Reference Book:- Operating Systems: Internals and Design Principles

By William Stallings

File Management

Files

- Data collections created by users
- The File System is one of the most important parts of the OS to a user

Files

- Desirable properties of files:

Long-term existence

- files are stored on disk or other secondary storage and do not disappear when a user logs off

Sharable between processes

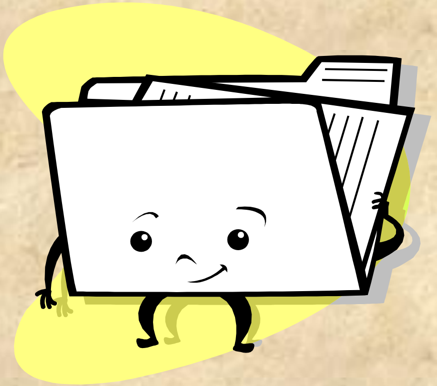
- files have names and can have associated access permissions that permit controlled sharing

Structure

- Depending upon the File System, A file can have an internal structure
- Files can be organized into hierarchical or more complex structure to reflect the relationships among files

File Systems

- Provide a means to store data organized as files as well as a collection of functions that can be performed on files
- Maintain a set of attributes associated with the file
- Typical operations include:
    - Create
    - Delete
    - Open
    - Close
    - Read
    - Write



File Structure

Four terms are commonly used when discussing files:

- Field
- Record
- File
- Database

File Structure

- Files can be structured as a collection of records or as a sequence of bytes
- UNIX, Linux, Windows, Mac OS's consider files as a sequence of bytes
- Other OS's, notably many IBM mainframes, adopt the collection-of-records approach; useful for DB

Structure Terms

Field

- basic element of data
- contains a single value
- Eg- Employee’s Last name, date
- characterized by its length and data type (e.g., ASCII string, decimal).
- fixed or variable length

Structure Terms

Record

- Collection of related fields that can be treated as a unit by some application program
- One field is the **key** – a unique identifier
- For example,
- An employee record would contain such fields-as name, social security number, job classification, date of hire, and so on.
- Depending on design, records may be of fixed length or variable length.

Structure Terms

File

- collection of similar records
- treated as a single entity by user and application
- may be referenced by name
- access control restrictions usually apply at the file level

Structure Terms

Database

- collection of related data
- relationships among elements of data are explicit
- designed for use by a number of different applications
- consists of one or more types of files

File Management System Objectives

- Meet the data management needs of the user
- Guarantee that the data in the file are valid
- Optimize performance
- Provide I/O support for a variety of storage device types
- Minimize the potential for lost or destroyed data
- Provide a standardized set of I/O interface routines to user processes
- Provide I/O support for multiple users in the case of multiple-user systems

Typical Software Organization

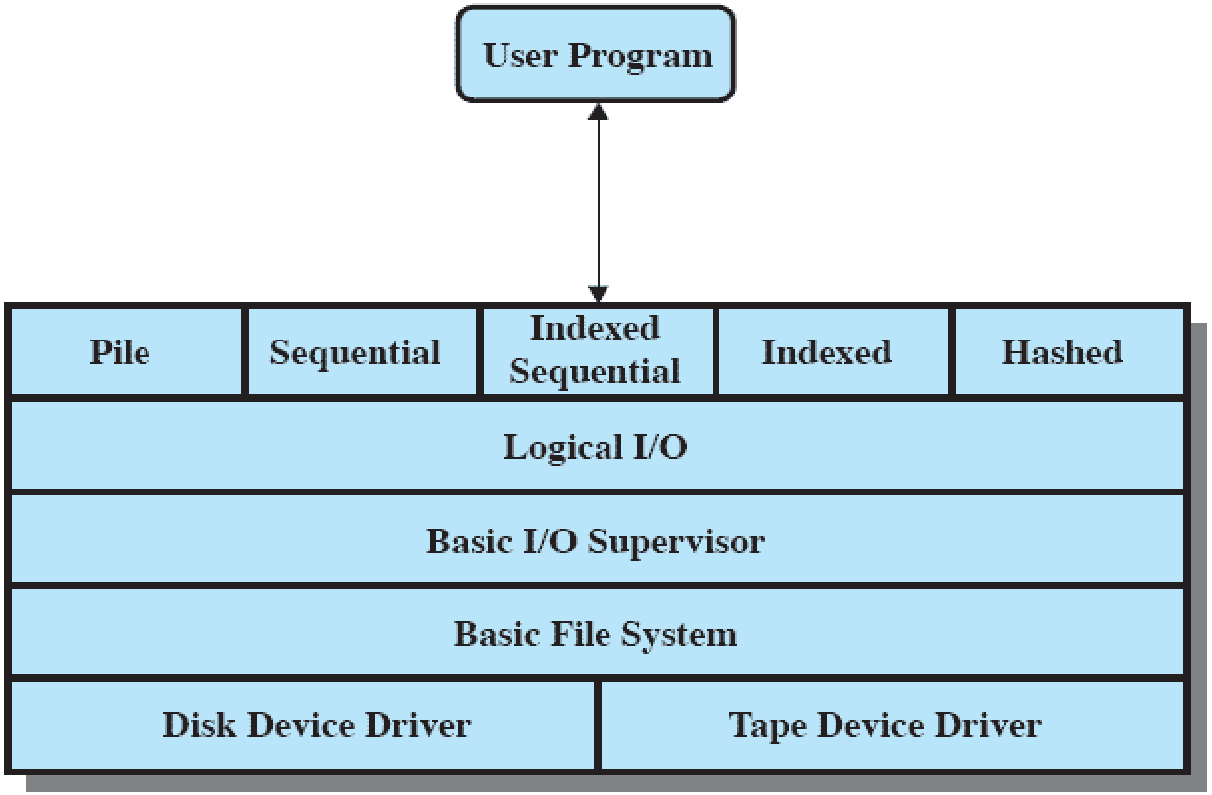


Figure 12.1 File System Software Architecture

File System Architecture

- Notice that the top layer consists of a number of different file formats: pile, sequential, indexed sequential, …
- These file formats are consistent with the collection-of-records approach to files and determine how file data is accessed

Layered File System Architecture

- File Formats – Access methods provide the interface to users
- Logical I/O
- Basic I/O
- Basic file system
- Device drivers

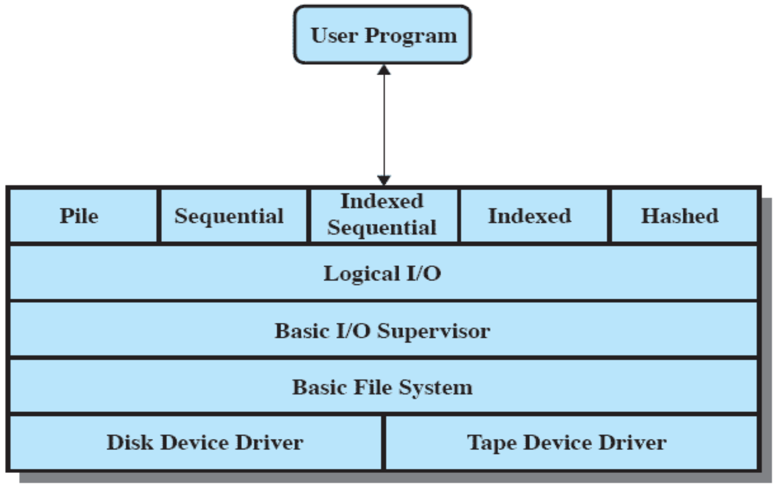
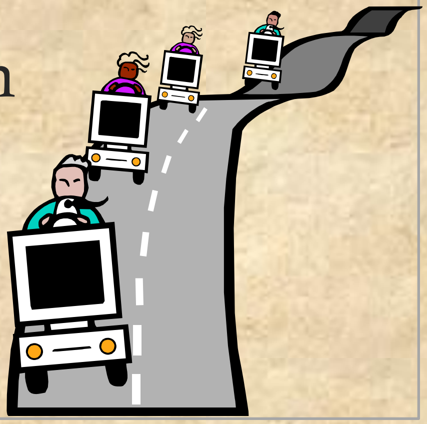


Figure 12.1 **File System Software Architecture**

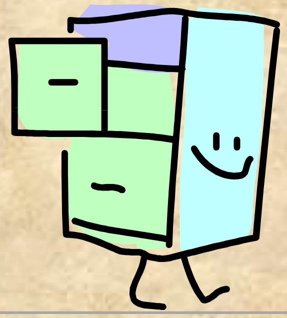
Device Drivers

- Lowest level
- Communicates directly with peripheral devices
- Responsible for starting I/O operations on a device
- Processes the completion of an I/O request
- Considered to be part of the operating system



Basic File System

- Also referred to as the physical I/O level
- Primary interface with the environment outside the computer system
- Deals with blocks of data that are exchanged with disk or other mass storage devices.
  - placement of blocks on the secondary storage device
  - buffering blocks in main memory
- Considered part of the operating system



Basic I/O Supervisor

- Responsible for all file I/O initiation and termination
- Control structures that deal with device I/O, scheduling, and file status are maintained
- Selects the device on which I/O is to be performed
- Concerned with scheduling disk and tape accesses to optimize performance
- I/O buffers are assigned and secondary memory is allocated at this level
- Part of the operating system

Logical I/O

- Enables users and applications to access records
- Provides general-purpose record I/O capability
- Maintains basic data about file

Logical I/O

This level is the interface between the logical commands issued by a program and the physical details required by the disk.

Logical units of data versus physical blocks of data to match disk requirements.

Access Method

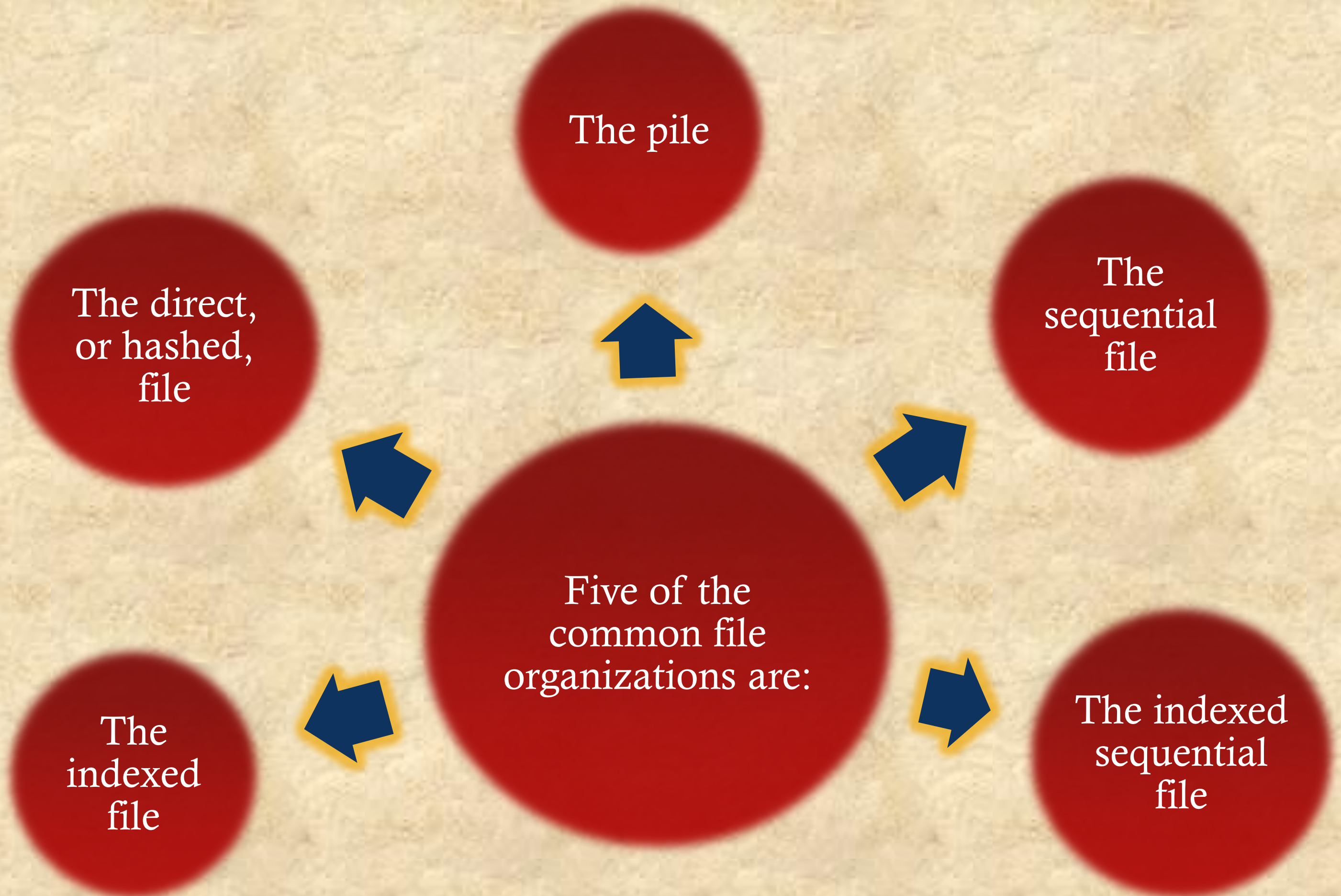
- Level of the file system closest to the user
- Provides a standard interface between applications and the file systems and devices that hold the data
- Different access methods reflect different file structures and different ways of accessing and processing the data

File Organization and Access

- ***File organization*** is the logical structuring of the records as determined by the way in which they are accessed
- In choosing a file organization, several criteria are important:
  - short access time
  - ease of update
  - economy of storage
  - simple maintenance
  - reliability

- Relative Priority of these criteria depends on the application that will use the file

File Organization Types



Grades of Performance

Table 12.1 Grades of Performance for Five Basic File Organizations [WIED87]

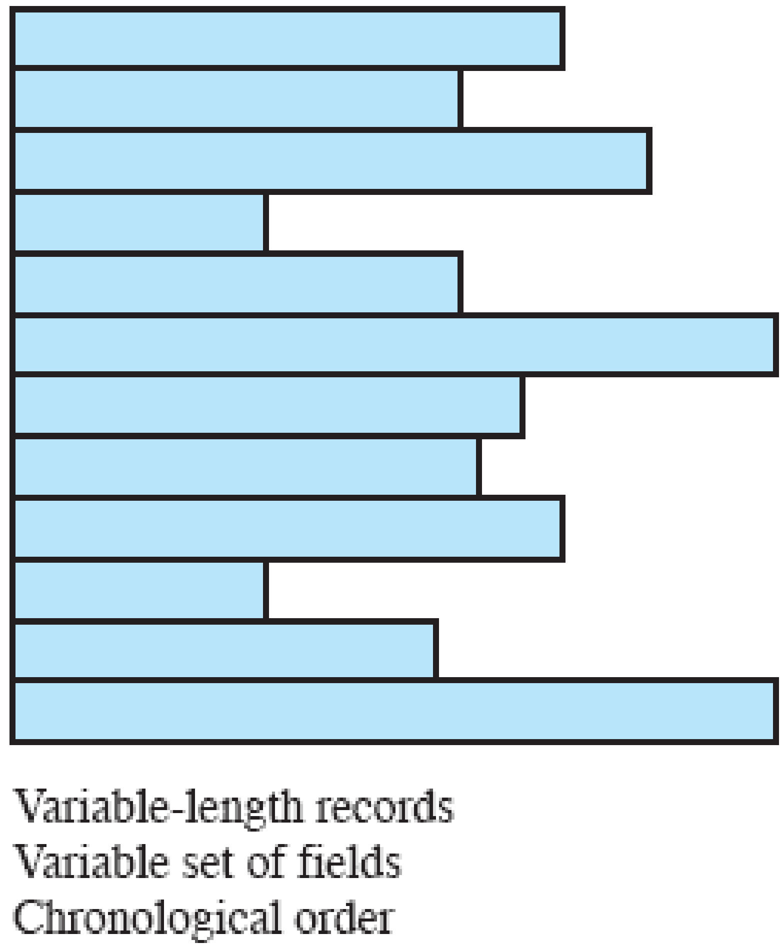
	Space Attributes		**Update** Record Size		**Retrieval**		
File Method	Variable	Fixed	Equal	Greater	Single record	Subset	Exhaustive
Pile	A	B	A	E	E	D	B
Sequential	F	A	D	F	F	D	A
Indexed sequential	F	B	B	D	B	D	B
Indexed	B	C	C	C	A	B	D
Hashed	F	B	B	F	B	F	E

A = Excellent, well suited to this purpose $\approx O(r)$
B = Good $\approx O(o \times r)$
C = Adequate $\approx O(r \log n)$
D = Requires some extra effort $\approx O(n)$
E = Possible with extreme effort $\approx O(r \times n)$
F = Not reasonable for this purpose $\approx O(n^{>1})$

where
r = size of the result
o = number of records that overflow
n = number of records in file

The Pile

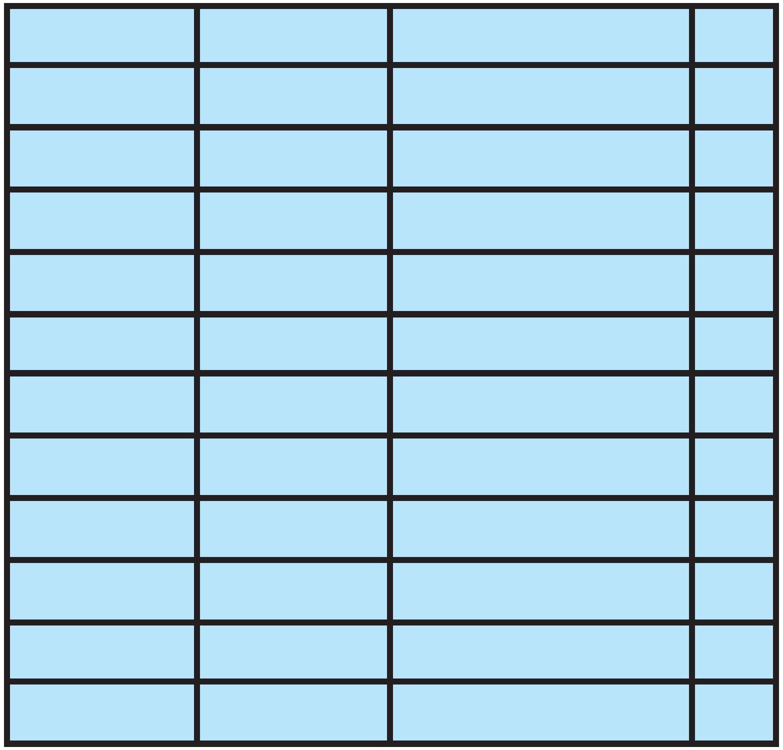
- Least complicated form of file organization
- Data are collected in the order they arrive
- Each record consists of one burst of data
- Purpose is simply to accumulate the mass of data and save it
- Record access is by exhaustive search



(a) Pile File

The Sequential File

- Most common form of file structure
- A fixed format is used for records
- Key field uniquely identifies the record & determines storage order
- Typically used in batch applications
- Only organization that is easily stored on tape as well as disk

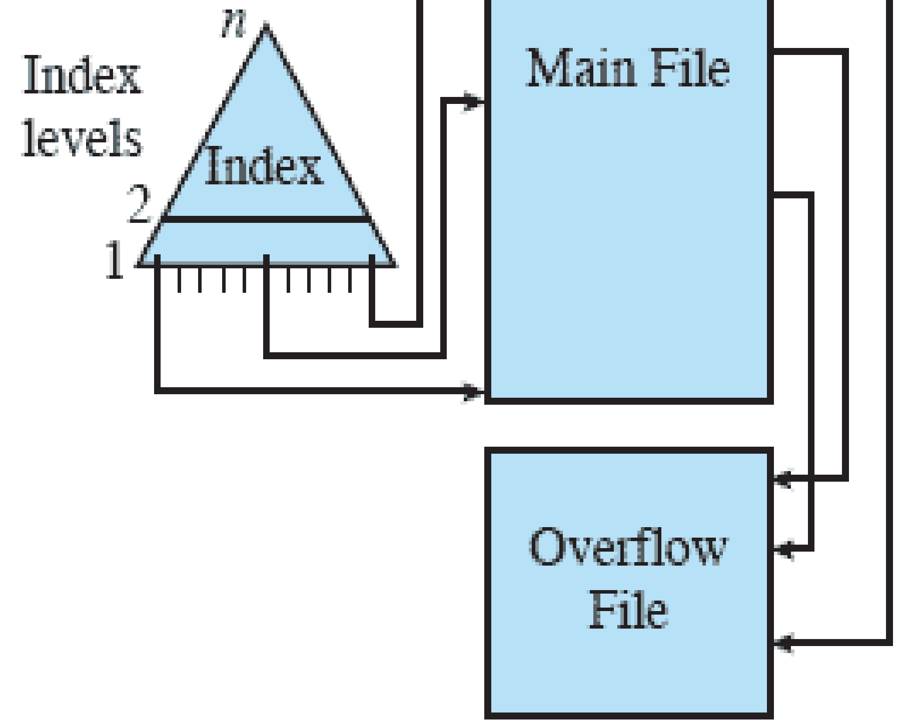


Fixed-length records
Fixed set of fields in fixed order
Sequential order based on key field

(b) Sequential File

Indexed Sequential File

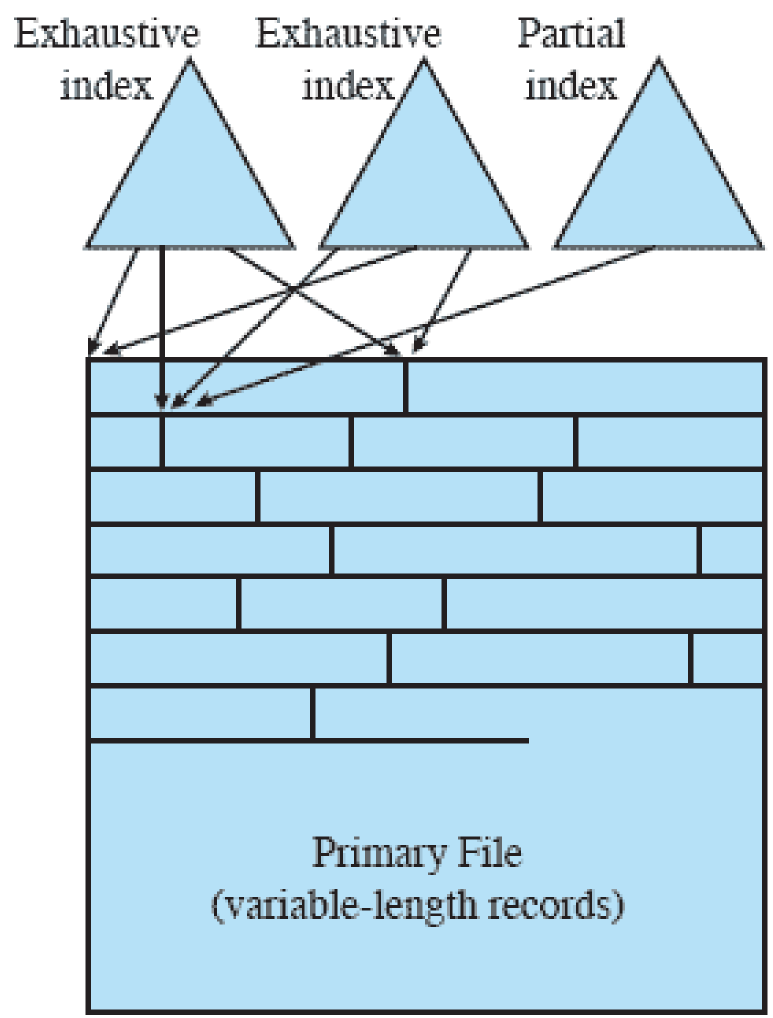
- Records are organized in sequence based on a key field
- Adds an index to the file to support random access
- The index provides a lookup capability to reach quickly the vicinity of a desired record.
- A single level of indexing is used.
- Adds an overflow file, similar to log file
- Greatly reduces the time required to access a single record



(c) Indexed Sequential File

Indexed File

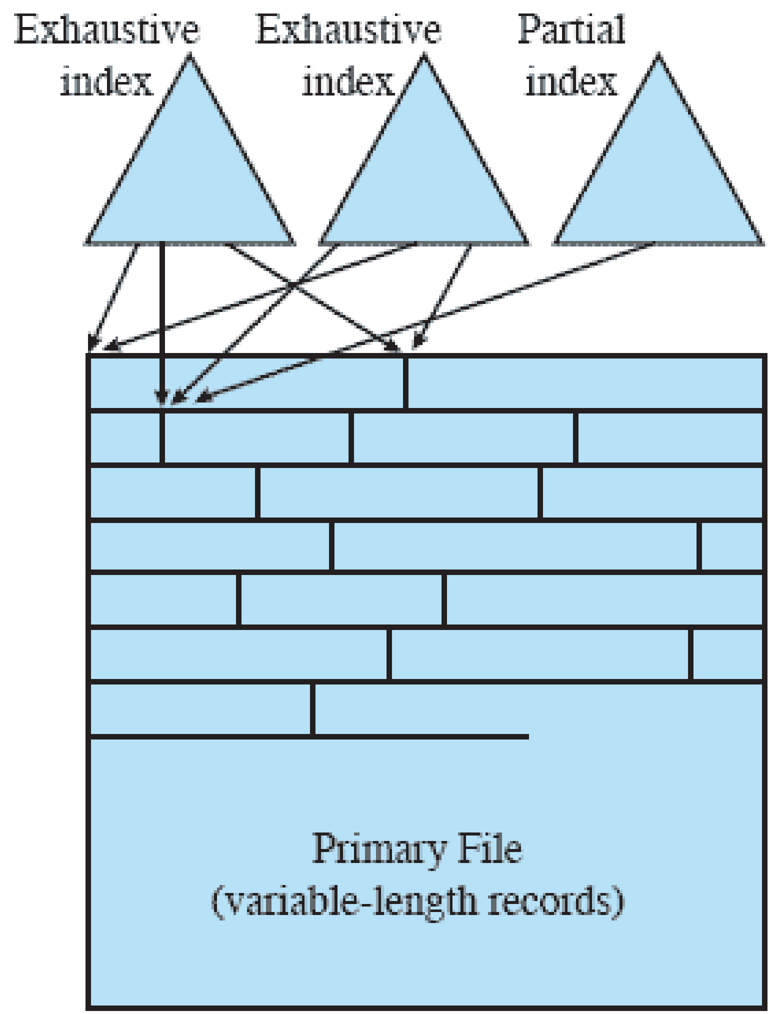
- Records are accessed only through their indexes
- Variable-length records can be employed
- Employs multiple indexes
- Exhaustive index contains one entry for every record in the main file
- Partial index contains entries to records where the field of interest exists
- With variable-length records, some records will not contain all fields.



(d) Indexed File

Indexed File

- When a new record is added to the main file, all of the index files must be updated.
- Used mostly in applications where timeliness of information is critical
- Examples would be airline reservation systems and inventory control systems



(d) Indexed File

Direct or Hashed File

- Access directly any block of a known address
- As with sequential and indexed sequential files, a key field is required in each record. However, there is no concept of sequential ordering here.
- Makes use of hashing on the key value
- Often used where:
  - very rapid access is required
  - fixed-length records are used
  - records are always accessed one at a time

Examples are:

- directories
- pricing tables
- schedules
- name lists

File Directory Information

Table 12.2 Information Elements of a File Directory

Basic Information	
File Name	Name as chosen by creator (user or program). Must be unique within a specific directory.
File Type	For example: text, binary, load module, etc.
File Organization	For systems that support different organizations
Address Information	
Volume	Indicates device on which file is stored
Starting Address	Starting physical address on secondary storage (e.g., cylinder, track, and block number on disk)
Size Used	Current size of the file in bytes, words, or blocks
Size Allocated	The maximum size of the file
Access Control Information	
Owner	User who is assigned control of this file. The owner may be able to grant/deny access to other users and to change these privileges.
Access Information	A simple version of this element would include the user's name and password for each authorized user.
Permitted Actions	Controls reading, writing, executing, transmitting over a network
Usage Information	
Date Created	When file was first placed in directory
Identity of Creator	Usually but not necessarily the current owner
Date Last Read Access	Date of the last time a record was read
Identity of Last Reader	User who did the reading
Date Last Modified	Date of the last update, insertion, or deletion
Identity of Last Modifier	User who did the modifying
Date of Last Backup	Date of the last time the file was backed up on another storage medium
Current Usage	Information about current activity on the file, such as process or processes that have the file open, whether it is locked by a process, and whether the file has been updated in main memory but not yet on disk

Operations Performed on a Directory

- To understand the requirements for a file structure, it is helpful to consider the types of operations that may be performed on the directory:

Search → Create files → Delete files → List directory → Update directory

Two-Level Scheme

There is one directory for each user and a master directory

Master directory has an entry for each user directory providing address and access control information

Each user directory is a simple list of the files of that user

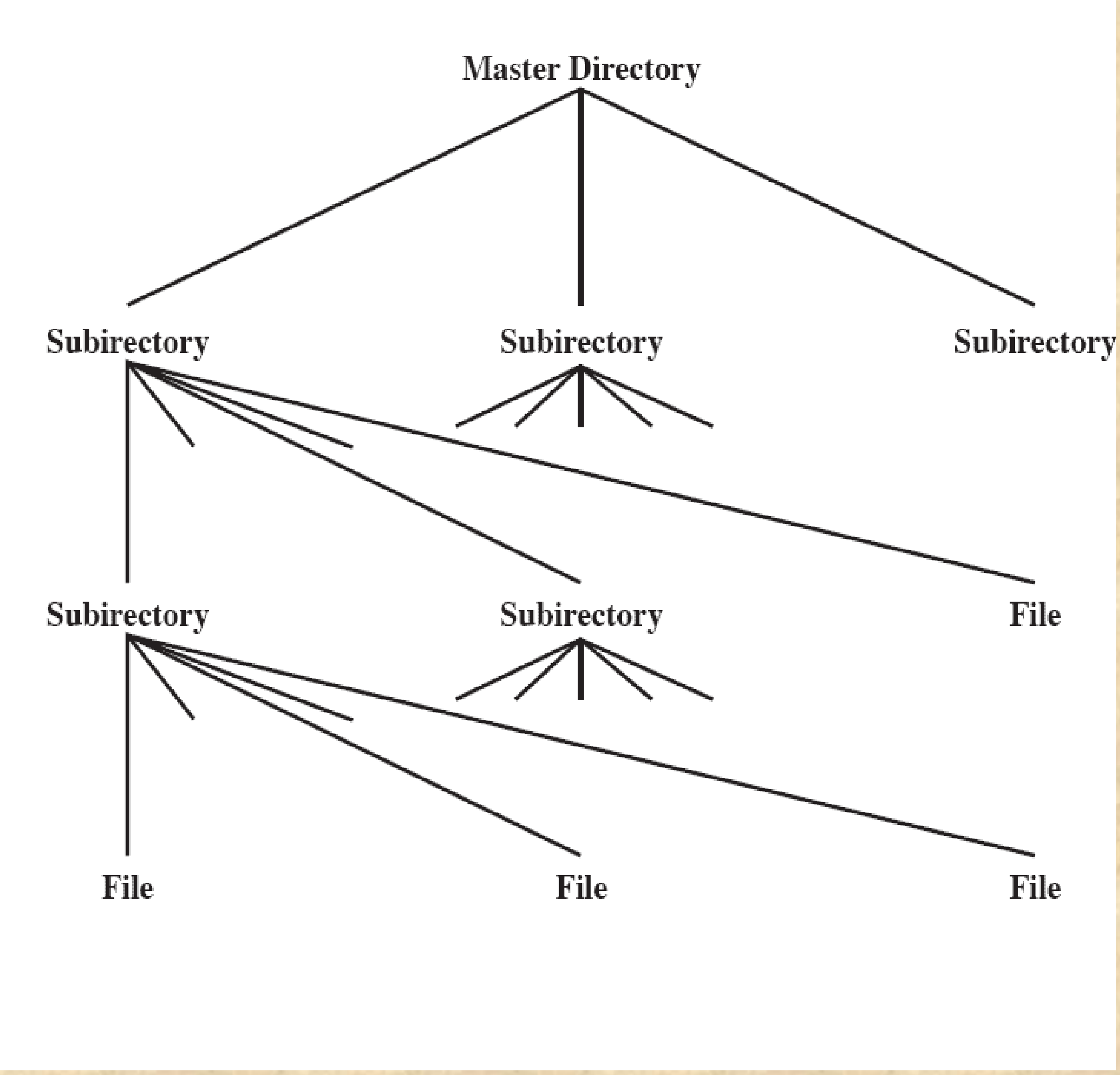
Names must be unique only within the collection of files of a single user

File system can easily enforce access restriction on directories

Figure 12.4

Tree-Structured Directory

- Master directory with user directories underneath it
- Each user directory may have subdirectories and files as entries



Example of Tree-Structured Directory

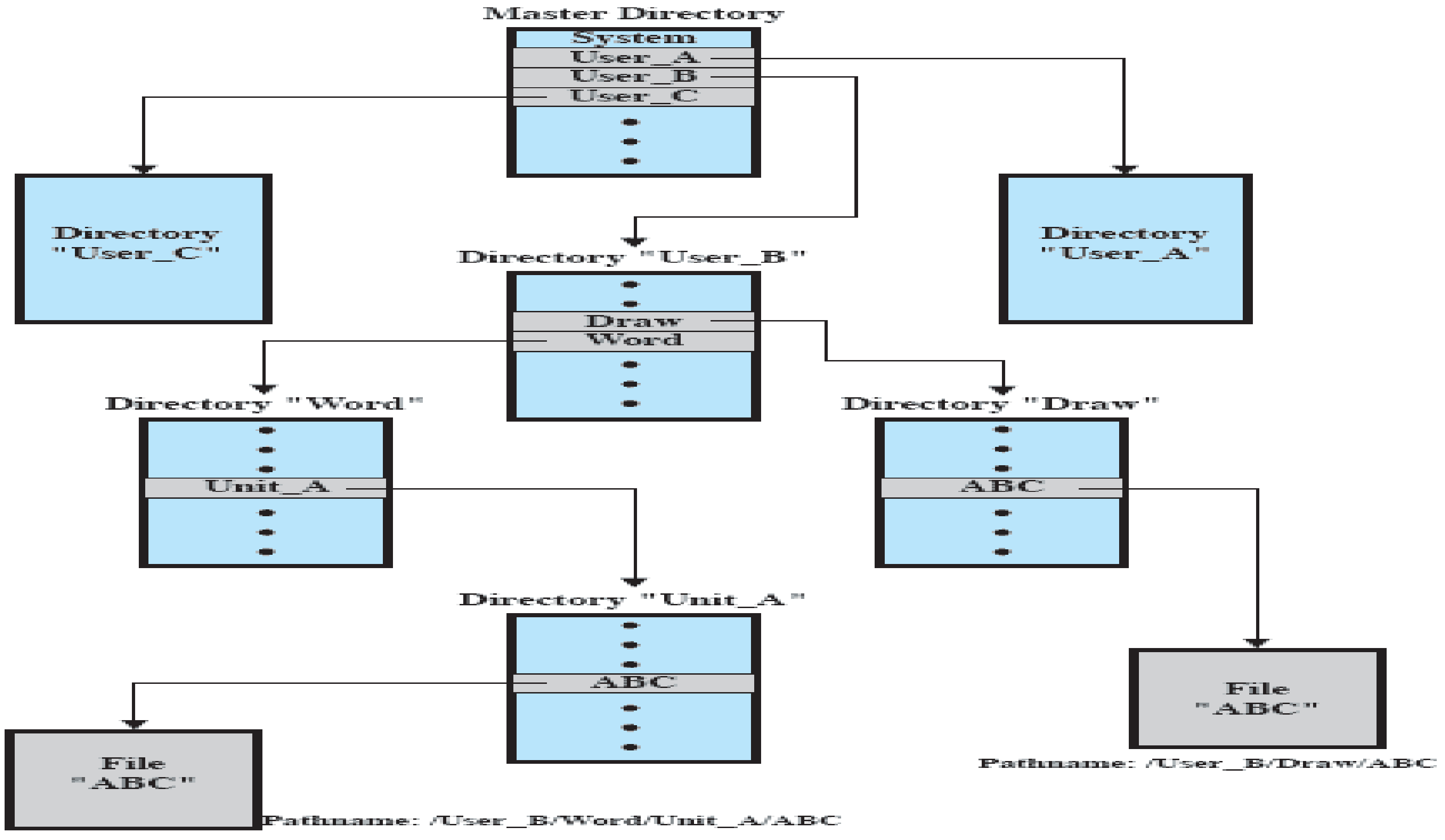


Figure 12.5 Example of

File Sharing

Two issues arise when allowing files to be shared among a number of users:

- access rights
- management of simultaneous access

Access Rights

- *None*
  - the user would not be allowed to read the user directory that includes the file
- *Knowledge*
  - the user can determine that the file exists and who its owner is and can then petition the owner for additional access rights
- *Execution*
  - the user can load and execute a program but cannot copy it
- *Reading*
  - the user can read the file for any purpose, including copying and execution
- *Appending*
  - the user can add data to the file but cannot modify or delete any of the file's contents
- *Updating*
  - the user can modify, delete, and add to the file's data
- *Changing protection*
  - the user can change the access rights granted to other users
- *Deletion*
  - the user can delete the file from the file system

User Access Rights

Owner

- usually the initial creator of the file
- has full rights
- may grant rights to others

Specific Users

- individual users who are designated by user ID

User Groups

- a set of users who are not individually defined

All

- all users who have access to this system
- these are public files

Secondary Storage Management

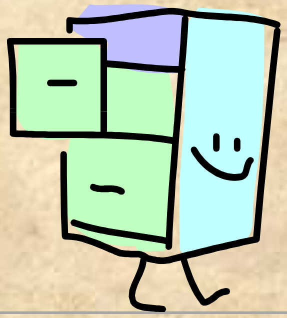
- On secondary storage, a file consists of a collection of blocks.
- The operating system or file management system is responsible for allocating blocks to files.
- This raises two management issues.
  - First, space on secondary storage must be allocated to files,
  - Second, it is necessary to keep track of the space available for allocation.

File Allocation

- Disks are divided into physical blocks (sectors on a track)
- Files are divided into logical blocks (subdivisions of the file)
- Logical block size = some multiple of a physical block size
- The operating system or file management system is responsible for allocating blocks to files
- Space is allocated to a file as one or more ***portions*** (contiguous set of allocated disk blocks). A portion is the logical block size
- ***File allocation table (FAT)***
    - data structure used to keep track of the portions assigned to a file

Preallocation vs Dynamic Allocation

- A preallocation policy requires that the maximum size of a file be declared at the time of the file creation request
- For many applications it is difficult to estimate reliably the maximum potential size of the file
  - tends to be wasteful because users and application programmers tend to overestimate size
- Dynamic allocation allocates space to a file in portions as needed



Portion Size

- In choosing a portion size there is a trade-off between efficiency from the point of view of a single file versus overall system efficiency
- Items to be considered:
  1) contiguity of space increases performance, especially for Retrieve_Next operations, and greatly for transactions running in a transaction-oriented operating system
  2) having a large number of small portions increases the size of tables needed to manage the allocation information
  3) having fixed-size portions simplifies the reallocation of space
  4) having variable-size or small fixed-size portions minimizes waste of unused storage due to overallocation

Summarizing the Alternatives

- Two major alternatives:

Variable, large contiguous portions

- provides better performance
- the variable size avoids waste
- the file allocation tables are small

Blocks

- small fixed portions provide greater flexibility
- they may require large tables or complex structures for their allocation
- contiguity has been abandoned as a primary goal
- blocks are allocated as needed

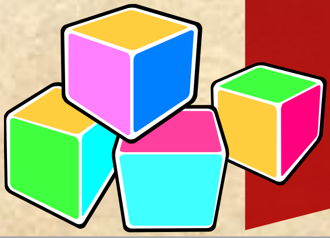
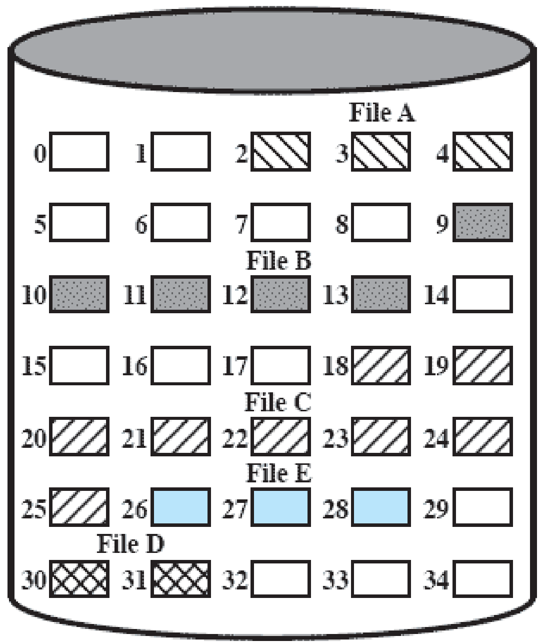


Table 12.3
File Allocation Methods

	Contiguous	Chained	Indexed	
Preallocation?	Necessary	Possible	Possible	
Fixed or variable size portions?	Variable	Fixed blocks	Fixed blocks	Variable
Portion size	Large	Small	Small	Medium
Allocation frequency	Once	Low to high	High	Low
Time to allocate	Medium	Long	Short	Medium
File allocation table size	One entry	One entry	Large	Medium

Contiguous File Allocation

- A single contiguous set of blocks is allocated to a file at the time of file creation
- Preallocation strategy using variable-size portions
- Is the best from the point of view of the individual sequential file



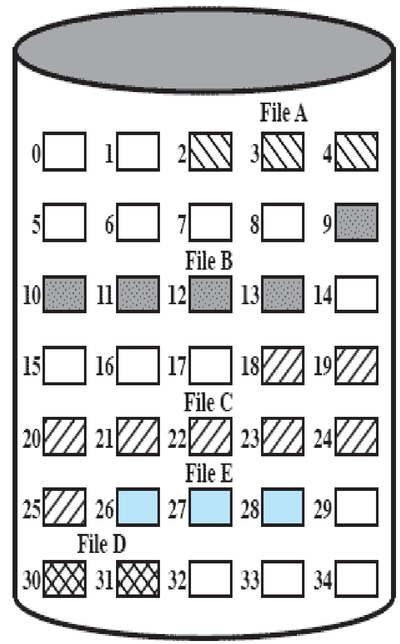
File Allocation Table

File Name	Start Block	Length
File A	2	3
File B	9	5
File C	18	8
File D	30	2
File E	26	3

Figure 12.9 **Contiguous File Allocation**

Contiguous File Allocation

- Contiguous allocation presents some problems.
- External fragmentation will occur, making it difficult to find contiguous blocks of space of sufficient length.
- From time to time, it will be necessary to perform a compaction algorithm to free up additional space on the disk



File Allocation Table

File Name	Start Block	Length
File A	2	3
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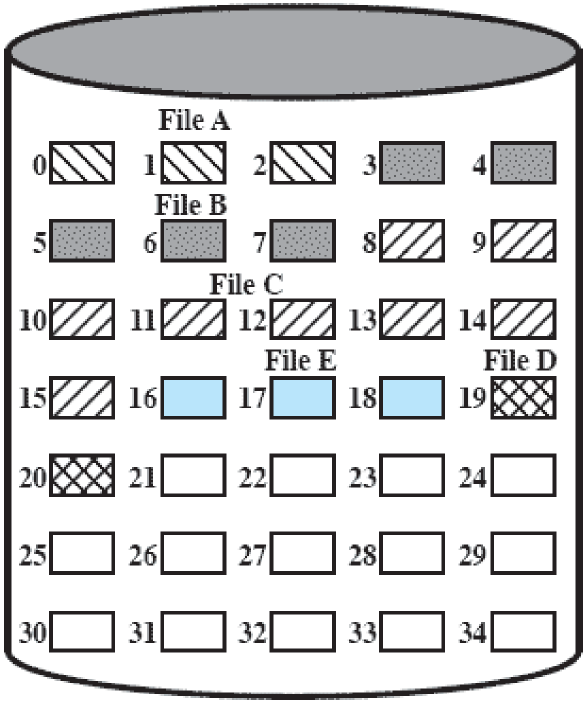
File E	26	3

12.9

Figure 12.7 Contiguous File Allocation

After Compaction



File Allocation Table

File Name	Start Block	Length
File A	0	3
File B	3	5
File C	8	8
File D	19	2
File E	16	3

Figure 12.10 Contiguous File Allocation (After Compaction)

Chained Allocation

- Allocation is on an individual block basis
- Each block contains a pointer to the next block in the chain
- The file allocation table needs just a single entry for each file
- No external fragmentation to worry about
- Better for sequential files

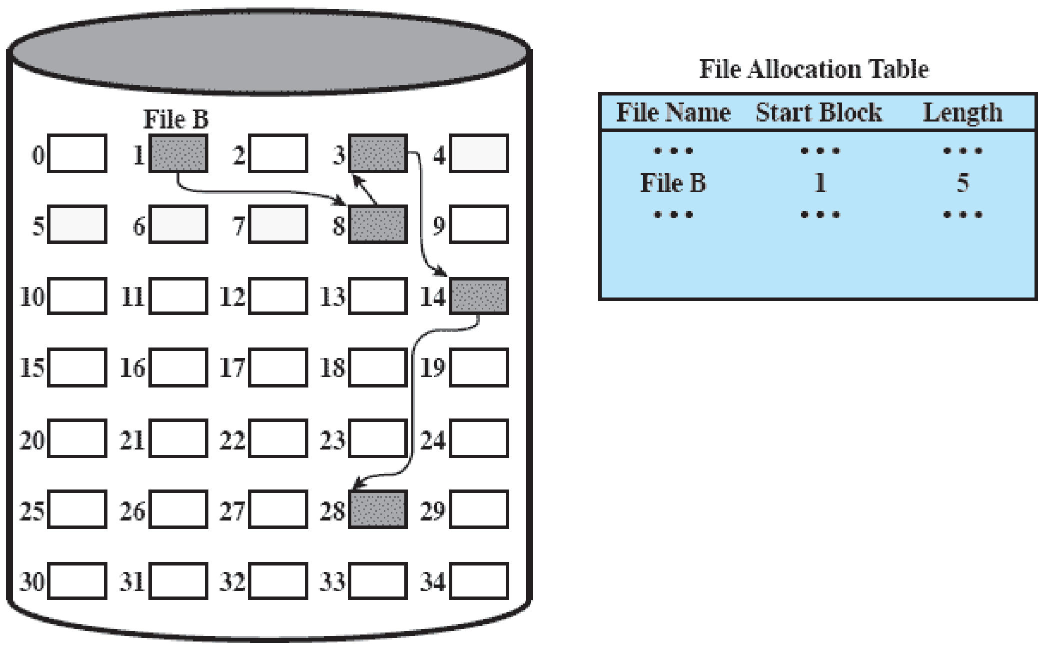
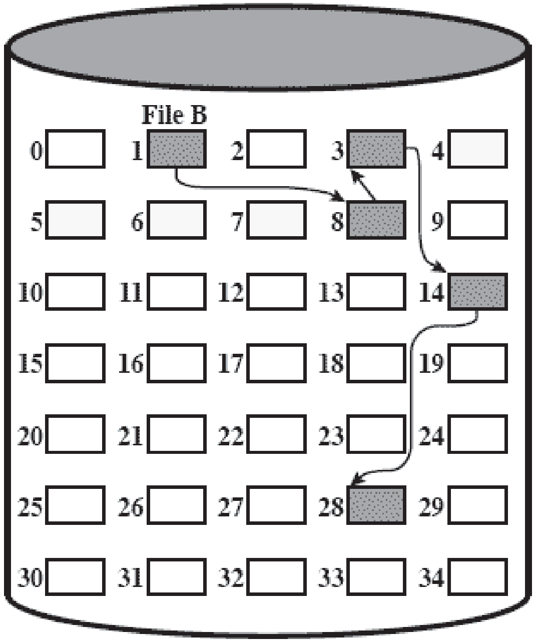


Figure 12.11 **Chained Allocation**

Chained Allocation

- One consequence of chaining, as described so far, is that there is no accommodation of the principle of locality.
- To overcome this problem
- Some systems periodically consolidate files

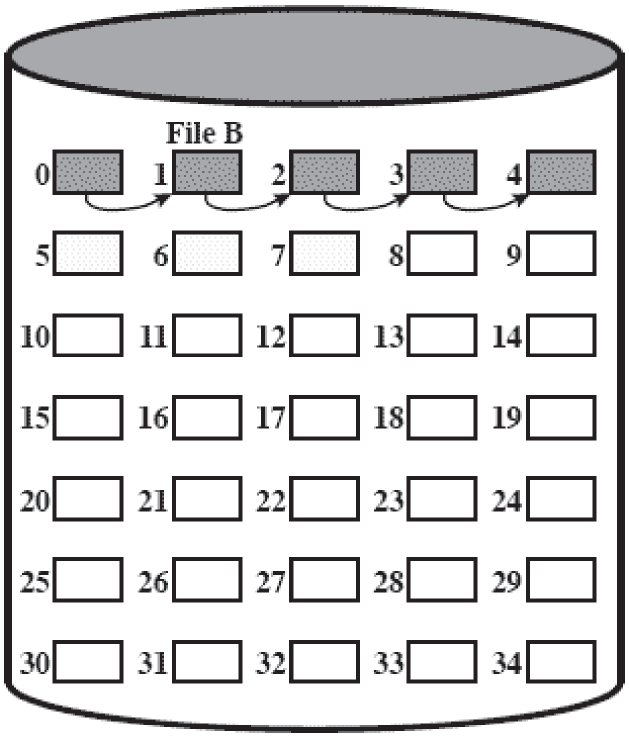


File Allocation Table

File Name	Start Block	Length
• • •	• • •	• • •
File B	1	5
• • •	• • •	• • •

Figure 12.11 **Chained Allocation**

Chained Allocation After Consolidation



File Allocation Table

File Name	Start Block	Length
• • •	• • •	• • •
File B	0	5
• • •	• • •	• • •

Figure 12.12 **Chained Allocation (After Consolidation)**

Indexed Allocation with Block Portions

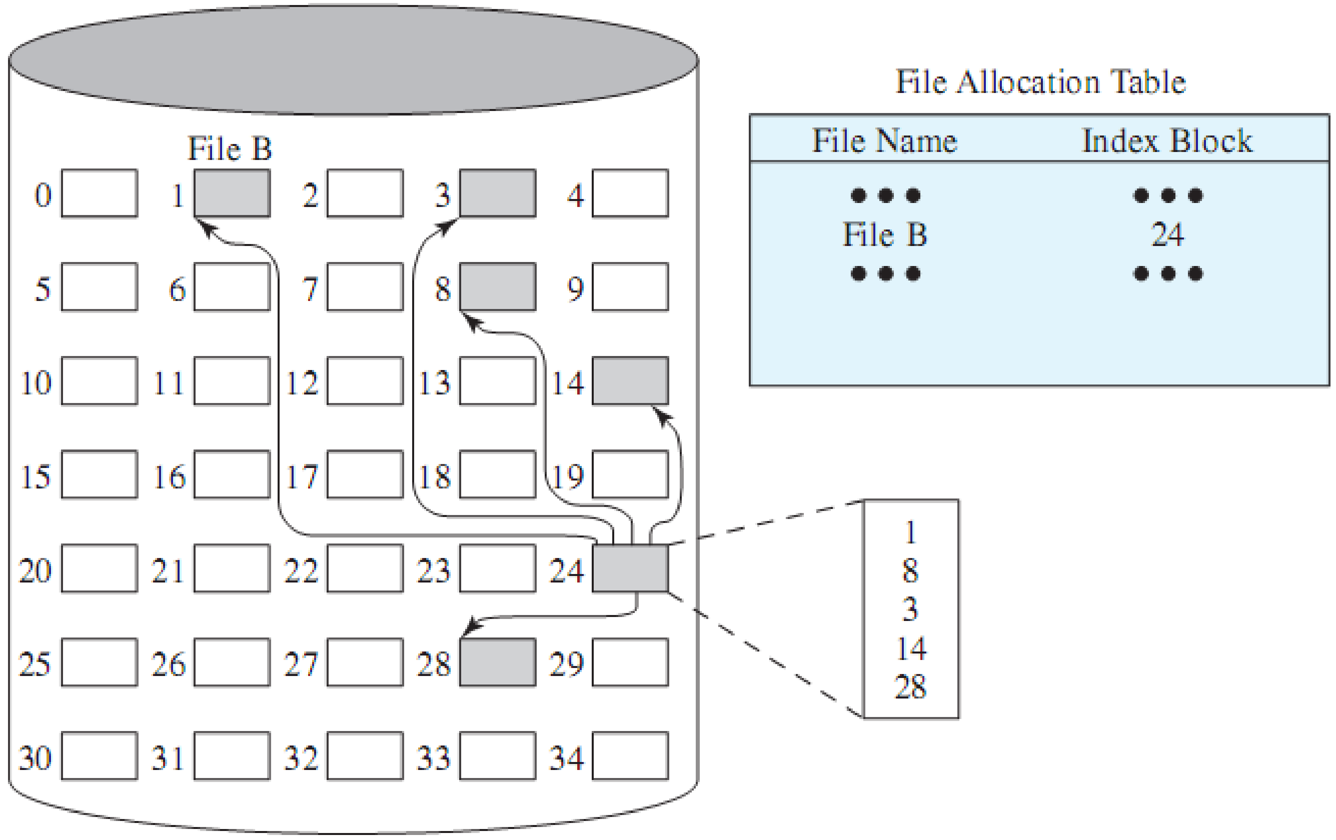


Figure 12.13 **Indexed Allocation with Block Portions**

Indexed Allocation with Block Portions

- In this case, the file allocation table contains a separate one-level index for each file
- The index has one entry for each portion allocated to the file.
- File index for a file is kept in a separate block, and the entry for the file in the file allocation table points to that block

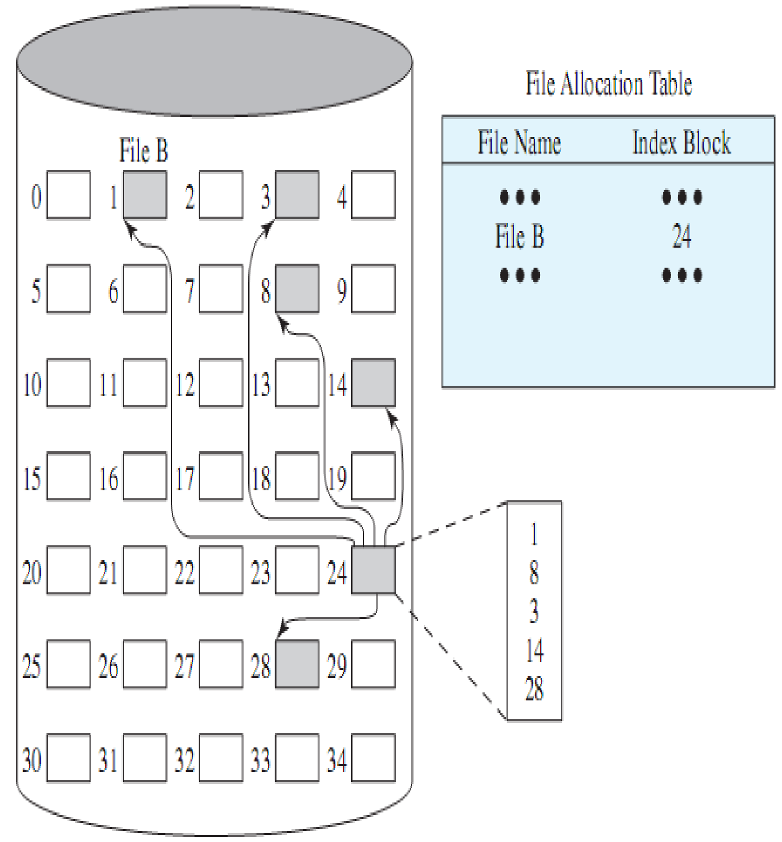


Figure 12.11 Indexed Allocation with Block Portions

Indexed Allocation with Variable Length Portions

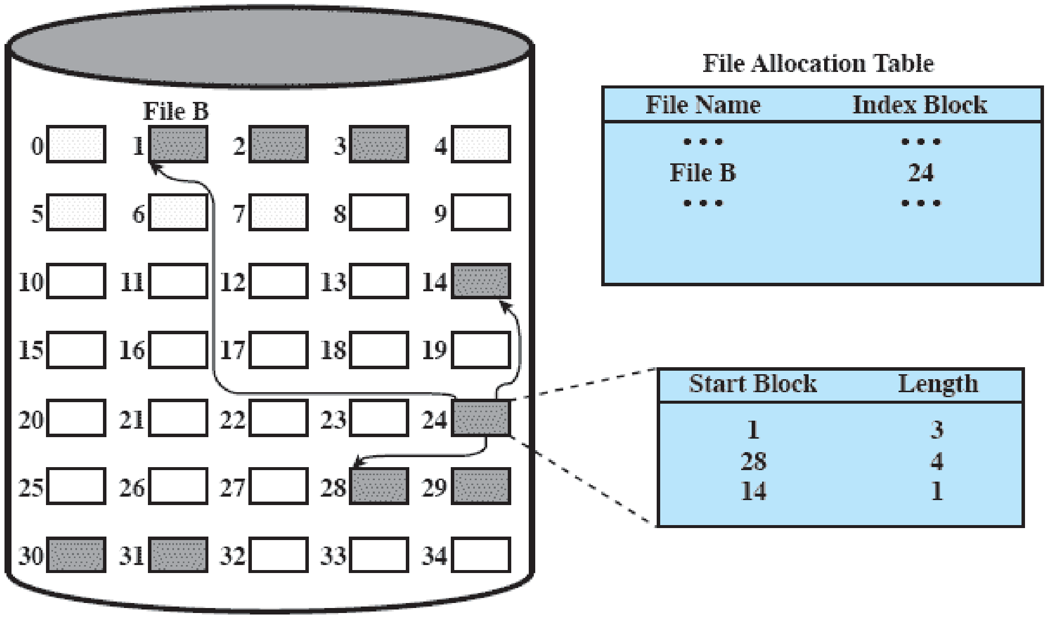


Figure 12.14 **Indexed Allocation with Variable-Length Portions**

Free Space Management

- Just as allocated space must be managed, so must the unallocated space
- To perform file allocation, it is necessary to know which blocks are available
- A ***disk allocation table*** is needed in addition to a file allocation table

Bit Tables (Bit Vectors)

- This method uses a vector containing one bit for each block on the disk
- Each entry of a 0 corresponds to a free block, and each 1 corresponds to a block in use

Advantages:

- works well with any file allocation method
- it is as small as possible

Bit Tables (Bit Vectors)

- For the disk layout of Figure 12.9 , A vector of length 35 is needed and would have the following value:
- 00111000011111000011111111111011000

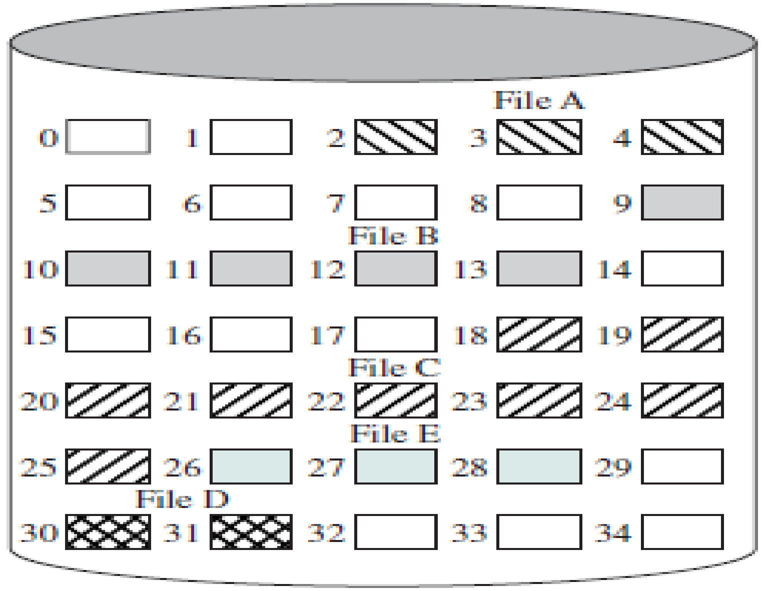


Figure 12.9 **Contiguous File Allocation**

Chained Free Portions

- The free portions may be chained together by using a pointer and length value in each free portion
- Negligible space overhead because there is no need for a disk allocation table
- Suited to all file allocation methods

Disadvantages:

- leads to fragmentation
- every time you allocate a block you need to read the block first to recover the pointer to the new first free block before writing data to that block

Indexing

- Treats free space as a file and uses an index table as it would for file allocation
- For efficiency, the index should be on the basis of variable-size portions rather than blocks
- This approach provides efficient support for all of the file allocation methods

Free Block List

Each block is assigned a number sequentially

- the list of the numbers of all free blocks is maintained in a reserved portion of the disk

Depending on the size of the disk, either 24 or 32 bits will be needed to store a single block number

- the size of the free block list is 24 or 32 times the size of the corresponding bit table and must be stored on disk

There are two effective techniques for storing a small part of the free block list in main memory:

- the list can be treated as a push-down stack with the first few thousand elements of the stack kept in main memory
- the list can be treated as a FIFO queue, with a few thousand entries from both the head and the tail of the queue in main memory

Review

- File systems can support files organized as a sequence of bytes or as a sequence of records
- Access methods depend on file organization
- Disk storage of files can be contiguous, linked or indexed
- Logical blocks of a file are mapped to one or more disk sectors to create physical blocks.
- File Allocation Tables map files to disk locations

UNIX File Management

- In the UNIX file system, six types of files are distinguished:

Regular, or ordinary

- contains arbitrary data in zero or more data blocks
- Regular files contain information entered in them by a user, an application
- program, or a system utility program.

Directory

- contains a list of file names plus pointers to associated inodes (index nodes)

Special

- Contains no data but provides a mechanism to map physical devices to file names
- The file names are used to access peripheral devices, such as terminals and printers.
- Each I/O device is associated with a special file

UNIX File Management

- In the UNIX file system, six types of files are distinguished:

Named pipes

- An interprocess communications facility
- A pipe file buffers data received in its input so that a process
- that reads from the pipe's output receives the data on a first-in-first-out basis.

Links

- An alternative file name for an existing file

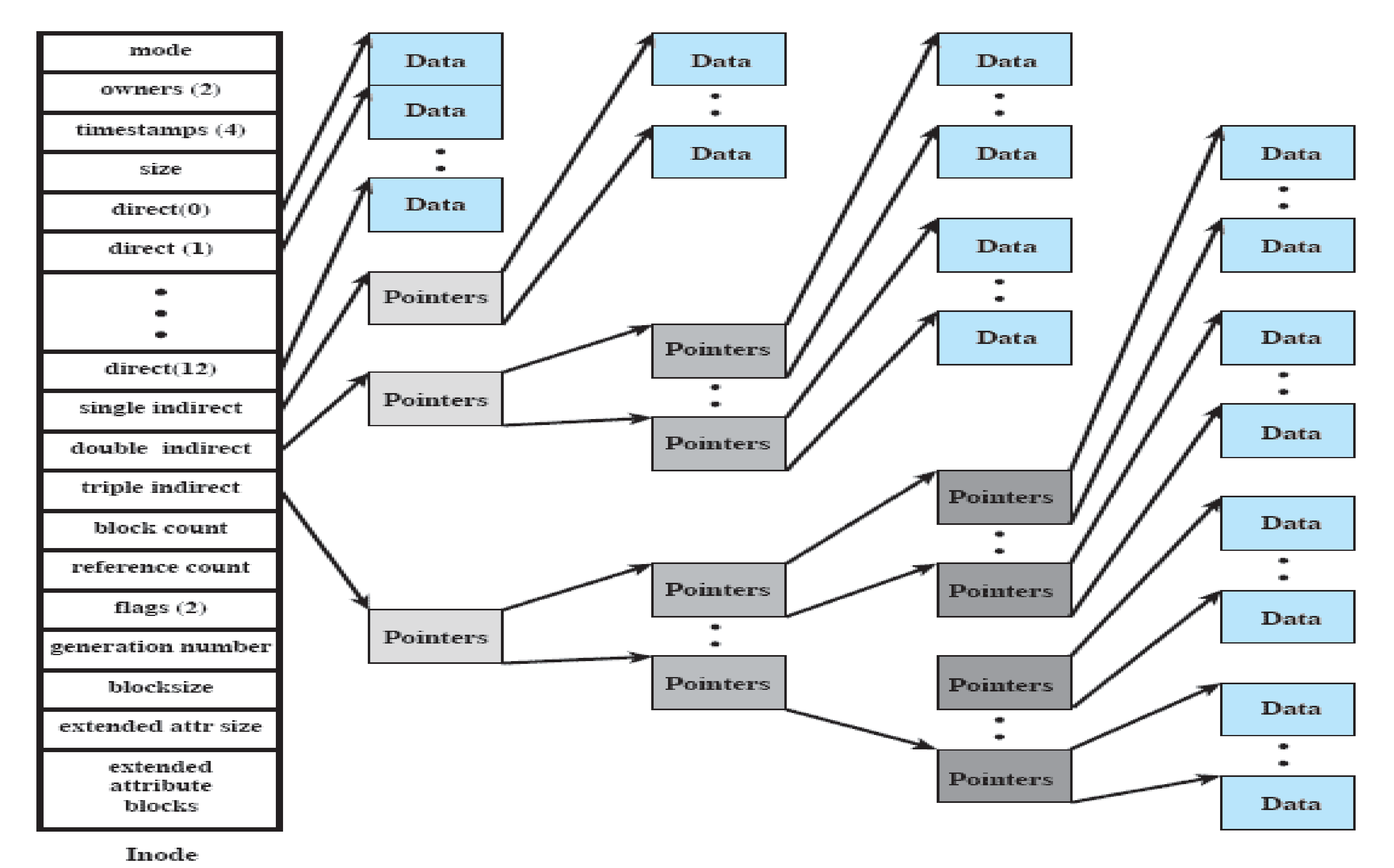
Symbolic links

- A data file that contains the name of the file it is linked to

Inodes

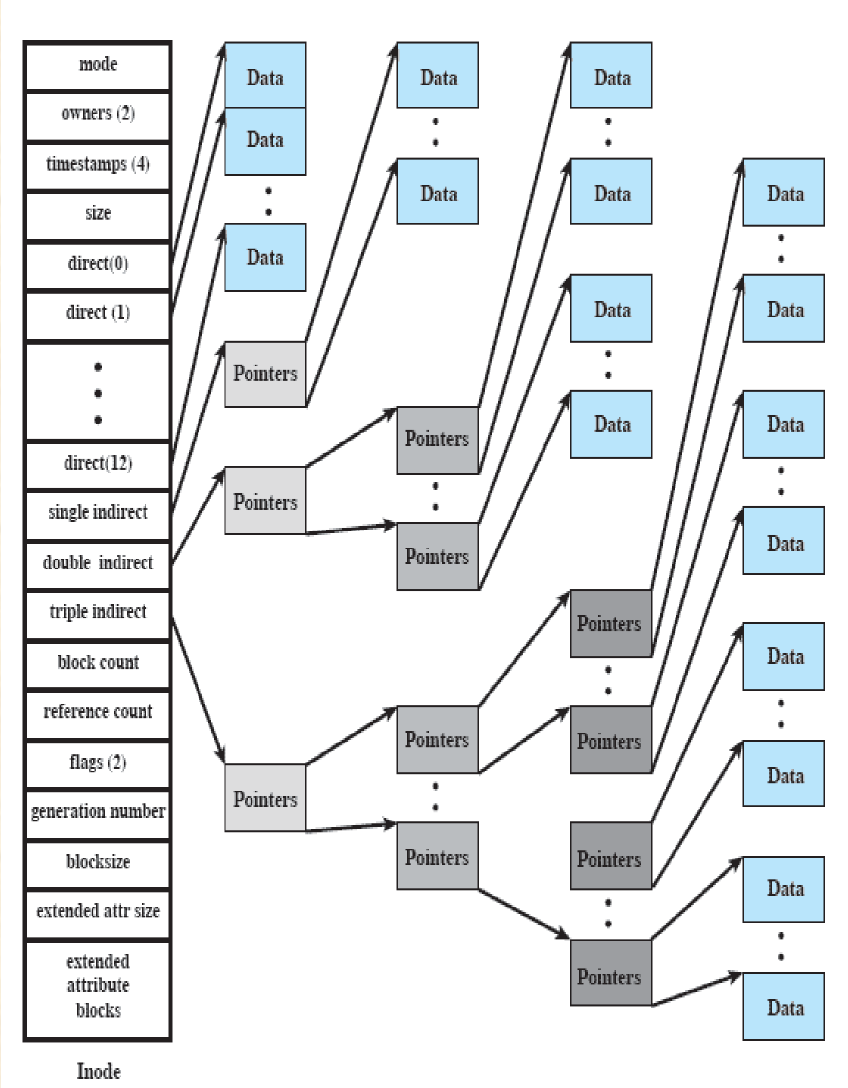
- Modern UNIX operating systems support multiple file systems but map all of these into a uniform underlying system for supporting file systems and allocating disk space to files. All types of UNIX files are administered by the OS by means of inodes.
- An inode (index node) is a control structure that contains the key information needed by the operating system for a particular file
- Several file names may be associated with a single inode
  - an active inode is associated with exactly one file
  - each file is controlled by exactly one inode

FreeBSD Inode and File Structure



FreeBSD Inode and File Structure

- The exact inode structure varies from one UNIX implementation to another.



FreeBSD Inode and File Structure

The FreeBSD inode structure, includes the following data elements:

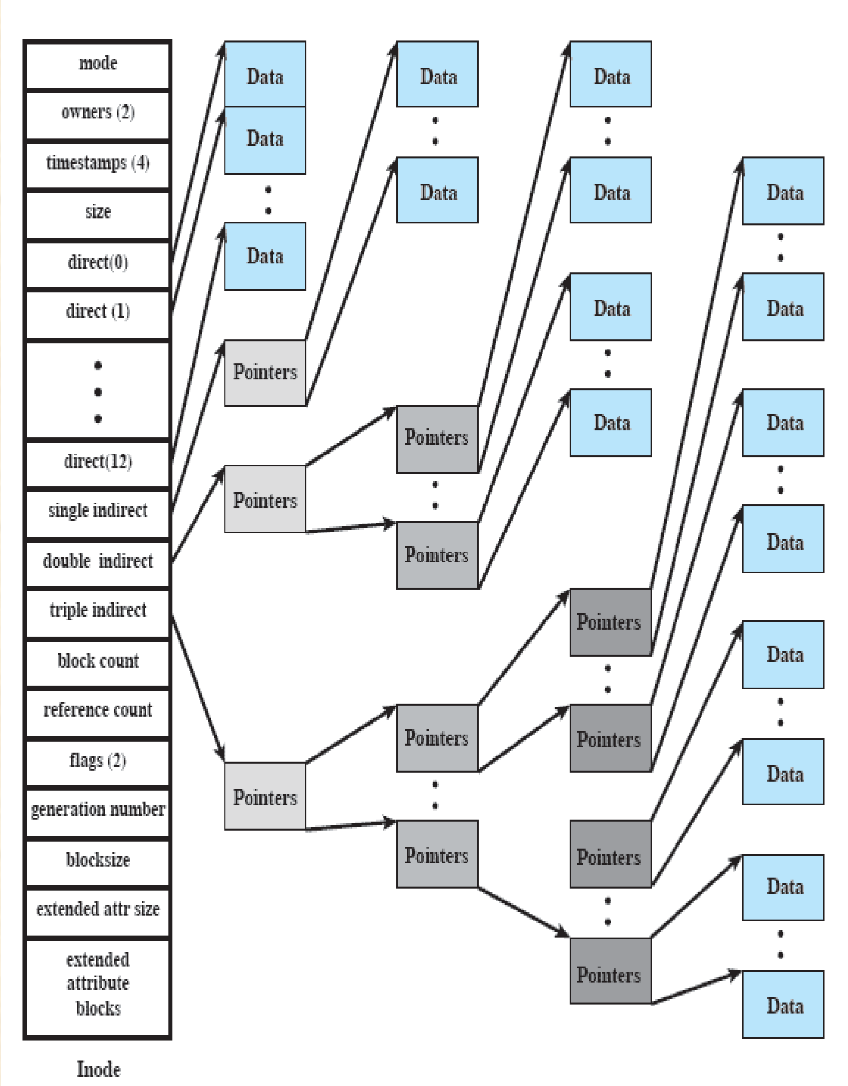
- The type and access mode of the file

- The file's owner and group-access identifiers

- The time that the file was created, when it was most recently read and written,and when its inode was most recently updated by the system

- The size of the file in bytes

- A sequence of block pointers, explained in the next subsection



FreeBSD Inode and File Structure

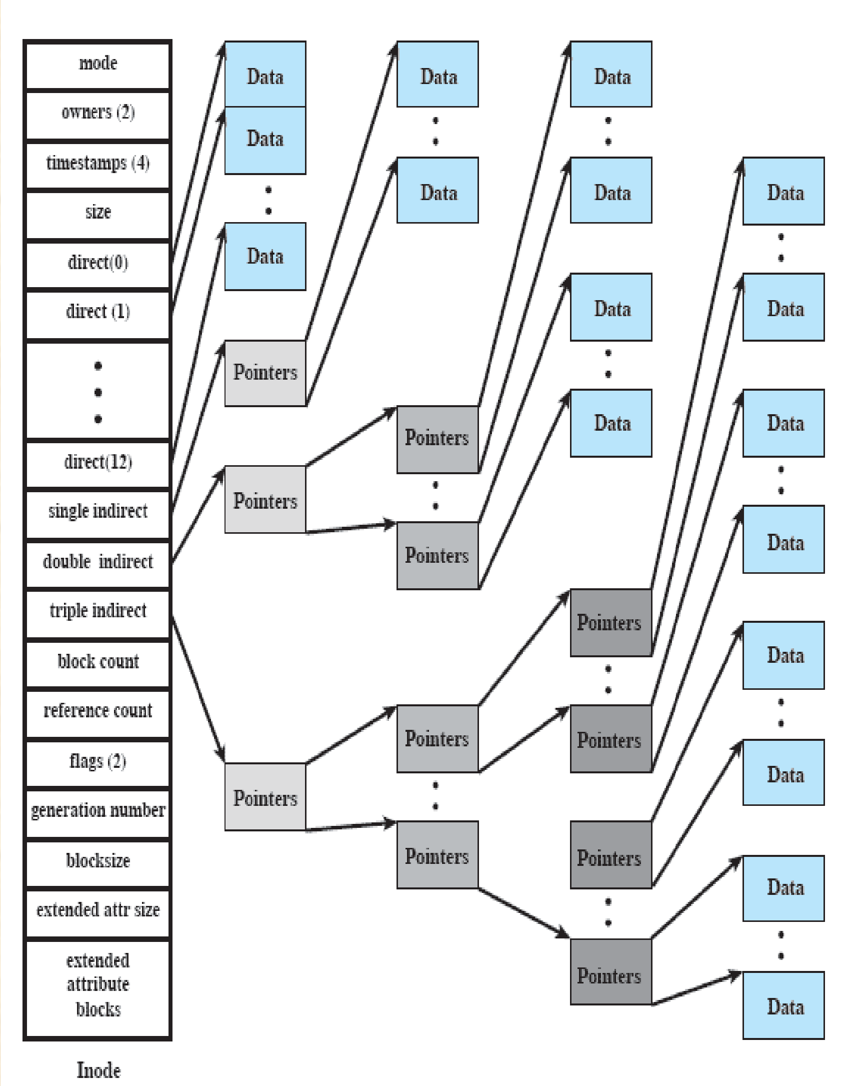
- The number of physical blocks used by the file

- The number of directory entries that reference the file

- The kernel and user-settable flags that describe the characteristics of the file

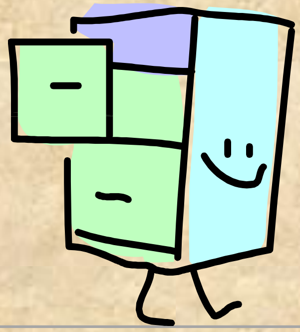
- The generation number of the file (a randomly selected number assigned to the inode, each time that the latter is allocated to a new file;

- The blocksize of the data blocks referenced by the inode



File Allocation

- File allocation is done on a block basis
- Allocation is dynamic, as needed, rather than using preallocation
- An indexed method is used to keep track of each file, with part of the index stored in the inode for the file
- In all UNIX implementations the inode includes a number of direct pointers and three indirect pointers (single, double, triple)



UNIX Directories and Inodes

- Directories are structured in a hierarchical tree
- Each directory can contain files and/or other directories
- A directory that is inside another directory is referred to as a subdirectory

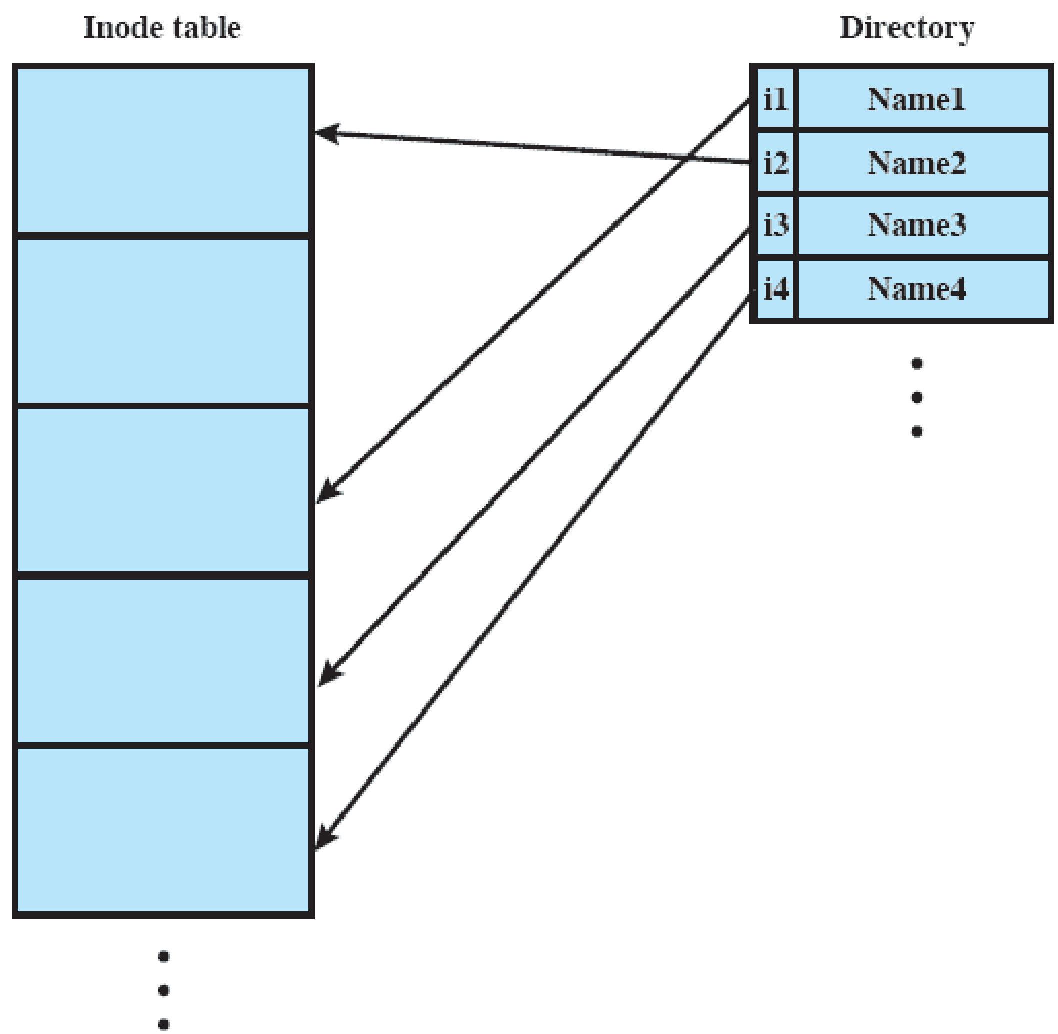


Figure 12.17 UNIX Directories and Inodes

UNIX Directories and Inodes

- A directory is simply a file that contains
- a list of file names plus pointers to associated inodes.

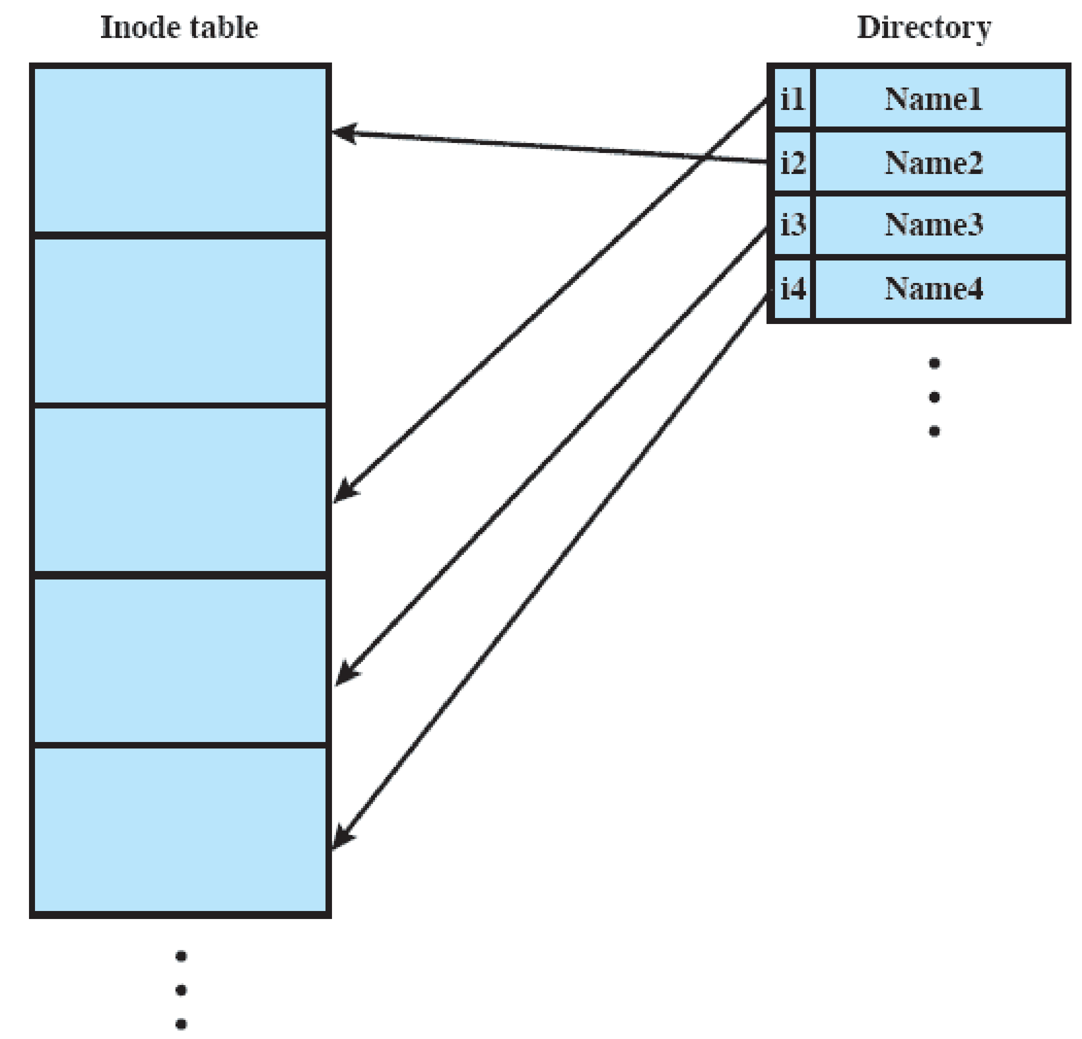


Figure 12.17 UNIX Directories and Inodes

UNIX Directories and Inodes

- Each directory entry (dentry) contains a name for the associated file or subdirectory plus an integer called the i-number (index number).
- When the file or directory is accessed, its i-number is used as an index into the inode table.

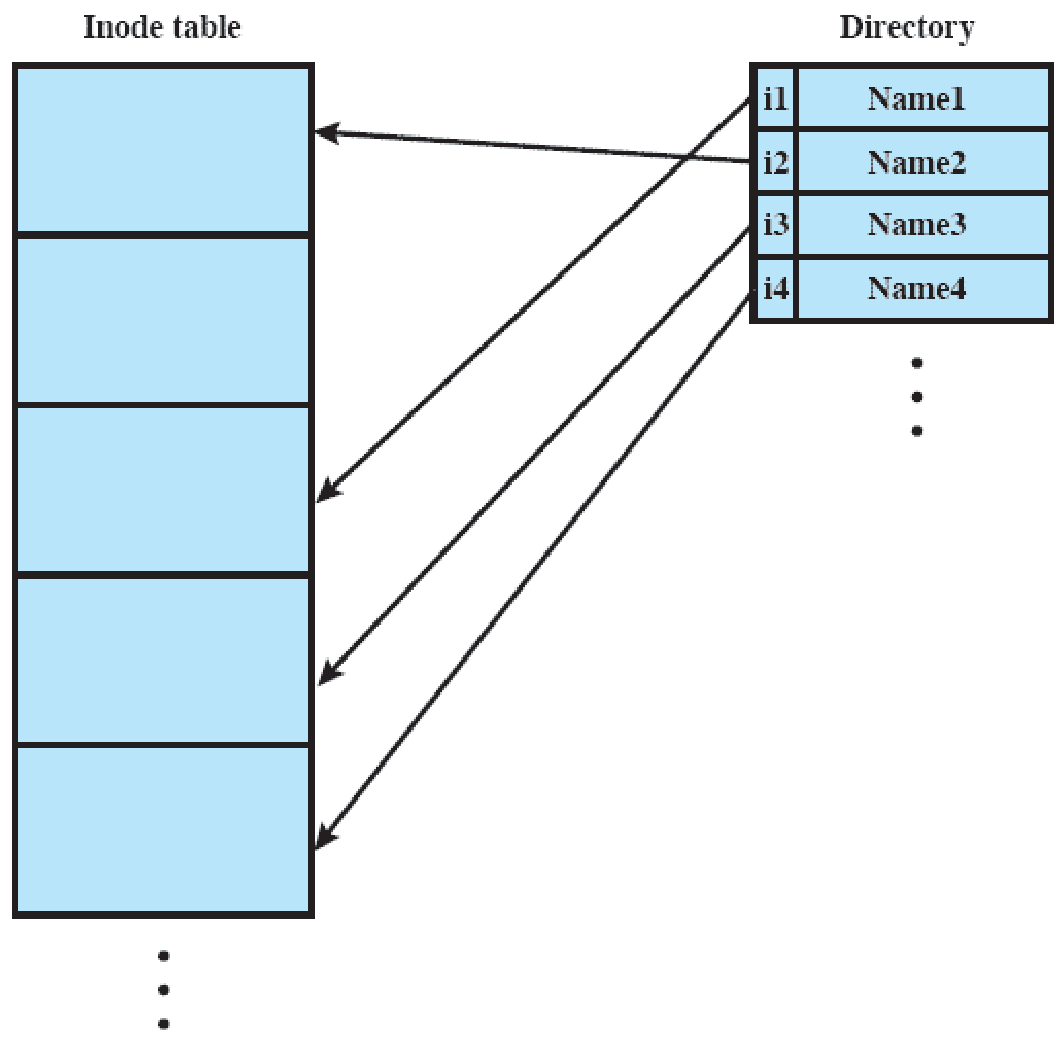


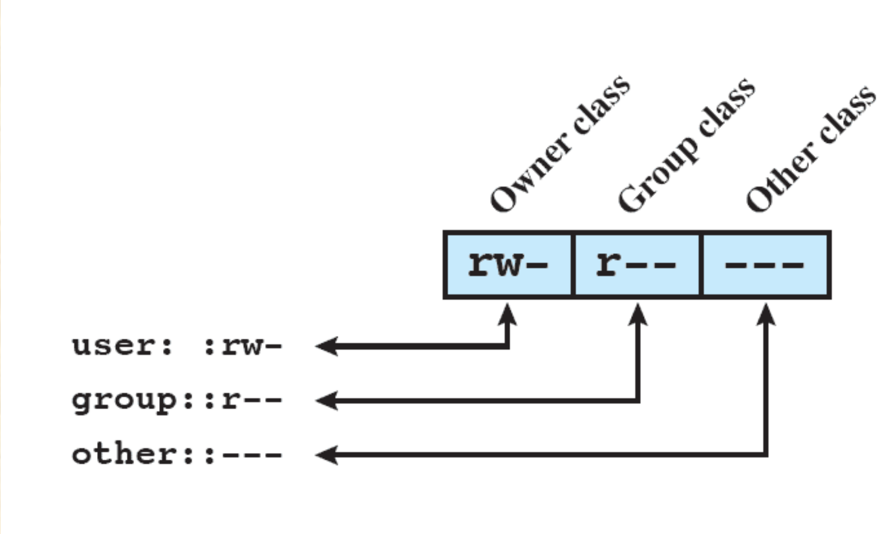
Figure 12.17 UNIX Directories and Inodes

Volume Structure

- A UNIX file system resides on a single logical disk or disk partition and is laid out with the following elements:

Boot block	Superblock	Inode table	Data blocks
contains code required to boot the operating system	contains attributes and information about the file system	collection of inodes for each file	storage space available for data files and subdirectories

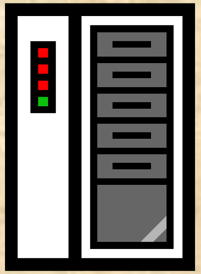
UNIX File Access Control

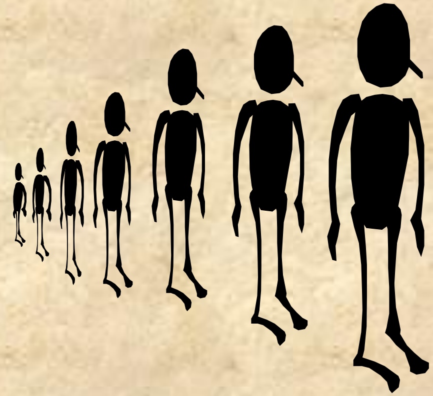


(a) Traditional UNIX approach (minimal access control list)

Access Control Lists in UNIX

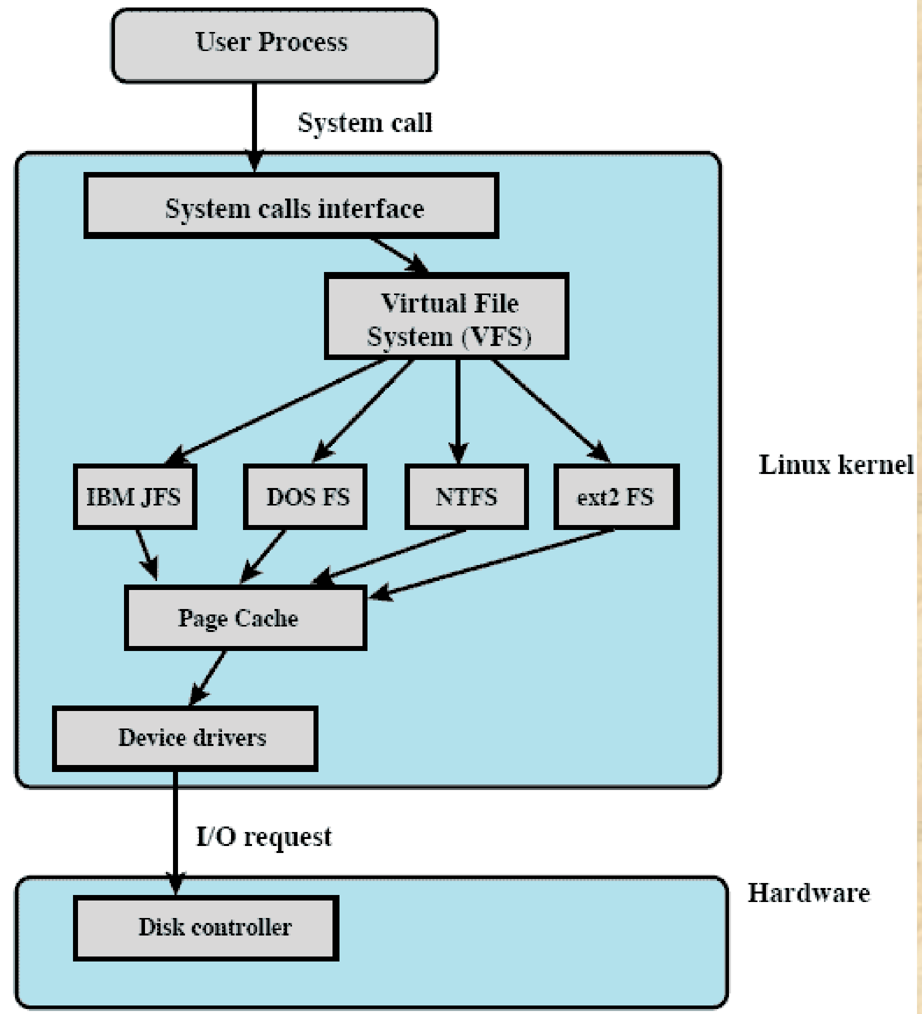
- FreeBSD allows the administrator to assign a list of UNIX user IDs and groups to a file
- Any number of users and groups can be associated with a file, each with three protection bits (read, write, execute)
- A file may be protected solely by the traditional UNIX file access mechanism
- FreeBSD files include an additional protection bit that indicates whether the file has an extended ACL





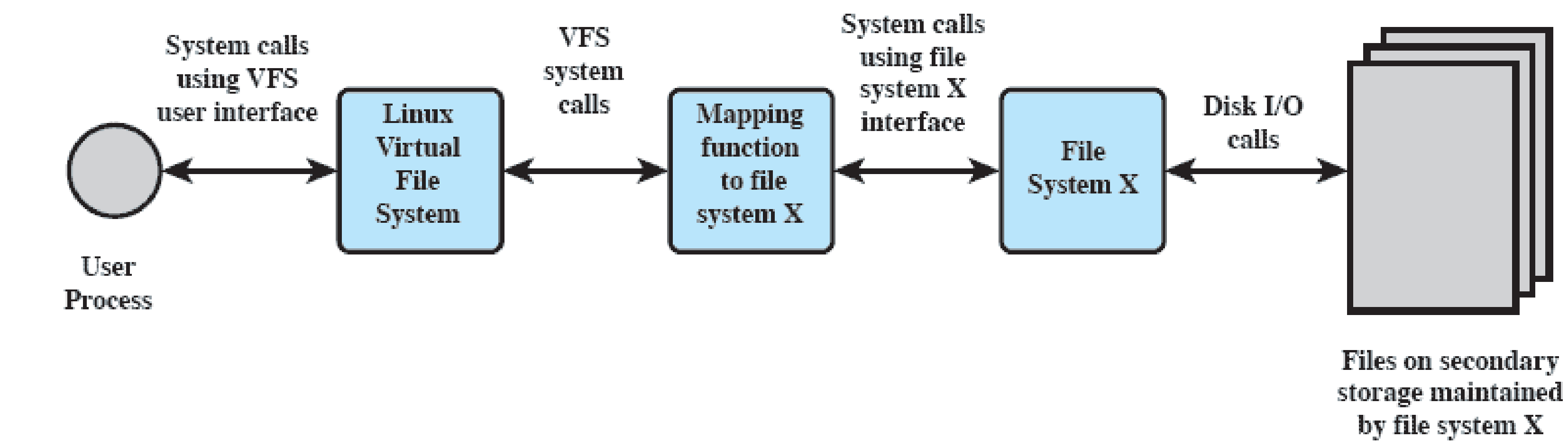
Linux Virtual File System (VFS)

- Linux includes a versatile and powerful file-handling facility, designed to support a wide variety of file management systems and file structures.
- Presents a single, uniform file system interface to user processes
- Defines a common file model that is capable of representing any conceivable file system's general feature and behavior
- Assumes files are objects that share basic properties regardless of the target file system or the underlying processor hardware



Linux Virtual File System Context

The Role of VFS Within the Kernel



Linux Virtual File System Concept

Primary Object Types in VFS

Superblock Object

- represents a specific mounted file system

Dentry Object

- represents a specific directory entry

Inode Object

- represents a specific file

File Object

- represents an open file associated with a process