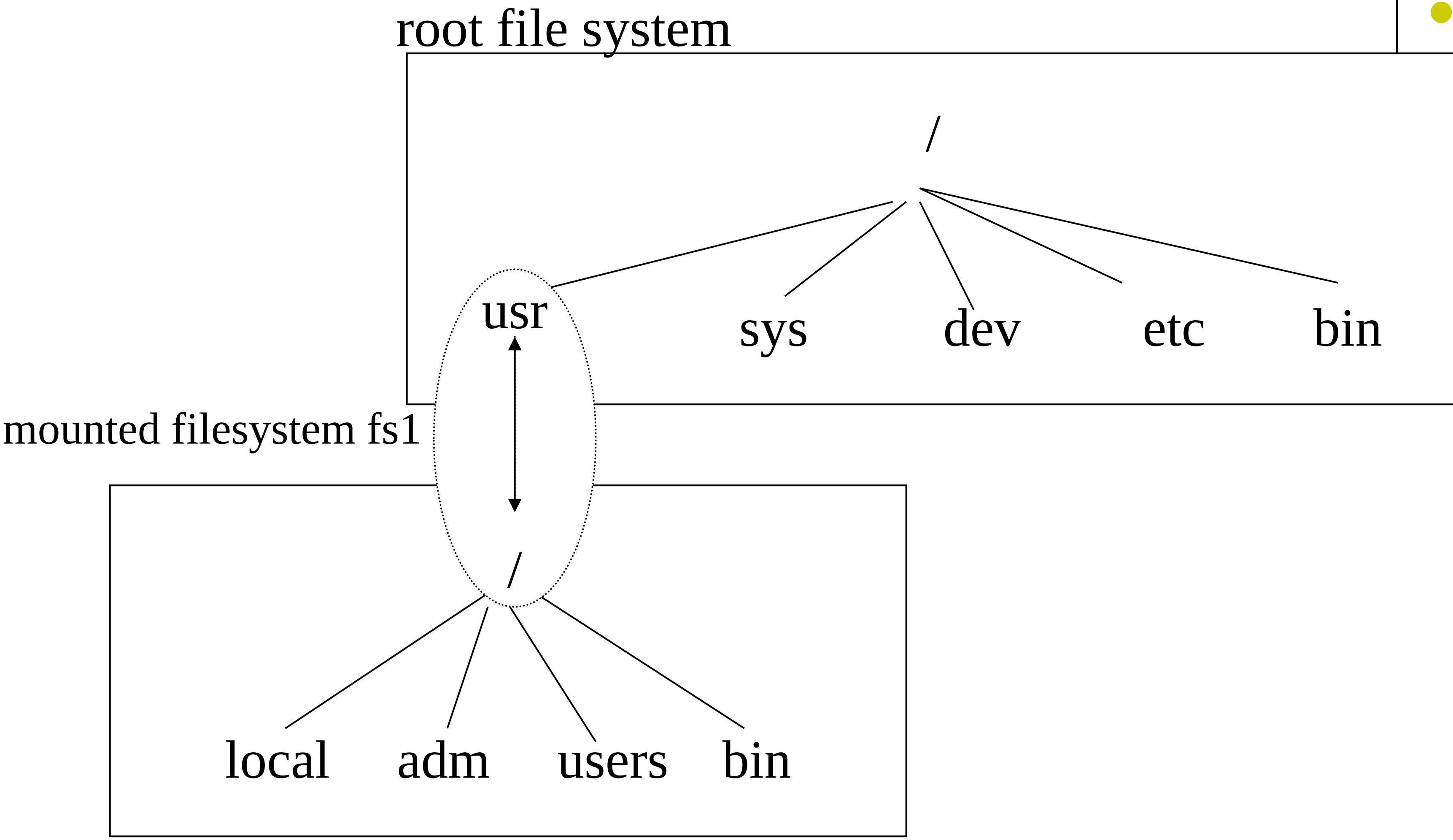


# General Graph Directory (Cont.)

- 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 filesystem must be mounted before it can be accessed
- One file system designated as root filesystem
- Root directory of root filesystem is system root directory
- Parts of other filesystems are added to directory tree under root by mounting onto a directory in the root filesystem.
- The directory onto which it is mounted on is called the mount point
- The previous contents of the mount point become inaccessible


root file system
/
usr
sys
dev
etc
bin
mounted filesystem fs1
/
local
adm
users
bin

- Accessing /usr/adm/… now actually accesses /adm/.. in filesystem fs1
- /usr in the root file system is the mountpoint
- Anything under /usr in the root filesystem becomes inaccessible until fs1 is unmounted
- Mounting now can be done on any other mountpoint, including any directory on an earlier mounted filesystem
  - Ex. can now mount some other filesystem fs2 on /usr/adm, will hide all files under /adm under fs1 and access to /usr/adm will go to corresponding part of fs2
- Need not mount ‘/’ always, can mount any subtree of a filesystem on a mountpoint to add only part of a filesystem (but has to be a complete subtree)

# File Sharing

- Create links to files
  - Same file accessed from two different places in directory structure using possibly different names
- Soft Link vs. Hard Links

# Protection

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

# Filesystem Implementation

# Basic Topics

- Data Structures for File Access
- Disk Layout of Filesystems
- Allocating Storage for Files
- Directory Implementation
- Free-Space Management
- Virtual Filesystems
- Efficiency and Performance
- Recovery

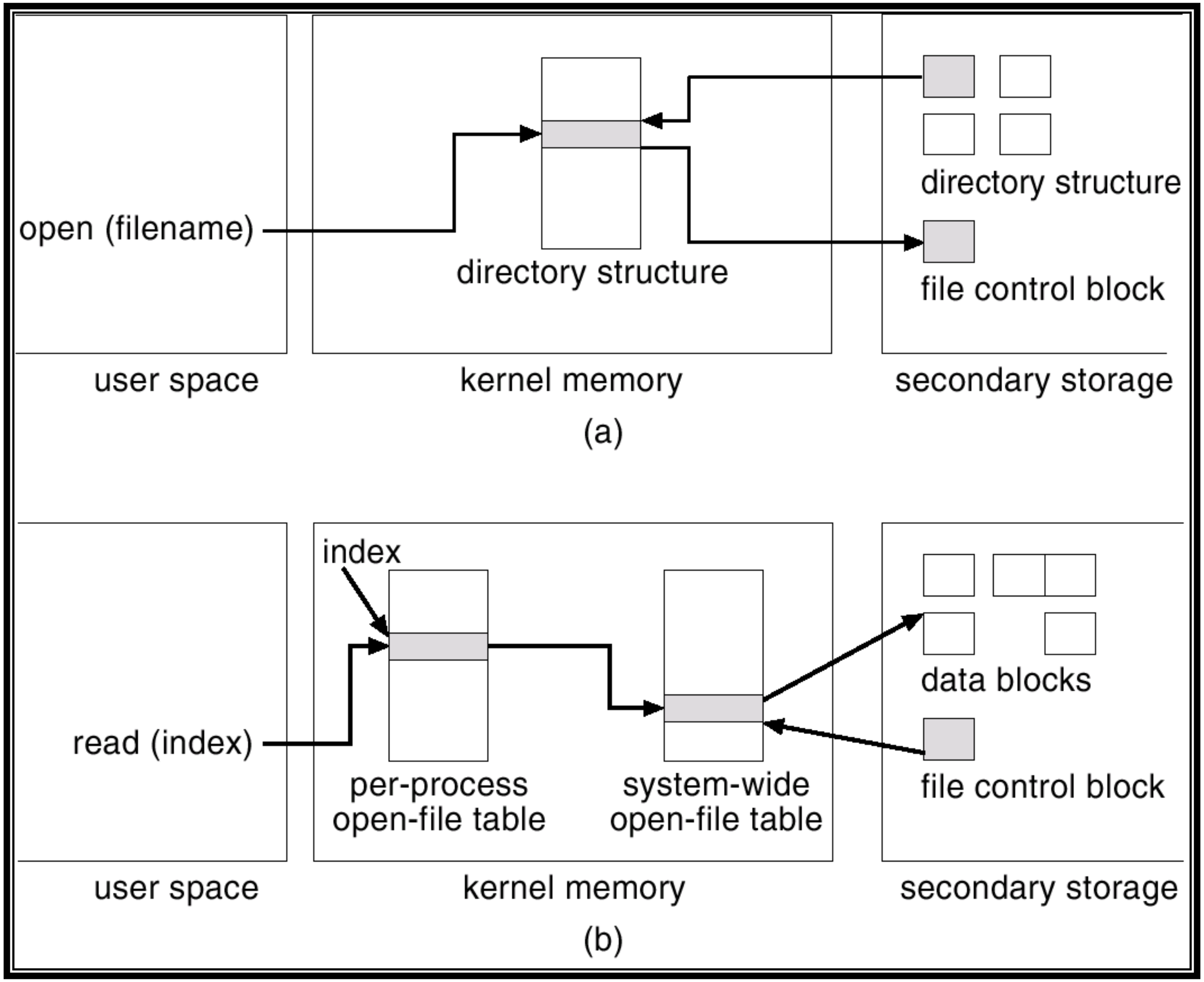
# Data Structures for File Access

- File Control Block (FCB)
  - One per file
  - Contains file attributes and location of disk blocks of the file
  - Stored in disk, usually brought to memory when file is opened
- Open File Table
  - In-memory table with one entry per open file
  - Each entry points to the FCB of the file (on disk or usually to copy in memory)
  - Can be hierarchical
    - Per-process table with entries pointing to entries in a single system-wide table
    - System-wide table points to FCB of file

# A Typical File Control Block

| |
|---|
| file permissions |
| file dates (create, access, write) |
| file owner, group, ACL |
| file size |
| file data blocks |

# In-Memory Open File Tables



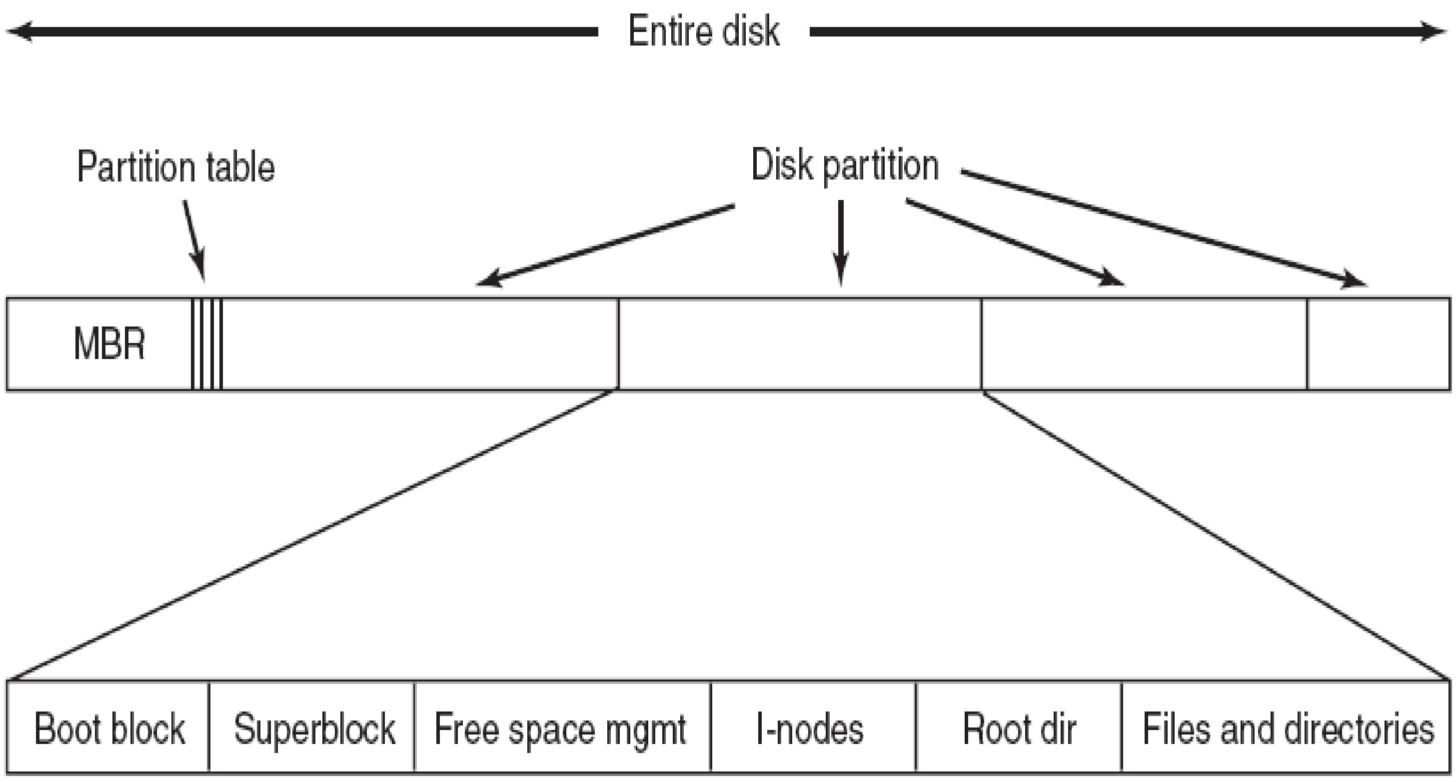
# Disk Layout

- Files stored on disks. Disks broken up into one or more partitions, with separate filesystem on each partition
- Sector 0 of disk is the Master Boot Record
- Used to boot the computer
- End of MBR has partition table. Has starting and ending addresses of each partition.
- One of the partitions is marked active in the master boot table

# Disk Layout (contd.)

- Boot computer => BIOS reads/executes MBR
- MBR finds active partition and reads in first block (boot block)
- Program in boot block locates the OS for that partition and reads it in
- All partitions start with a boot block

# One Possible Example



- Superblock contains info about the fs (e.g. type of fs, number of blocks, …)
- i-nodes contain info about files
  - Common Unix name for FCB

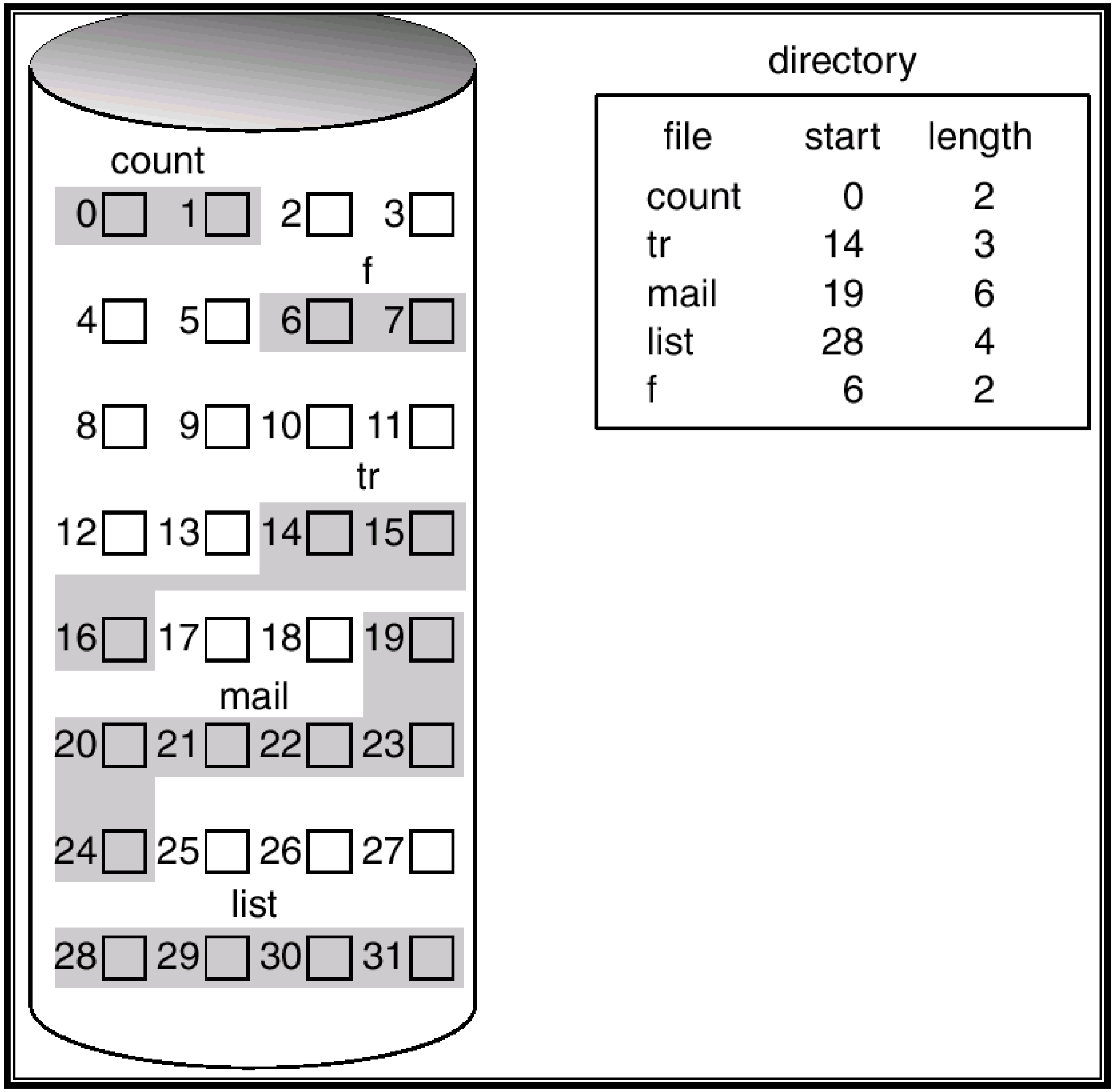
# Allocation Methods

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

# Contiguous Allocation

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

# Contiguous Allocation of Disk Space



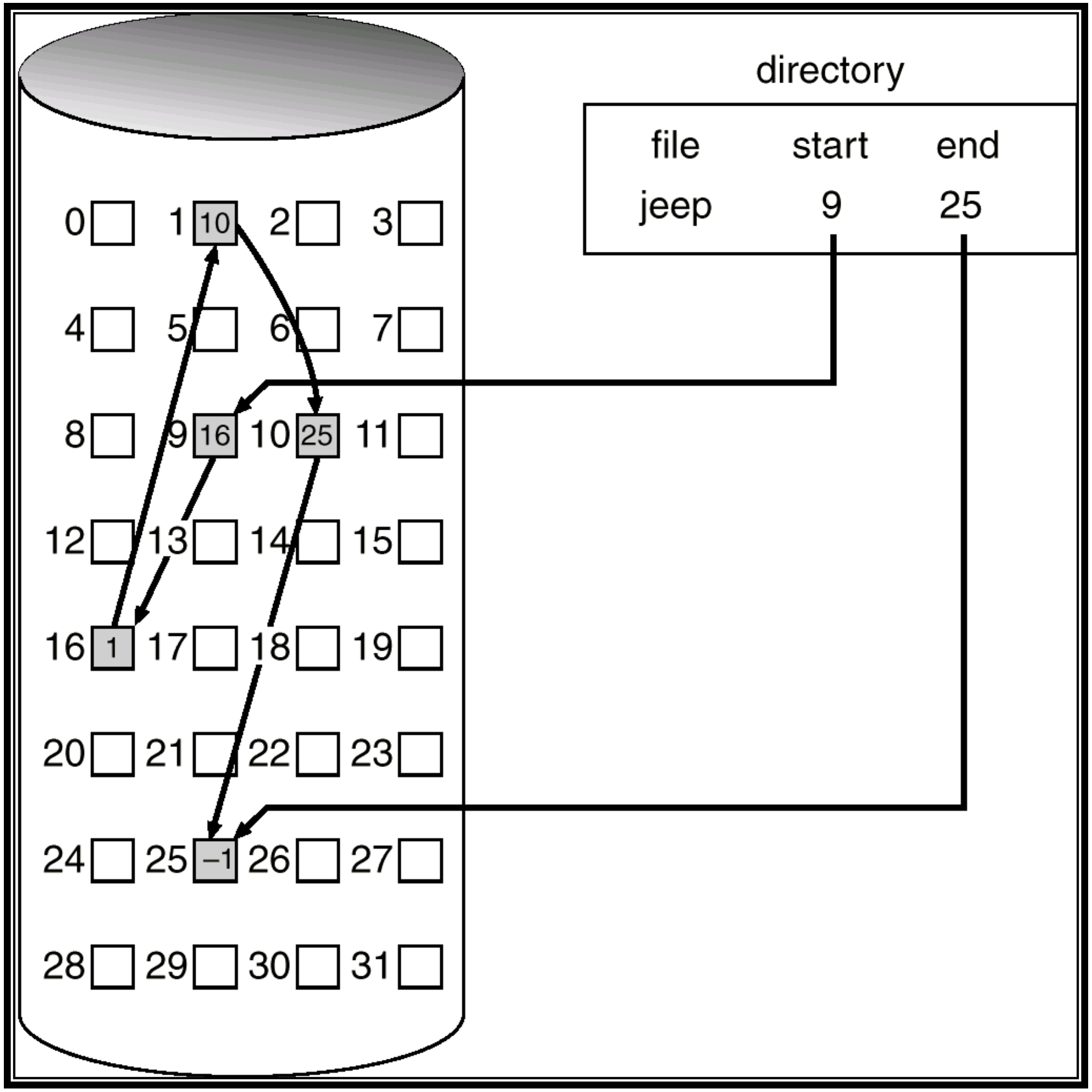
# Extent-Based Systems

- Many newer file systems 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

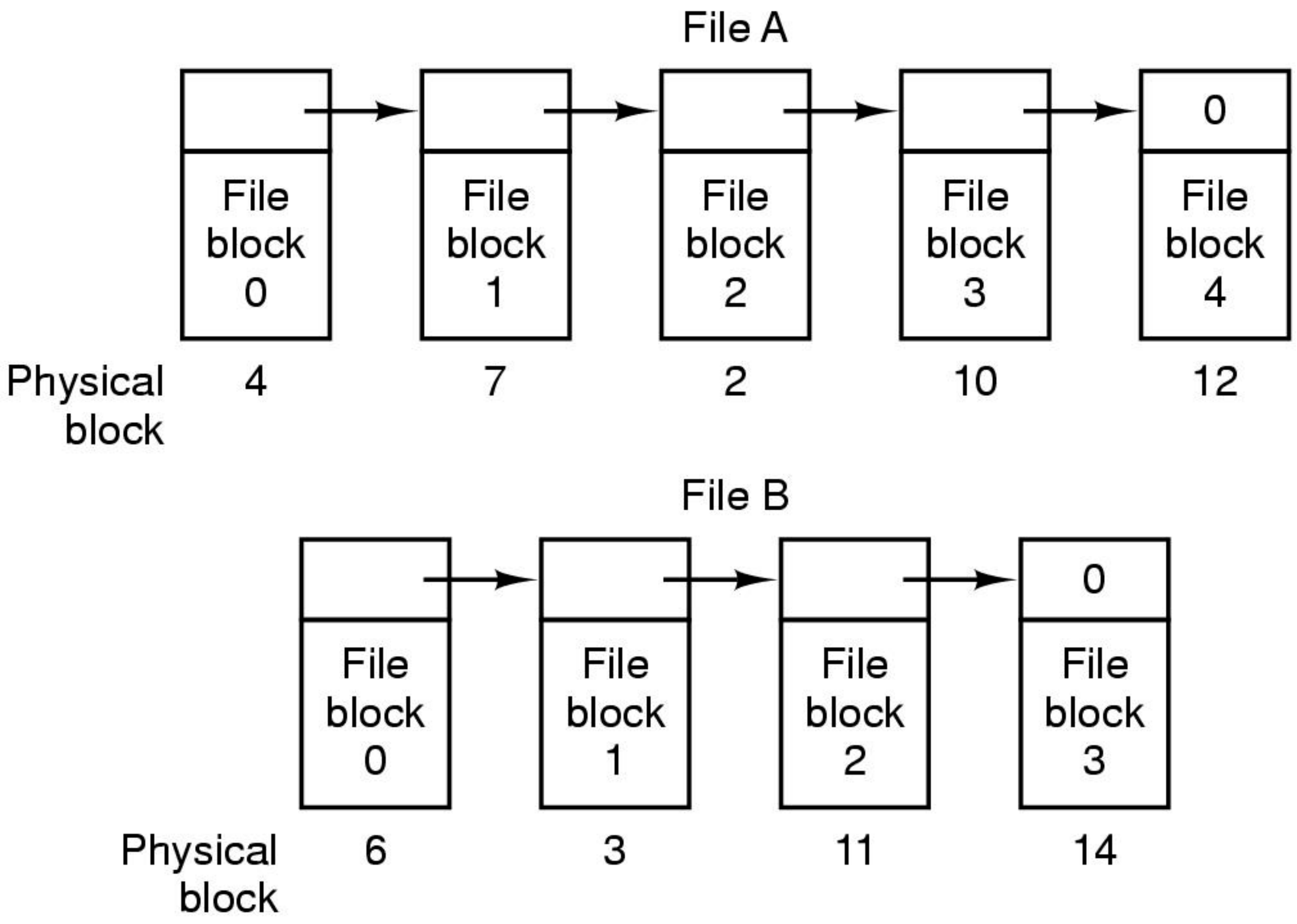
# Linked Allocation

- Each file is a linked list of disk blocks: blocks may be scattered anywhere on the disk
- Simple – need only starting address
- Free-space management system – no waste of space
- No random access

# Linked Allocation



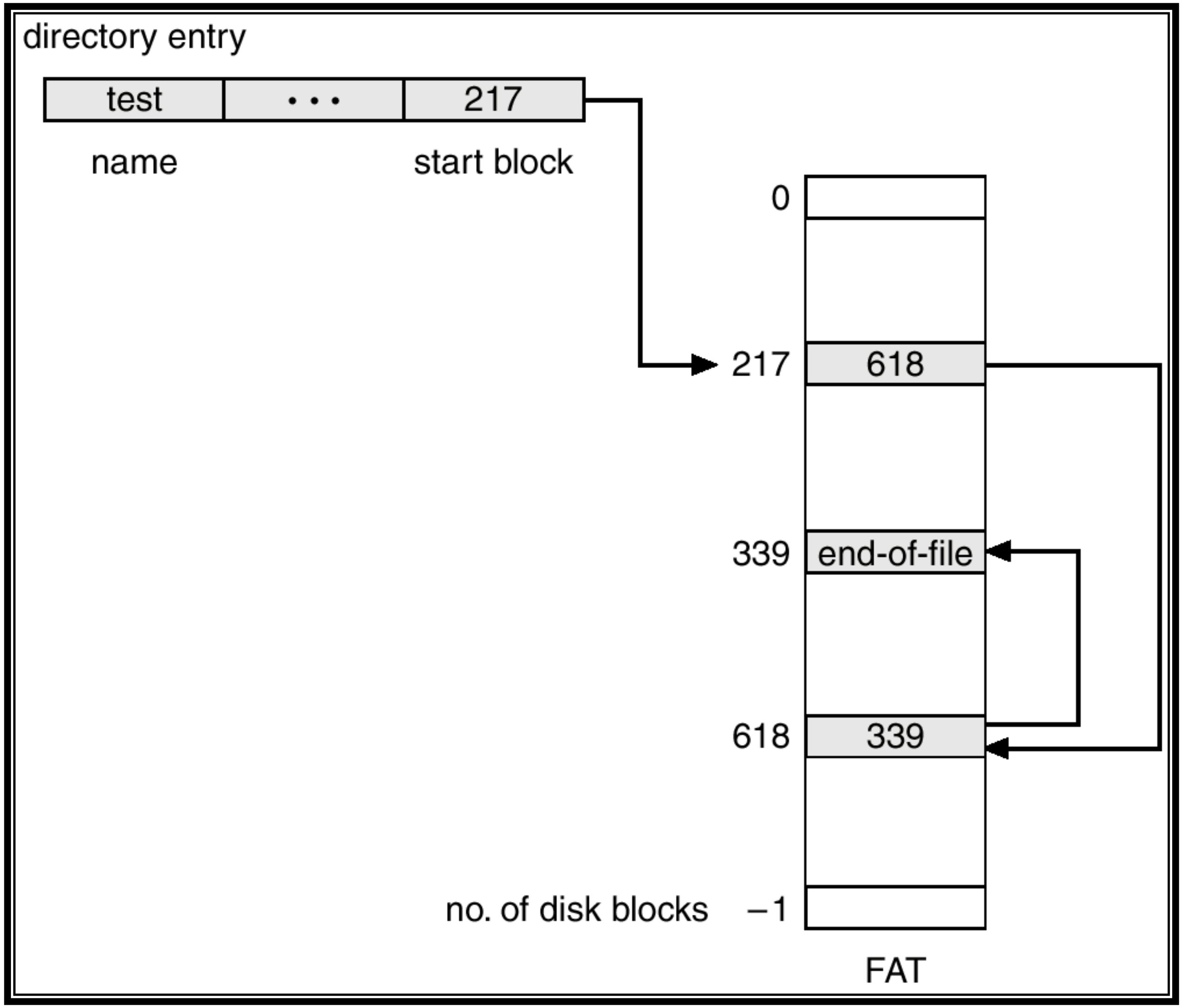
# Linked List Allocation



# Linked lists using a table in memory

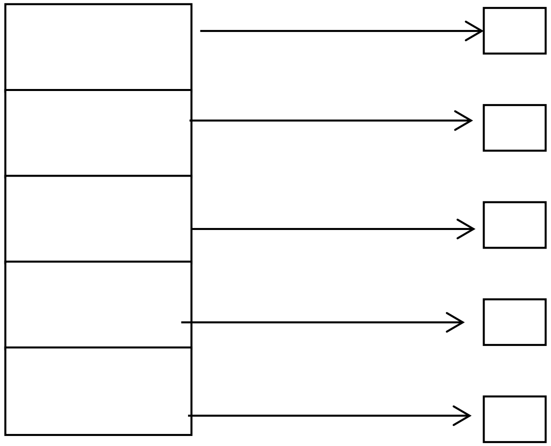
- Put pointers in table in memory
- File Allocation Table (FAT)
- Still have to traverse pointers, but now in memory
- But table becomes really big
  - 200 GB disk with 1 KB blocks needs a 600 MB table
  - Growth of the table size is linear with the growth of the disk size

# File-Allocation Table



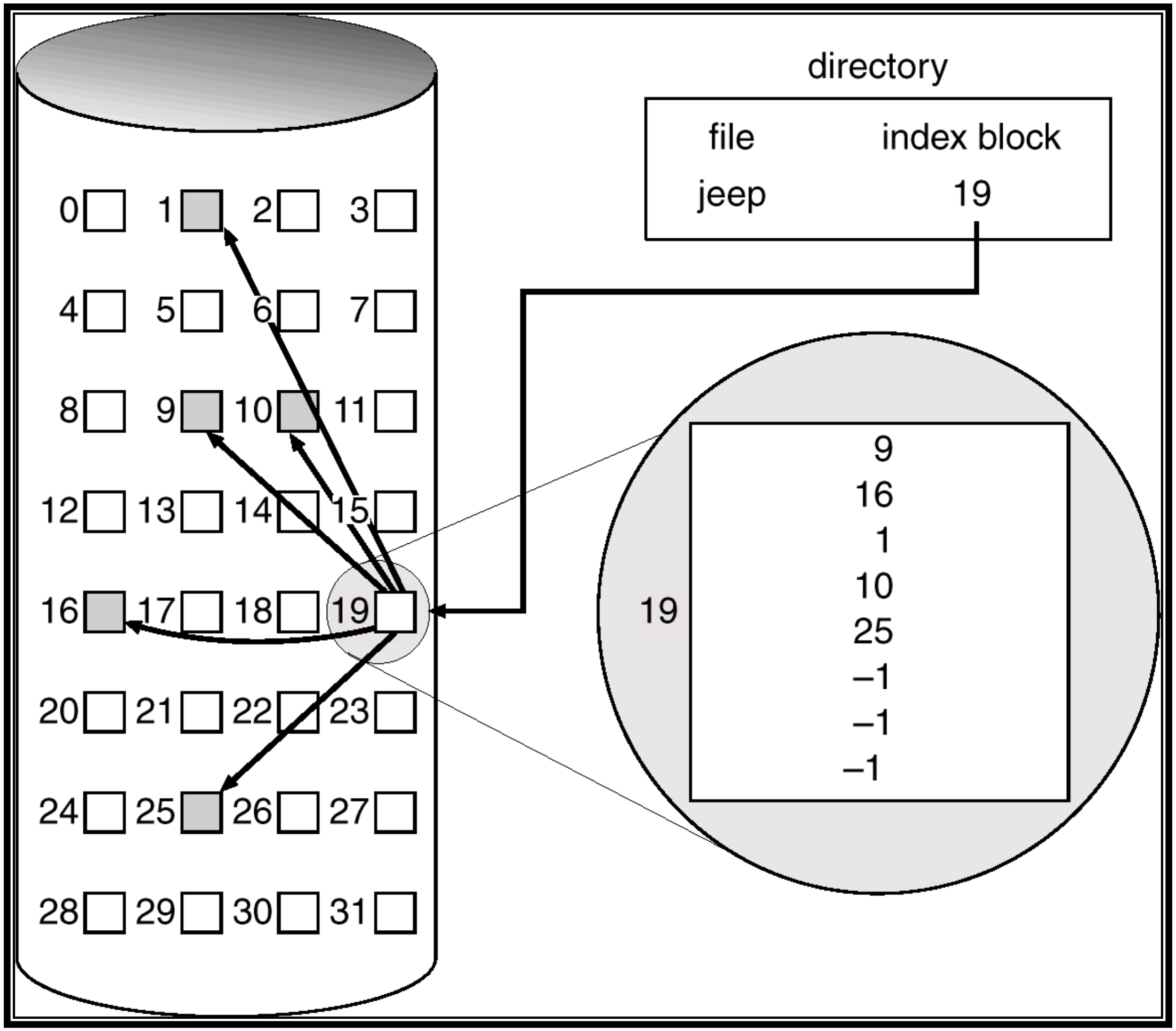
# Indexed Allocation

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



index table

# Example of Indexed Allocation



# Indexed Allocation (Cont.)

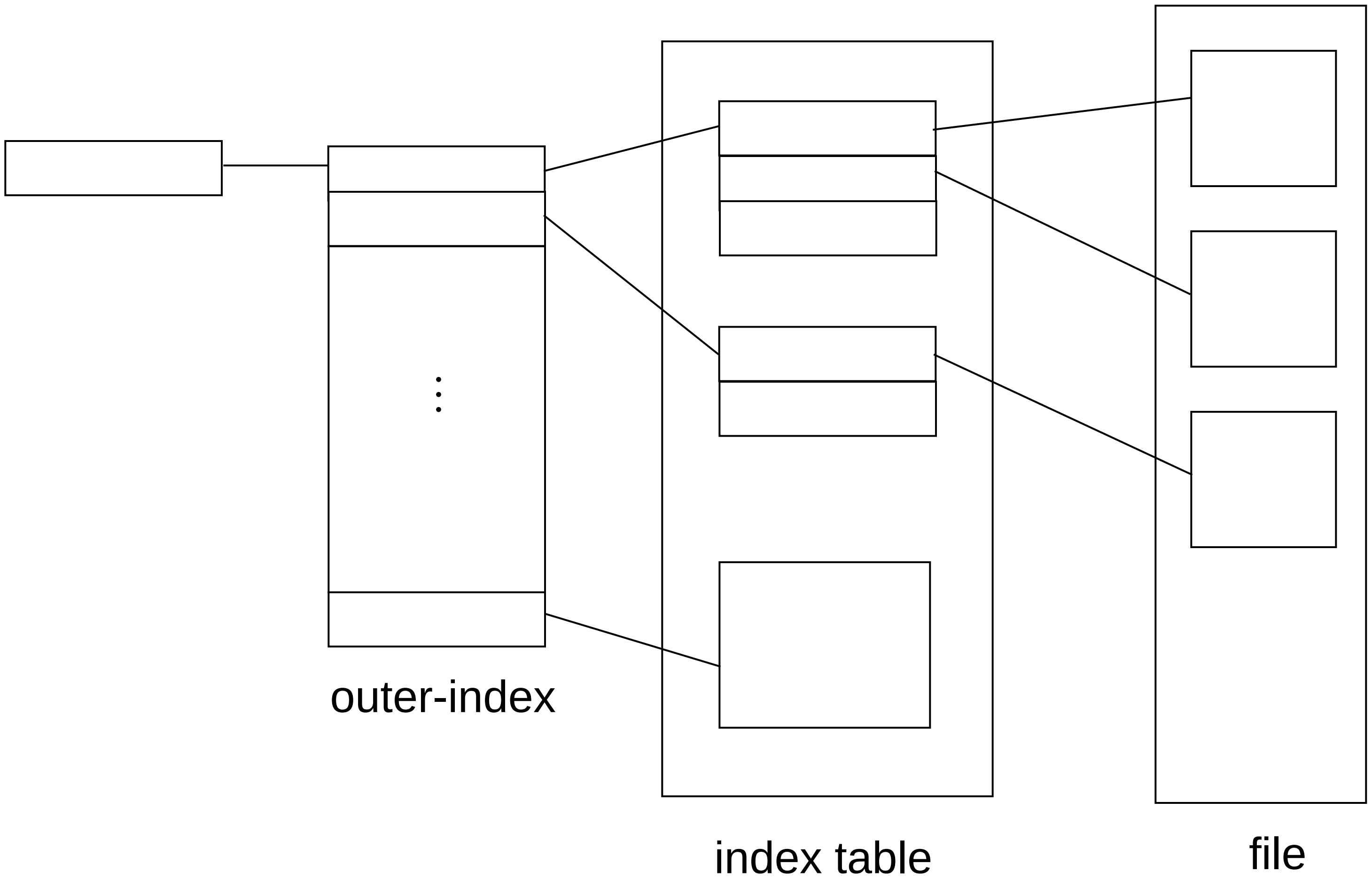
- Need index table
- Random access
- Dynamic access without external fragmentation, but have overhead of index block
- Mapping from logical to physical in a file of maximum size of 256K words and block size of 512 words.  We need only 1 block for index table

# 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)

# Two-level Indexing

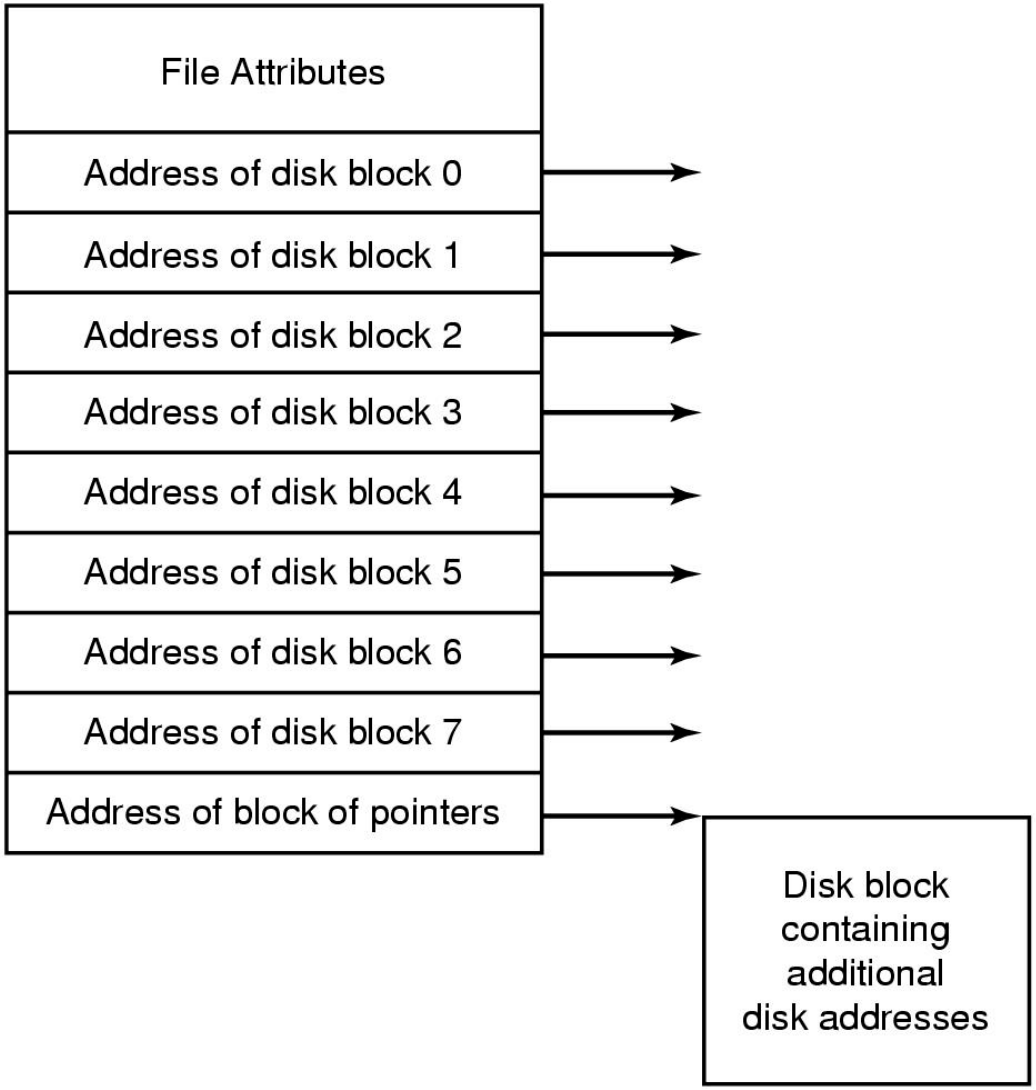
- Two-level index (maximum file size is $512^3$)



# i-nodes

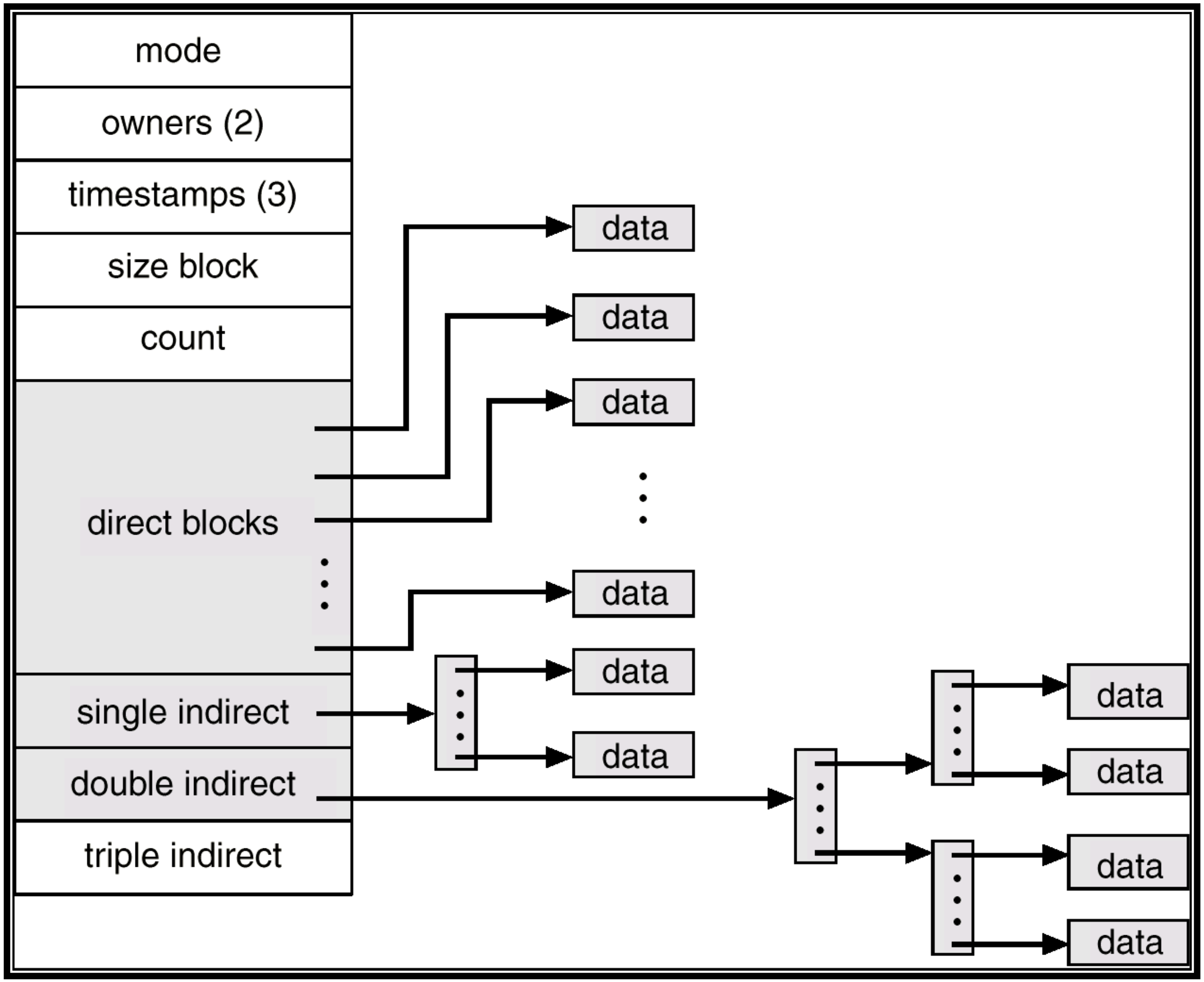
- FCB in Unix
- Contains file attributes and disk address of blocks
- One block can hold only limited number of disk block addresses, limits size of file
- Solution: use some of the blocks to hold address of blocks holding address of disk blocks of files
  - Can take this to more than one level

# i-node with one-level indirection



# Unix i-node

- File Attributes
- 12 direct pointers
- 1 singly indirect pointer
  - Points to a block that has disk block addresses
- 1 doubly indirect pointer
  - Points to a block that points to blocks that have disk block addresses
- 1 triply indirect pointer
  - Points to a block that points to blocks that point to blocks that have disk block addresses
- What is the max. file size possible??

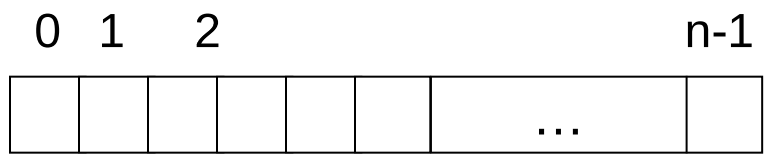

mode
owners (2)
timestamps (3)
size block
count
direct blocks
single indirect
double indirect
triple indirect
data
data
data
data
data
data
data
data
data
data

# Directory Implementation

- Linear list of file names with pointer to the data blocks
  - Address of first block (contiguous)
  - Number of first block (linked)
  - Number of i-node
- 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

# Free-Space Management

- 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 for first free block

(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

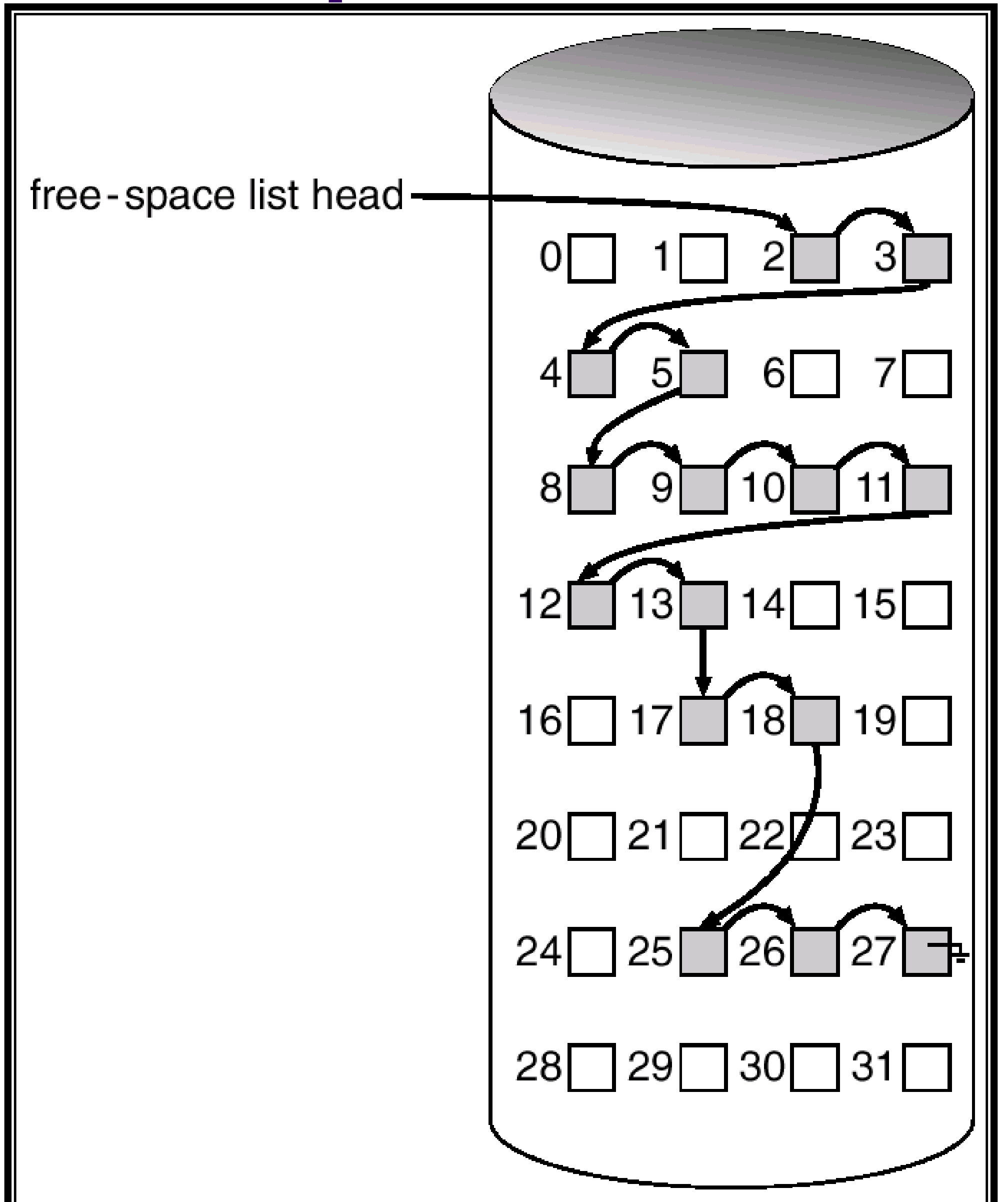
  disk size = $2^{30}$ bytes (1 gigabyte)

  $n = 2^{30}/2^{12} = 2^{18}$ bits (or 32K bytes)
- Easy to get contiguous files
- Linked list (free list)
  - Cannot get contiguous space easily
  - No waste of space
  - May need no. of disk accesses to find a free block
    - 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.

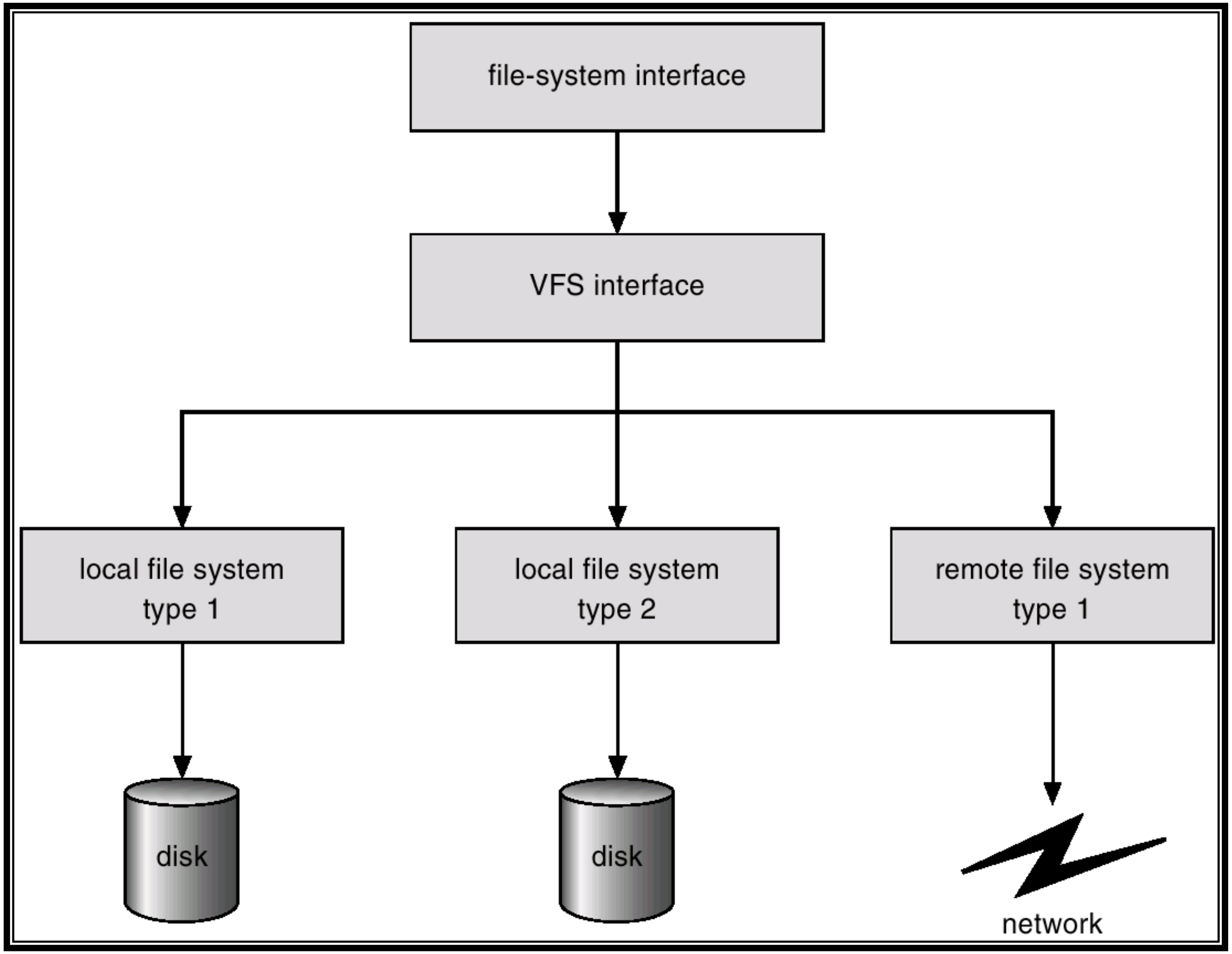
# Linked Free Space List on Disk



# Virtual File Systems

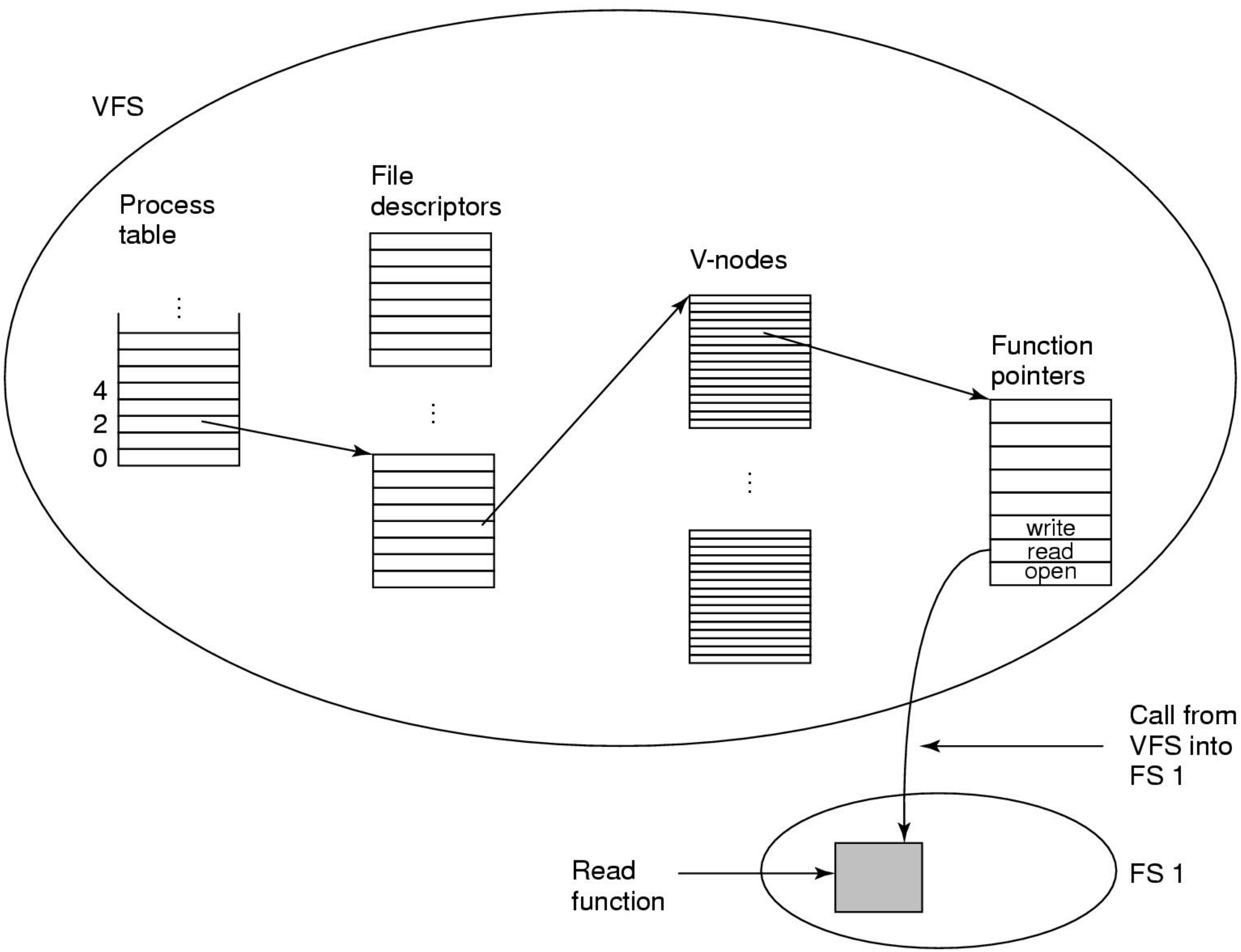
- Virtual File Systems (VFS) provide an object-oriented way of implementing file systems.
- VFS allows the same system call interface (the API) to be used for different types of file systems.
- The API is to the VFS interface, rather than any specific type of file system.

# Schematic View of Virtual File System



# How VFS works

- File system registers with VFS (e.g. at boot time)
- At registration time, fs provides list of addresses of function calls the vfs wants
- Vfs gets info from the new fs i-node and puts it in a v-node
- Makes entry in fd table for process
- When process issues a call (e.g. read), function pointers point to concrete function calls



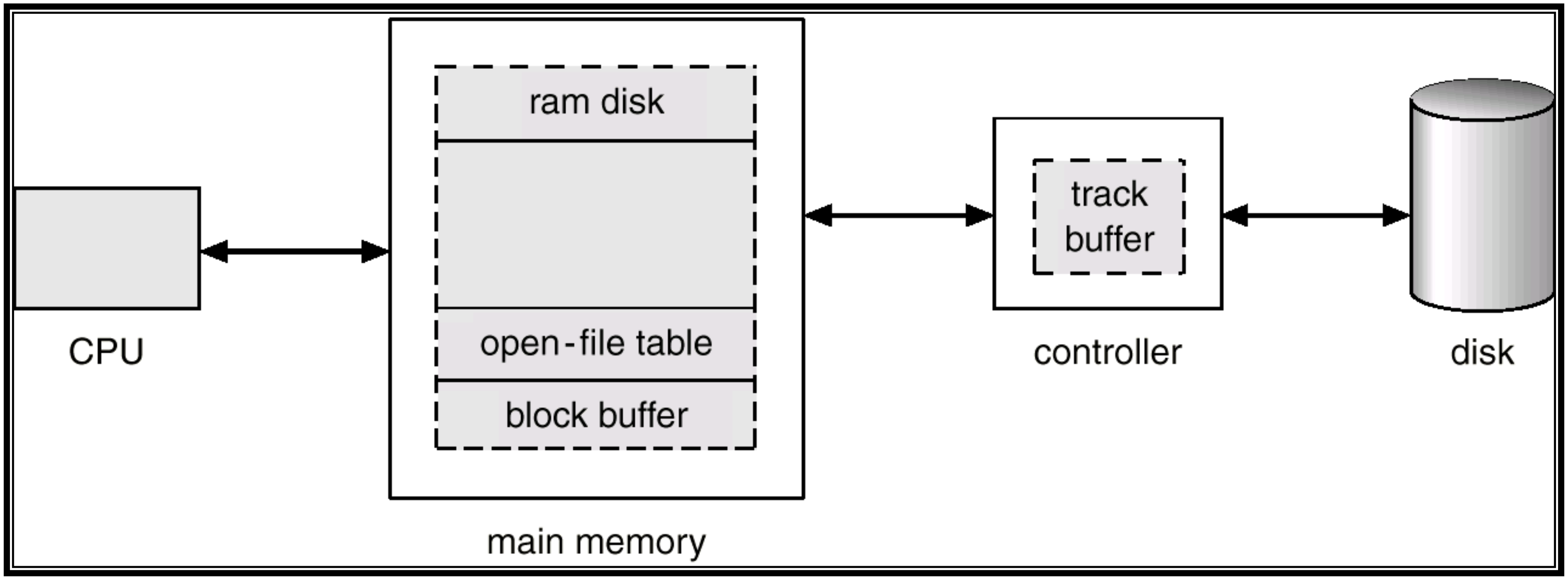

. A simplified view of the data structures and code used by the VFS and concrete file system to do a read.

# 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.

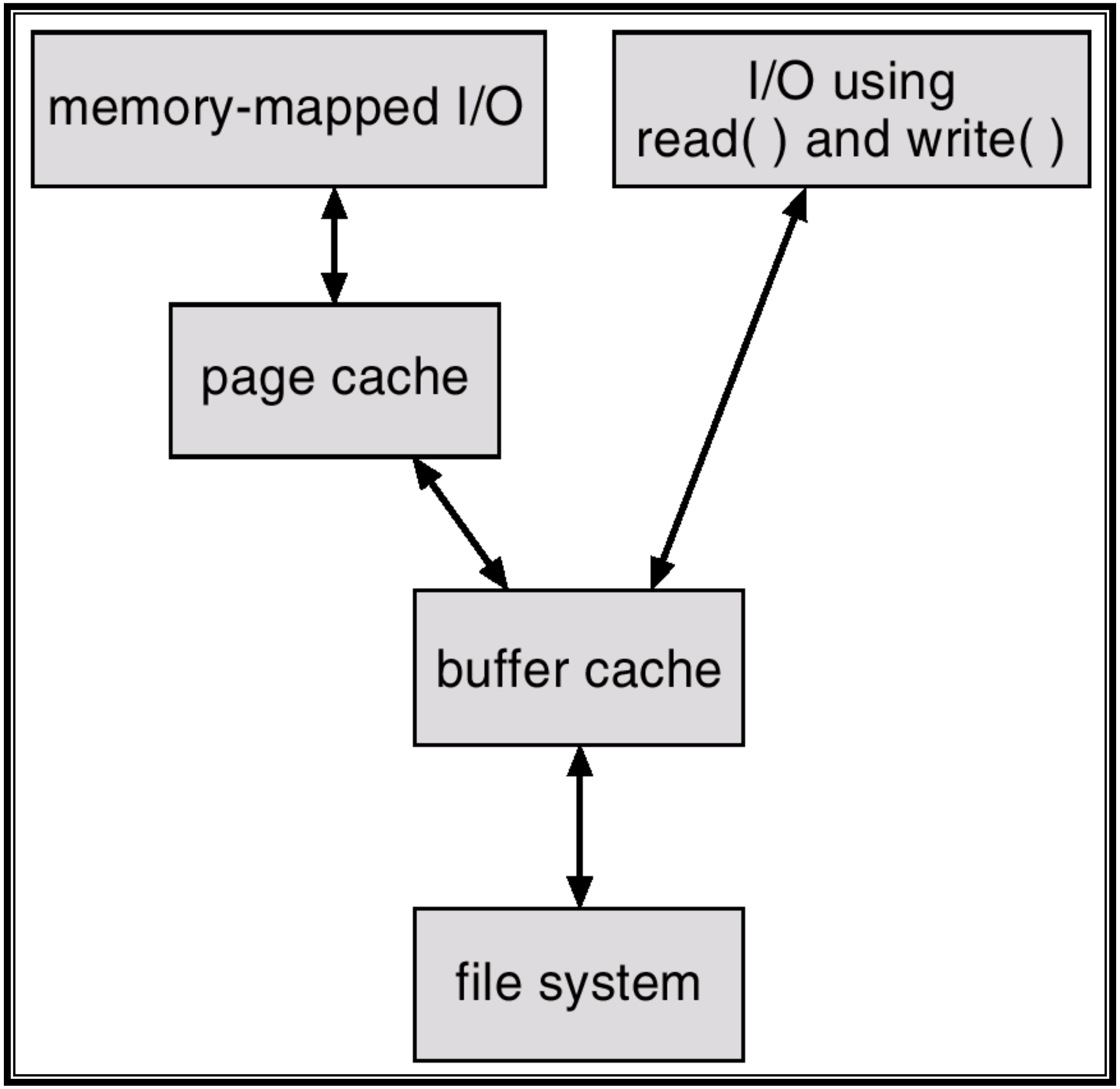
# Various Disk-Caching Locations



# 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

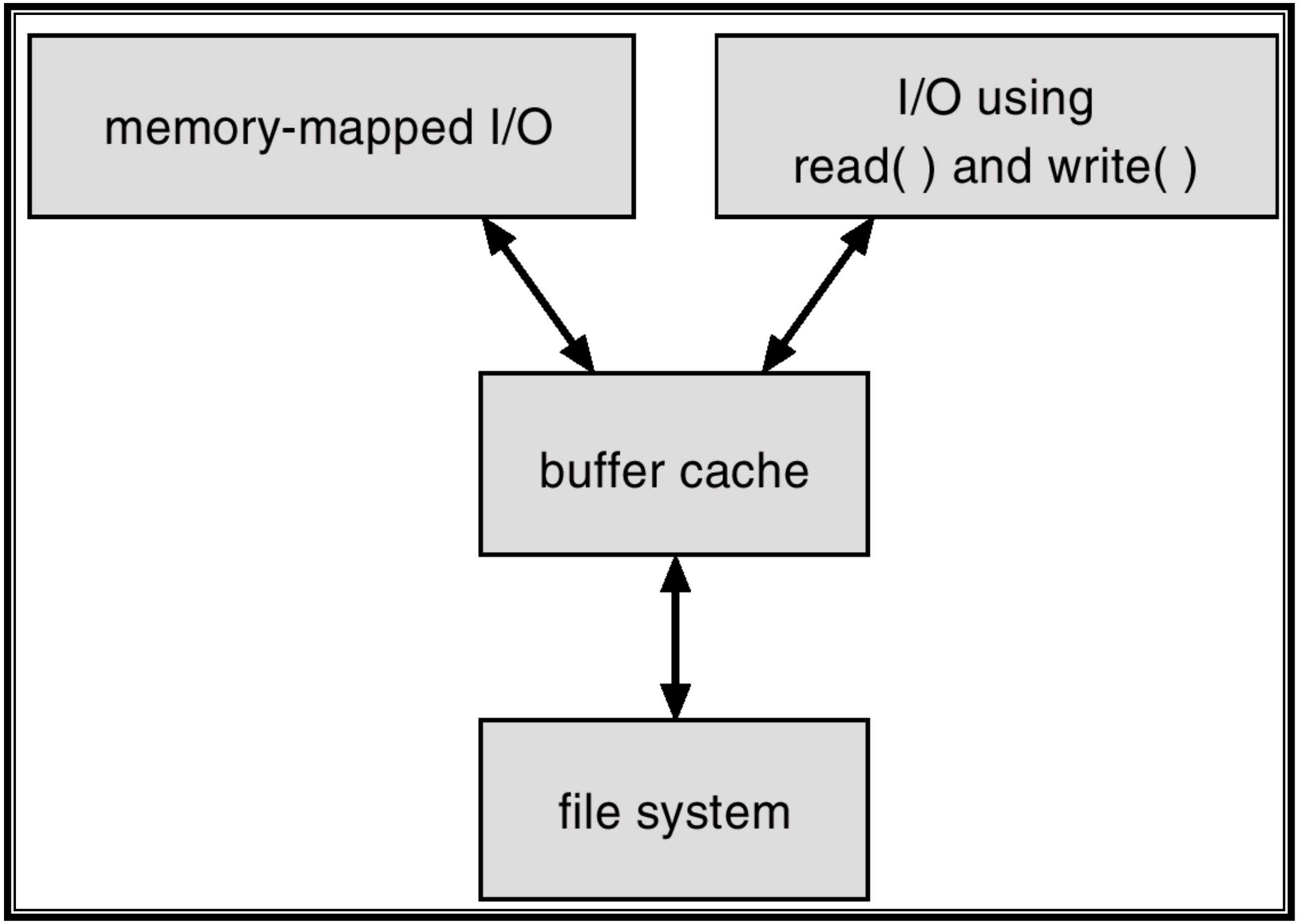
# I/O Without a Unified Buffer Cache



# 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)
- Recover lost file or disk by *restoring* data from backup