Operating System

Chapter 11. I/O Management and Disk Scheduling

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Categories of I/O Devices

- **I/O devices can be grouped into 3 categories**
  - Human readable devices
    - Suitable for communicating with the computer user
    - Printers, terminals, video display, keyboard, mouse
  - Machine readable devices
    - Suitable for communicating with electronic equipment
    - Disk drives, USB devices, sensors, controllers
  - Communication devices
    - Suitable for communicating with remote devices
    - Modems, digital line drivers

Data Rates

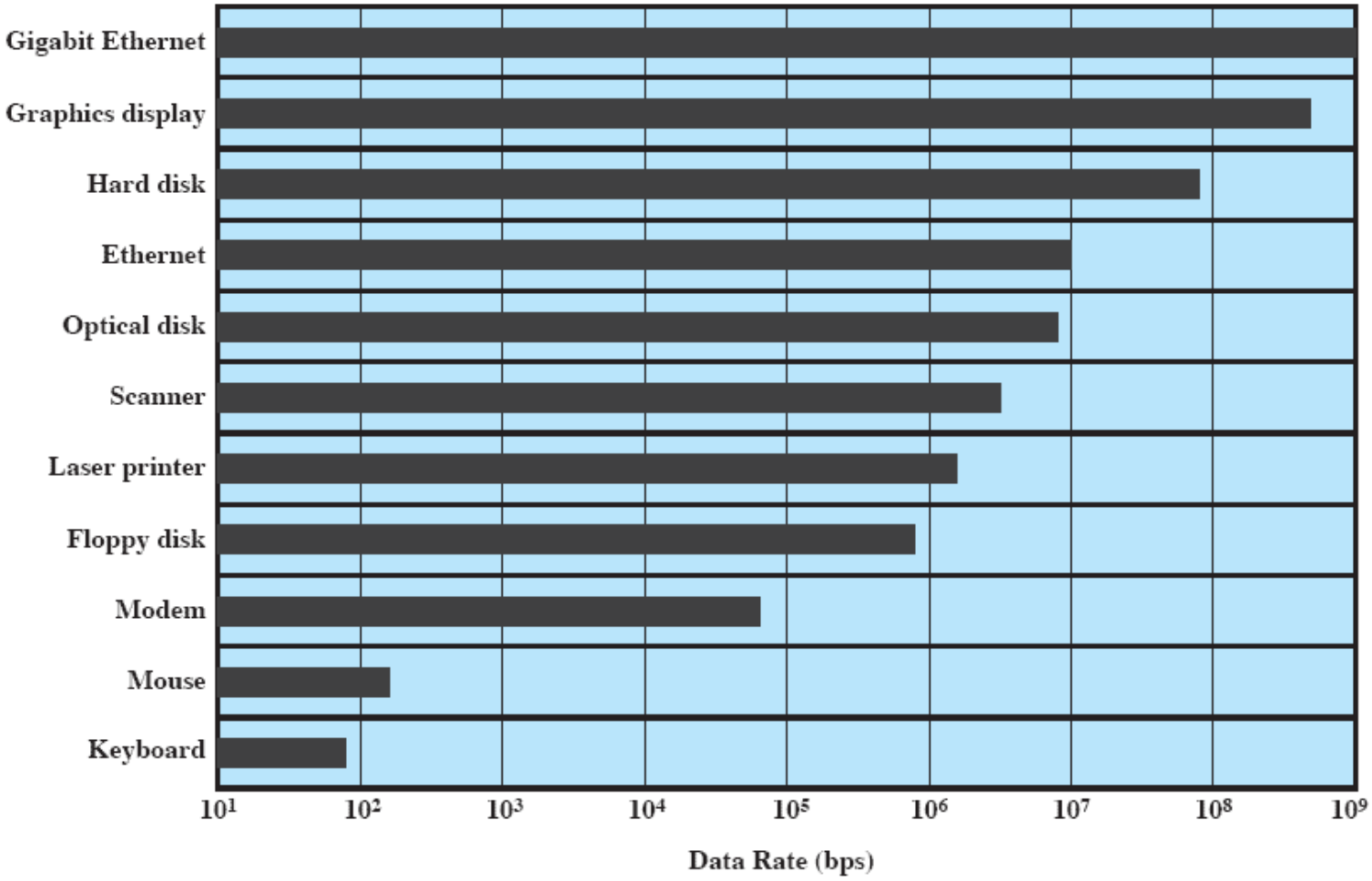


Figure 11.1 Typical I/O Device Data Rates

Source: Pearson

Organization of I/O Function

- **Three techniques for performing I/O are**
- **Programmed I/O**
  - The processor issues an I/O command on behalf of a process to an I/O module; that process then busy waits for the operation to be completed before proceeding
- **Interrupt-driven I/O**
  - The processor issues an I/O command on behalf of a process
    - If non-blocking – processor continues to execute instructions from the process that issued the I/O command
    - If blocking – the next instruction the processor executes is from the OS, which will put the current process in a blocked state and schedule another process
- **Direct Memory Access (DMA)**
  - The processor sends a request for a block transfer to the DMA module, which then controls the exchange of data between main memory and an I/O module. After the transfer, the DMA module interrupts the processor.

Techniques for Performing I/O

Table 11.1 I/O Techniques

	No Interrupts	Use of Interrupts
I/O-to-memory transfer through processor	Programmed I/O	Interrupt-driven I/O
Direct I/O-to-memory transfer		Direct memory access (DMA)

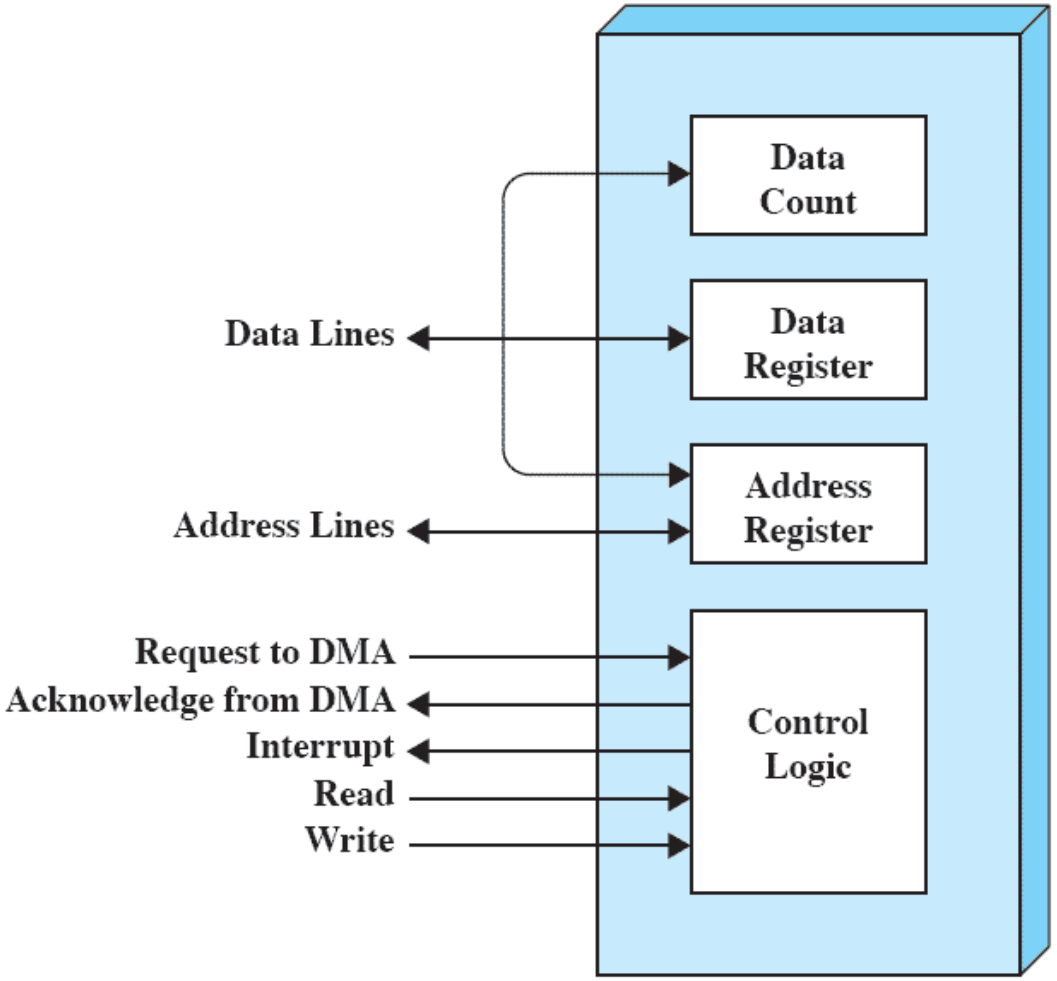
Source: Pearson

Evolution of I/O Function

- *Processor directly controls a peripheral device*
- *Programmed I/O without interrupt*
  - An I/O controller or I/O module is added
- *Programmed I/O with interrupt*
  - Same configuration as step 2, but now interrupts are employed
- *DMA*
  - The I/O module is given direct control of memory via DMA
- *I/O channel*
  - The I/O module is enhanced to become a separate processor, with a specialized instruction set tailored for I/O
- *I/O processor*
  - The I/O module has a local memory of its own and is, in fact, a computer in its own right

DMA Block Diagram

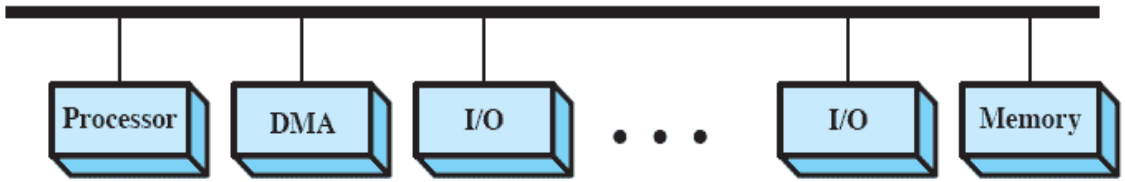
- *Processor issues a command to DMA module with the following information*
  - Read or Write
  - The address of IO device
  - The starting address of memory
  - The number of words to transfer
- *DMA module transfers the entire block and after completion, it interrupts the processor*



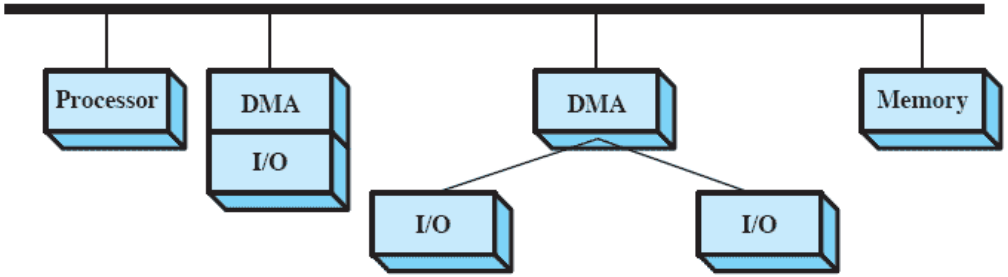
Source: Pearson

Figure 11.2 Typical DMA Block Diagram

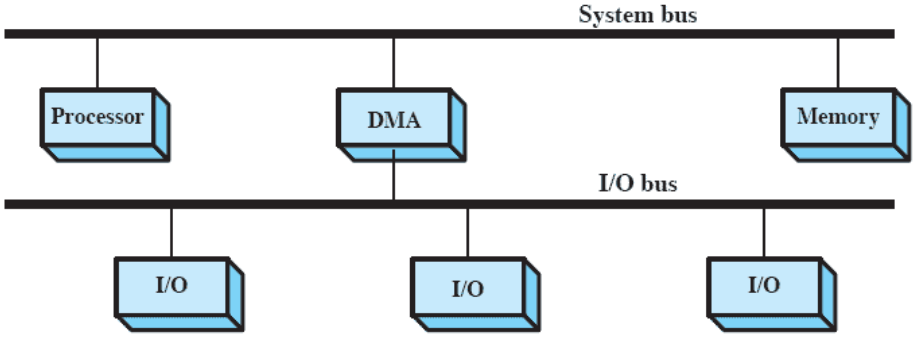
DMA Alternative Configurations



(a) Single-bus, detached DMA



(b) Single-bus, Integrated DMA-I/O



(c) I/O bus

Source: Pearson

Design Objectives

Efficiency

- Major effort in I/O design
- Important because I/O operations often form a bottleneck
- Most I/O devices are extremely slow compared with main memory and the processor
- The area that has received the most attention is disk I/O

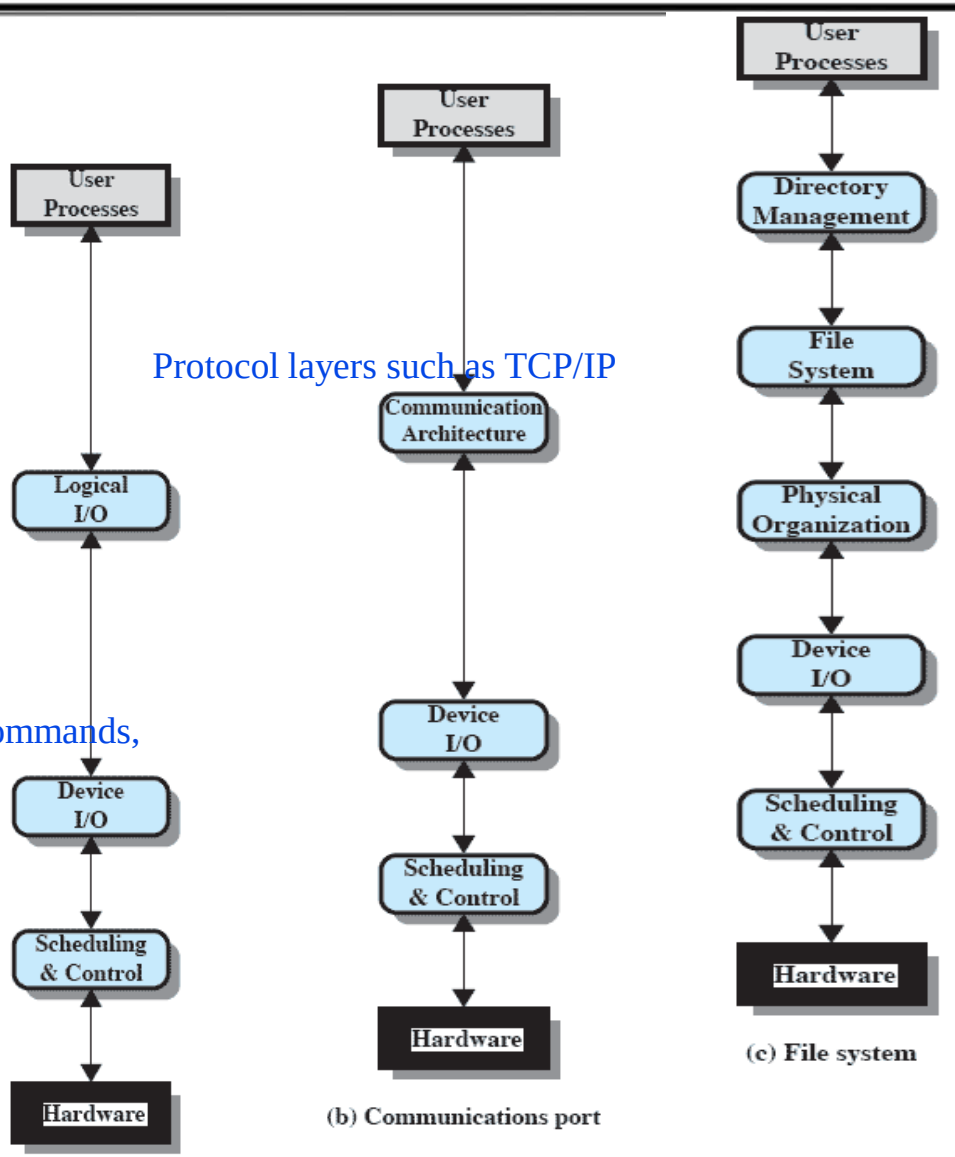
Generality

- Desirable to handle all devices in a uniform manner
- The way processes view I/O devices and the way the operating system manages I/O devices and operations
- Hide the details of device I/O so that user processes and upper levels of OS see devices in terms of general functions such as read, write, open, and close
- Diversity of devices makes it difficult to achieve true generality

Hierarchical Design

- **Hierarchical nature of modern operating systems**
  - Operating system functions should be separated according to their complexity, timescale, and their level of abstraction
  - Leads to an OS organization into a series of layers
  - Each layer performs a related subset of the functions and relies on the next lower layer to perform more primitive functions and to conceal the details of those functions. It provides services to the next higher layer.
  - Layers should be defined so that changes in one layer do not require changes in other layers

A Model of I/O Organization



Protocol layers such as TCP/IP

open, close, read, write

I/O instructions, channel commands, buffering techniques

interrupts, scheduling, and queuing

symbolic file names are converted to identifiers add, delete

open, close, read, write

logical reference to files are converted to physical addresses (track, sector)

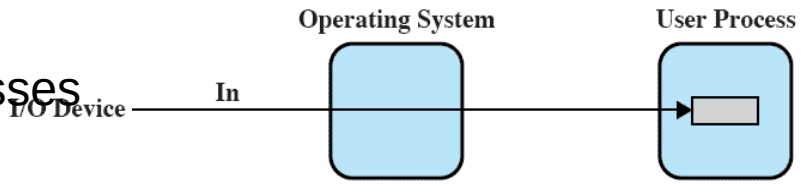
Source: Pearson

Buffering

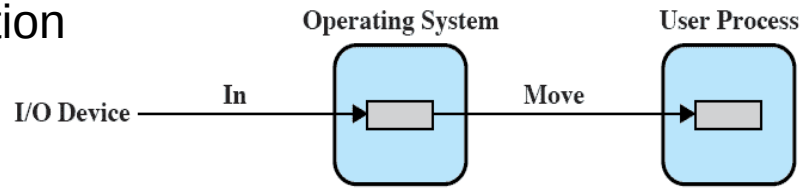
- **Perform data transfers in advance of requests**
  - For both inputs and outputs
  - Can reduce time waiting for I/O to complete
  - Also, avoid I/O interferences with OS swapping decisions
- **Block-oriented device**
  - Stores information in blocks that are usually of fixed size
  - Transfers are made one block at a time
  - Possible to reference data by its block number
  - Disks and USB devices are examples
- **Stream-oriented device**
  - Transfers data as a stream of bytes
  - No block structure
  - Terminals, printers, keyboards, mouse, communications ports, and most other devices that are not secondary storage are examples

I/O Buffering Schemes

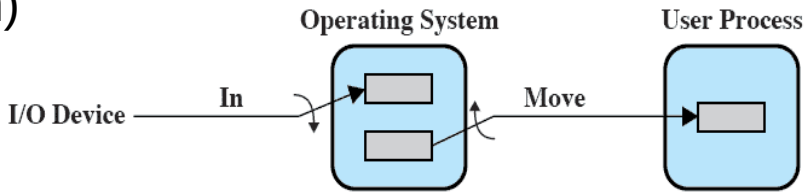
- **No buffering**
  - Without a buffer, the OS directly accesses the device when it needs
- **Single buffering**
  - OS assigns a buffer in the system portion of main memory
- **Double buffering**
  - Use two system buffers
  - A process can transfer data to (or from) one buffer while the operating system empties (or fills) the other buffer
  - Also known as buffer swapping
- **Circular buffering**
  - When more than two buffers are used, the collection of buffers is a circular buffer
  - Each individual buffer is one unit in a circular buffer



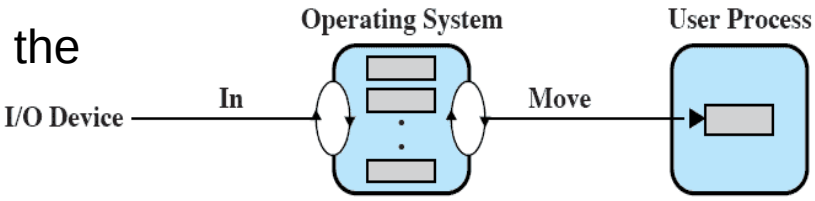
(a) No buffering



(b) Single buffering



(c) Double buffering



(d) Circular buffering

Source: Pearson

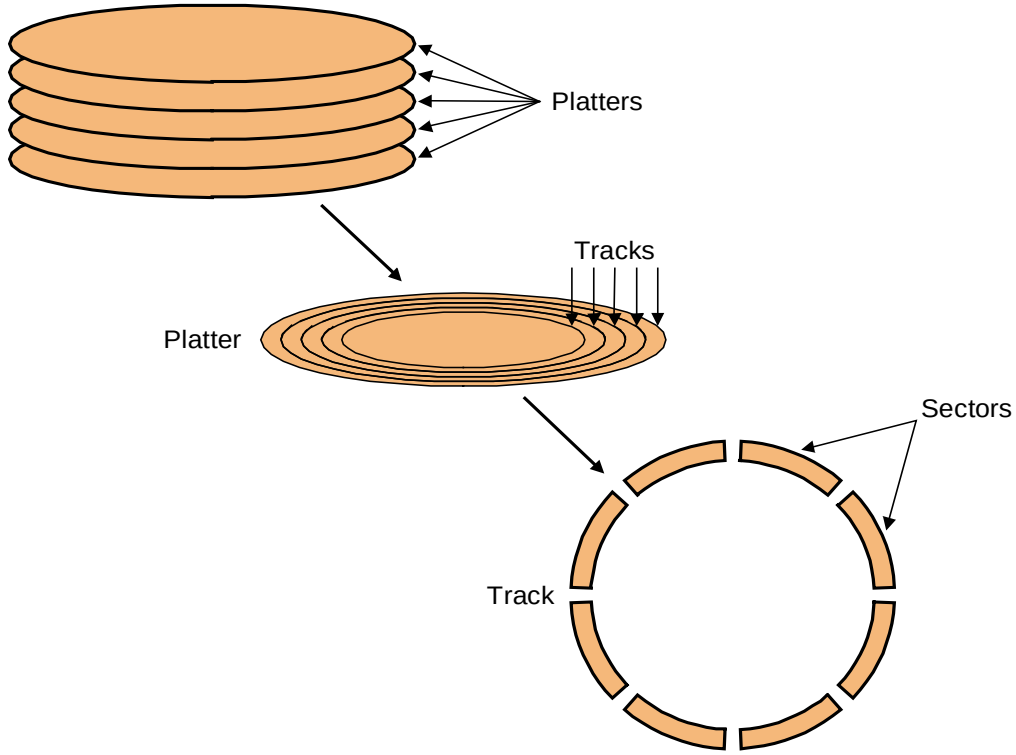
Single Buffering

- **For block-oriented devices**
  - Input transfers are made to the system buffer
  - When the transfer is complete, the process moves the block into user space and immediately requests another block
  - Can speed up I/O since data are usually accessed sequentially
- **For stream-oriented devices**
  - Line-at-a-time operation
    - Used for dumb terminals or line printers
    - User input is one line at a time with a carriage return
    - Output to the terminal is similarly one line at a time
  - Byte-at-a-time operation
    - Used on forms-mode terminals, sensors and controllers
    - When each keystroke is significant

Magnetic Disk

- **A magnetic disk consists of a collection of platters, each of which has two recordable surfaces.**
  - The stack of flatters rotate at 5400 RPM to 15000 RPM
  - The diameter of this aluminum platter is from 3 ~ 12 cm

- **Read/write heads**
  - To read or write, the read/write heads must be moved so that they are over the right track
  - Disk heads for each surface are connected together and move in conjunction



Magnetic Disk

- **Cylinder: a set of tracks at a given radial position**
  - All the tracks under the heads at a given point on all surfaces
- **Track: each surface is divided into concentric circles**
  - 10,000 to 50,000 tracks per surface
  - ZBR (Zone Bit Recording)
    - The number of sectors per track increases in outer zones
- **Sector - track is divided into fixed size sectors (100 ~ 500 sectors/track)**
  - Preamble - allows head to be synchronized before r/w
  - Data - 512B - 4KB
  - Error correcting code (ECC)
    - Hamming code or Reed-Solomon code
  - Inter-sector gap
  - Formatted capacity does not count preamble/ecc/gap

Magnetic Disk

- **Performance**
  - Seek time
    - To move the read/write head to the desired track
    - 3 ~ 14ms, consecutive tracks less than 1 ms
  - Rotational latency
    - To locate the desired sector under the read/write head
    - On average, it takes a half of a single rotation time
    - 5400 ~ 16200 rpm (90 ~ 270 rotations/s), 2 ~ 6ms avg.
  - Transfer time
    - Depends on the rotation speed and data density
    - 30 ~ 40MB/s, 512B sector takes 12 ~ 16us
- **Disk Controller**
  - Accept commands from CPU
    - read, write, format (write preambles), control the arm motion, detect/correct errors, convert byte to a serial bit pattern, buffering/caching,

Disk Access Time

- **Disk access time =**
  - Seek time + rotational latency + transfer time + controller overhead
- **For example,**
  - HDD with the following characteristics
    - 10,000 RPM
    - Average seek time 6ms
    - Transfer rate 50MB/s
    - Controller overhead 0.2ms
    - No disk idle time
  - Average acceess time for a 512B sector =
    - 6ms + 0.5 rotation / 10000RPM + 0.5KB/50MB/s + 0.2ms = 6 + 3 + 0.01 + 0.2 = 9.2ms
    - Usually seek time is only 25% ~ 33% of the advertised number due to locality of disk references
    - Most disk controllers have a built-in cache and transfer rates from the cache are typically much higher and up to 320MB/s

Timing Comparison

- **Consider a disk with**
  - Seek time of 4ms
  - Rotation speed of 7500 rpm
  - 512 byte sectors with 500 sectors per track
- **Read a file consisting of 2500 sectors (1.28MB)**
- **Sequential organization**
  - The file occupies all the sectors of 5 adjacent tracks.
  - Seek time = 4ms
  - Rotational latency = 4ms
  - Read 500 sectors = 8ms
  - Total time = 16 + 4 * 12 = 64ms
- **Random access**
  - Seek time = rotational latency = 4ms
  - Read 1 sector = 0.016ms
  - Total time = 2500 * 8.016 = 20.04s
- **Which sectors are read from the disk has a tremendous impact on I/O performance!**

Disk Scheduling Algorithms

Name	Description	Remarks
Selection according to requestor		
RSS	Random scheduling	For analysis and simulation
FIFO	First in first out	Fairest of them all
PRI	Priority by process	Control outside of disk queue management
LIFO	Last in first out	Maximize locality and resource utilization
Selection according to requested item		
SSTF	Shortest service time first	High utilization, small queues
SCAN	Back and forth over disk	Better service distribution
C-SCAN	One way with fast return	Lower service variability
N-step-SCAN	SCAN of *N* records at a time	Service guarantee
FSCAN	N-step-SCAN with *N* = queue size at beginning of SCAN cycle	Load sensitive

Source: Pearson

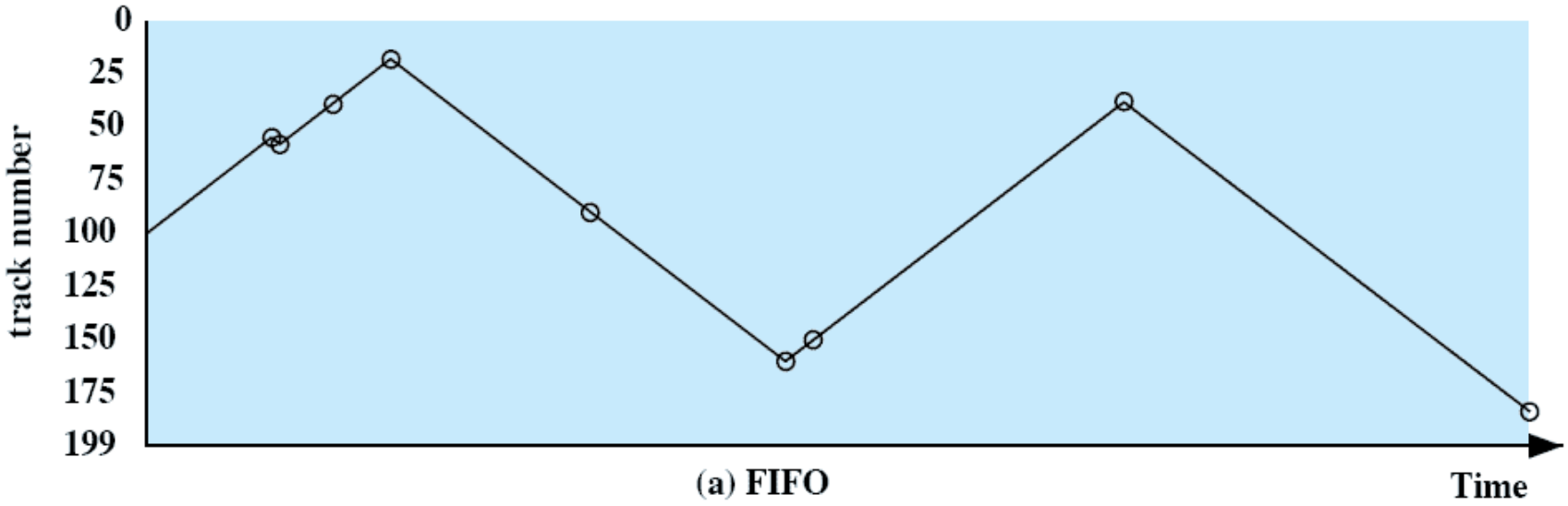
Comparison of Disk Scheduling Algorithms

(a) FIFO (starting at track 100)		(b) SSTF (starting at track 100)		(c) SCAN (starting at track 100, in the direction of increasing track number)		(d) C-SCAN (starting at track 100, in the direction of increasing track number)	
Next track accessed	**Number of tracks traversed**	**Next track accessed**	**Number of tracks traversed**	**Next track accessed**	**Number of tracks traversed**	**Next track accessed**	**Number of tracks traversed**
55	45	90	10	150	50	150	50
58	3	58	32	160	10	160	10
39	19	55	3	184	24	184	24
18	21	39	16	90	94	18	166
90	72	38	1	58	32	38	20
160	70	18	20	55	3	39	1
150	10	150	132	39	16	55	16
38	112	160	10	38	1	58	3
184	146	184	24	18	20	90	32
Average seek length	55.3	**Average seek length**	27.5	**Average seek length**	27.8	**Average seek length**	35.8

Source: Pearson

FIFO

- Processes requests from the queue in sequential order
- Fair to all processes
- Approximate random scheduling in performance if there are many processes competing for the disk



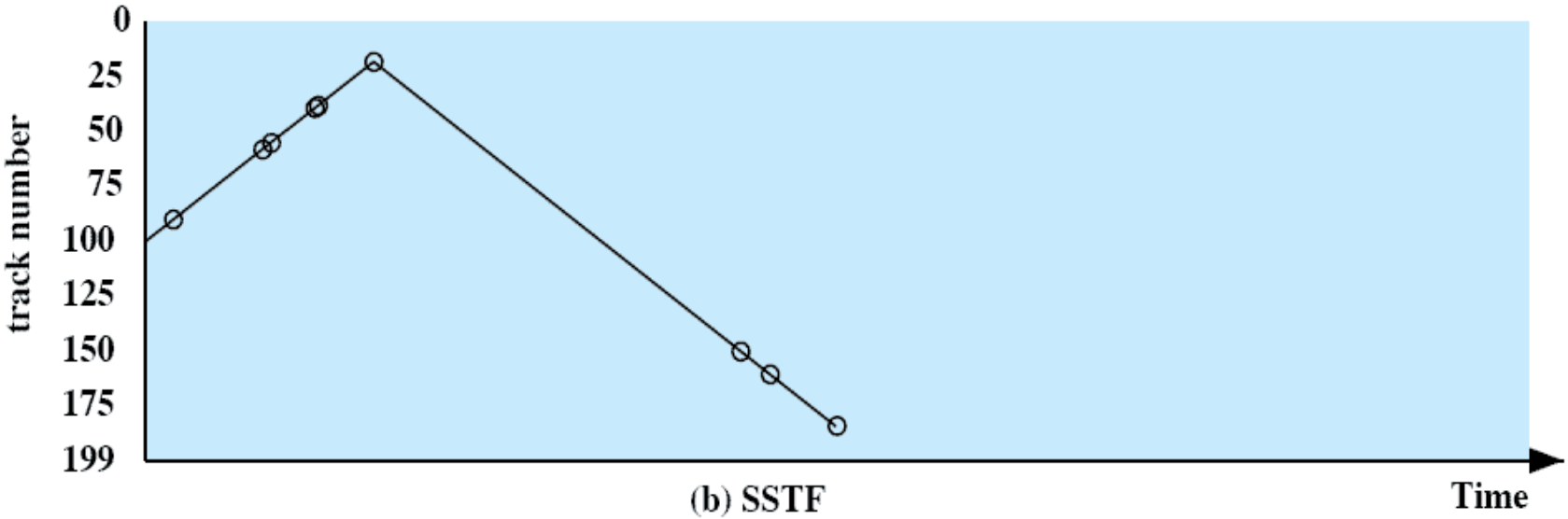
Source: Pearson

Priority (PRI)

- **The control of the scheduling is outside the control of disk management software**
- **Goal is not to optimize disk utilization but to meet other objectives**
- **Often short batch jobs and interactive jobs are given higher priority**
  - Provides good interactive response time
  - Longer jobs may have to wait an excessively long time

Shortest Service Time First (SSTF)

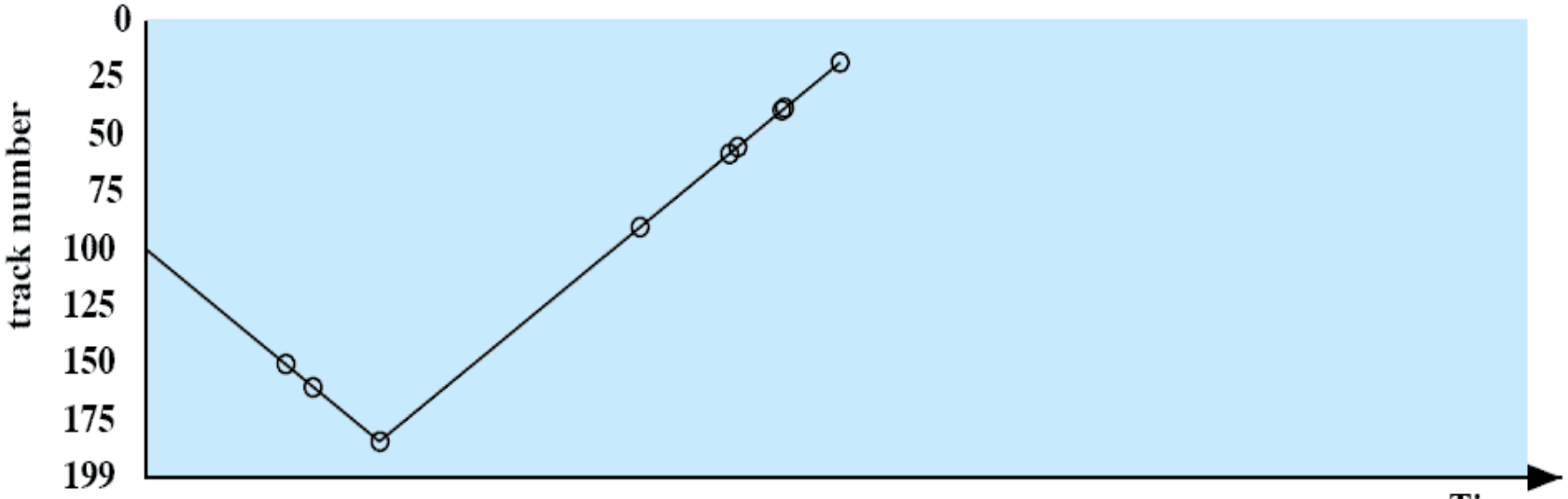
- **Select the disk I/O request that requires the least movement of the disk arm from its current position**
- **Always choose the minimum seek time**
  - Does not guarantee that the average seek time to be minimum



Source: Pearson

SCAN

- **Also known as the elevator algorithm**
- **Arm moves in one direction only**
  - Satisfies all outstanding requests until it reaches the last track in that direction then the direction is reversed
- **Favors jobs whose requests are for tracks nearest to both innermost and outermost tracks and favors the latest arriving jobs**

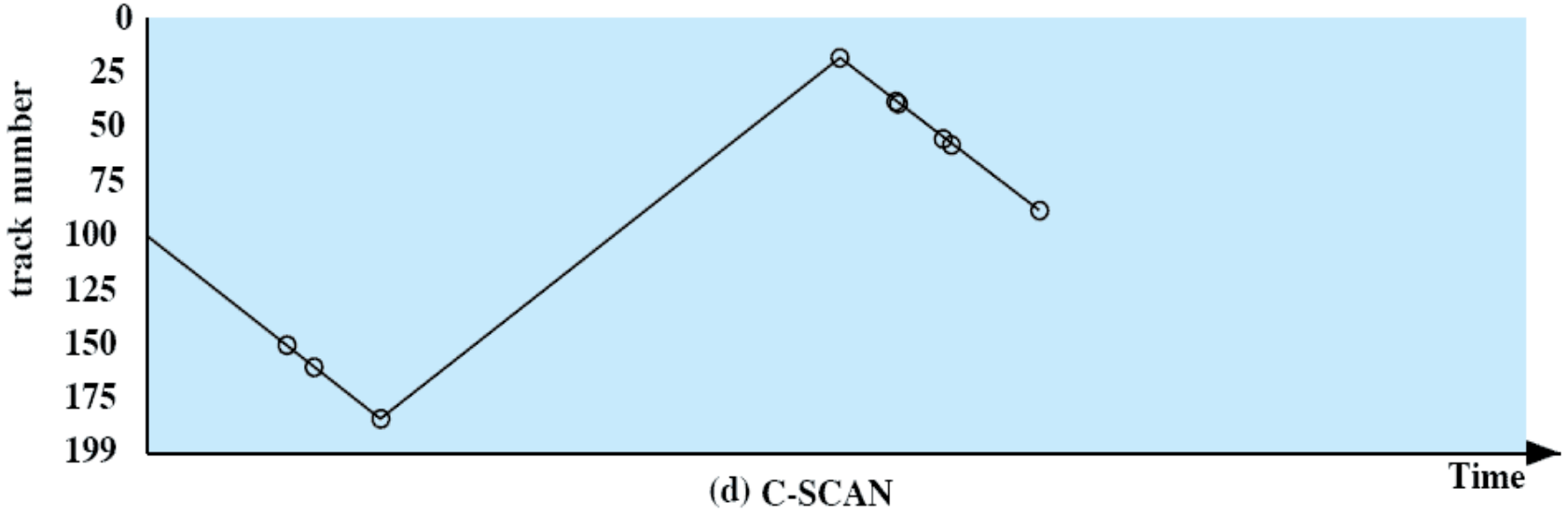


(c) SCAN

Source: Pearson

C-SCAN (Circular SCAN)

- Restricts scanning to one direction only
- When the last track has been visited in one direction, the arm is returned to the opposite end of the disk and the scan



(d) C-SCAN

Source: Pearson

N-Step-SCAN and FSCAN

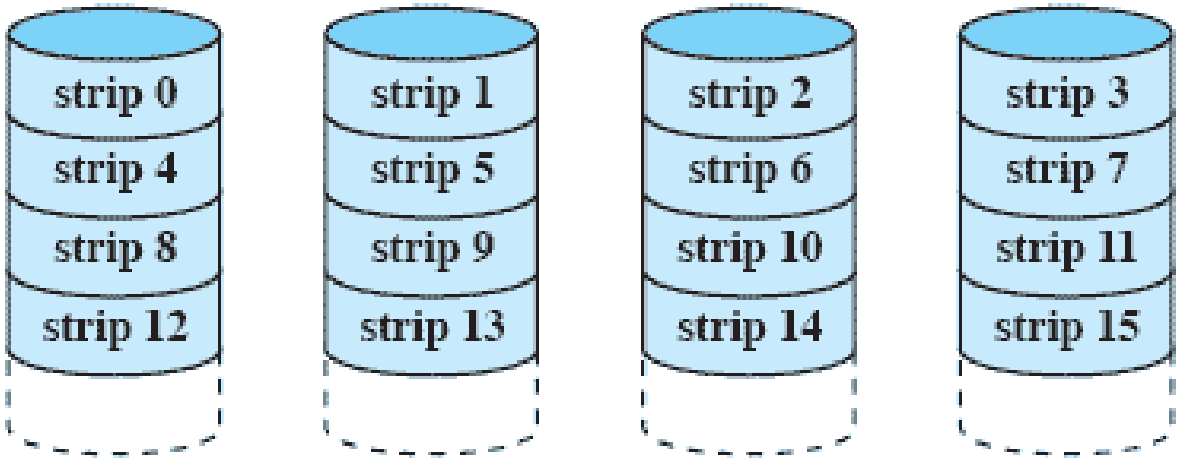
- **N-Step-Scan**
  - Segment the disk request queue into subqueues of length *N*
  - Subqueues are processed one at a time, using SCAN
  - For a large value of N, the performance of N-Step-Scan approaches that of SCAN. For a value of N = 1, it is the same as FIFO.
- **FSCAN**
  - Uses two subqueues
  - When a scan begins, all of the requests are in one of the queues, with the other empty
  - During scan, all new requests are put into the other queue
  - Service of new requests is deferred until all of the old requests have been processed

RAID

- **Motivation**
  - Disk seek time has continued to improve slowly over time
  - 970 (50~100ms), 1990 (10ms), 2010 (3ms)
- **Ideas**
  - Performance - parallel processing
  - Reliability
- **RAID (Redundant Array of Independent Disks)**
  - Consists of seven levels, zero through six
  - These levels denote different design architectures that share 3 characteristics
    - RAID is a set of physical disk drives viewed by the operating system as a single logical drive
    - Redundant disk capacity is used to store parity information, which guarantees data recoverability in case of a disk failure
    - Data are distributed across the physical drives of an array in a scheme known as striping

RAID Level 0

- ***Stripping* - distribute data over multiple disks**
  - When a transferred block consists of 8 sectors, 2 sectors (*strip*) are distributed to different disk drive
  - If a block size is bigger than # drives * strip size, multiple requests are needed
  - If a single request consists of multiple logically contiguous strips, then up to n strips for that request can be handled in parallel
- **No redundancy and no error detection/correction but widely used**

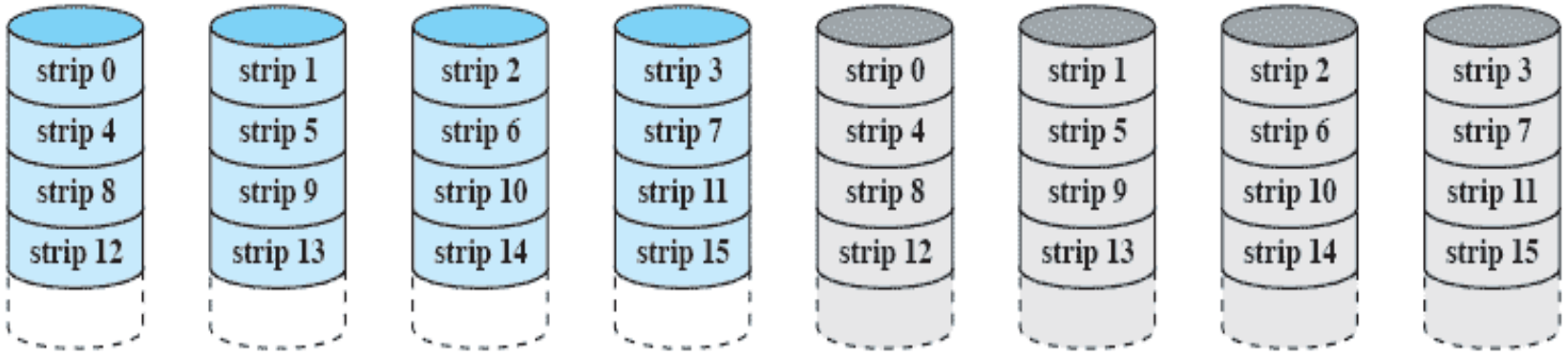


(a) RAID 0 (non-redundant)

Source: Pearson

RAID Level 1 (Mirroring)

- **Redundancy is achieved by duplicating all the data**
  - Every disk in the array has a mirror disk
    - When a drive fails the data may still be accessed from the second drive
- **Advantage**
  - A read request can be served by either of two disks.
  - There is no “write penalty”.
    - Write can be done in parallel. On a write, RAID levels 2-6 must compute and update parity bits as well as updating the actual strip.
- **Principal disadvantage is the cost**

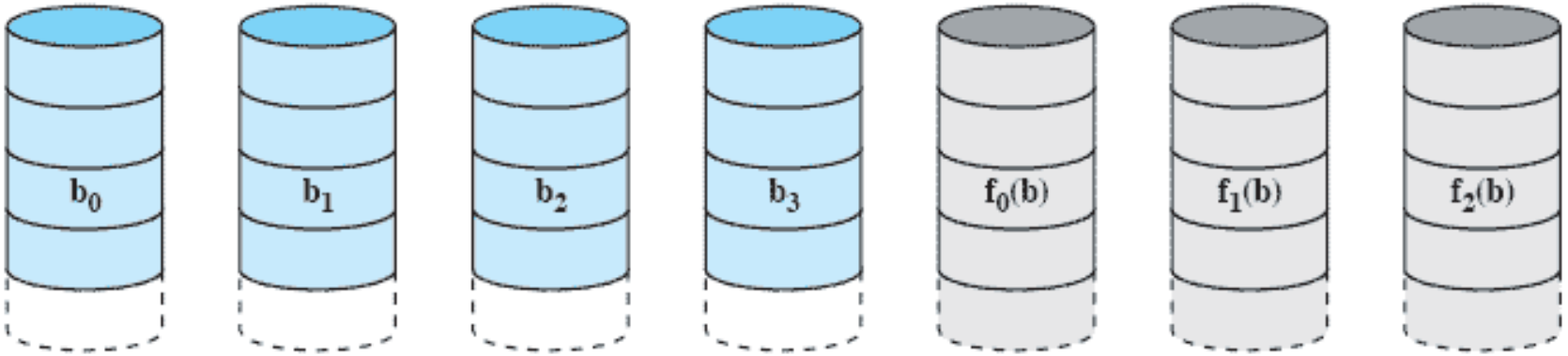


(b) RAID 1 (mirrored)

Source: Pearson

RAID Level 2

- **Distribute each byte/word over multiple disks**
- **Add hamming code**
  - For example, for 4b nibbles, 3b extra
- **Issues**
  - Require all drives to be rotationally synchronized
  - Require a substantial number of drives
  - On a write, all data disks and parity disk must be accessed
- **Effective choice where many disk errors occur**
  - Usually RAIS2 is a overkill and is not implemented

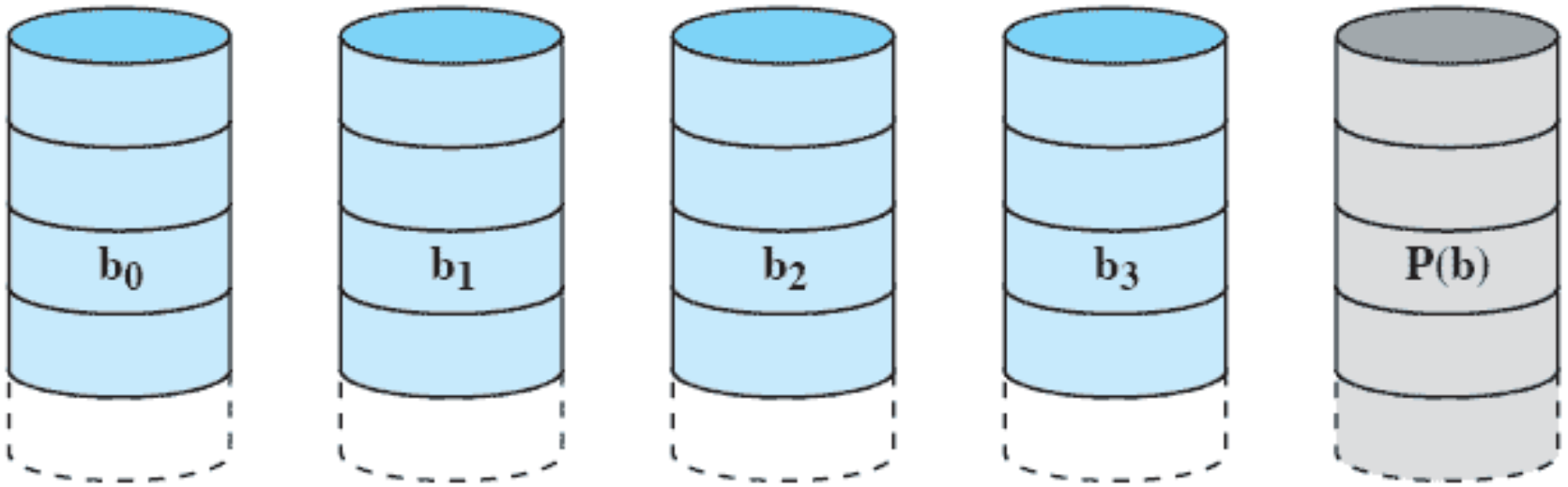


(c) RAID 2 (redundancy through Hamming code)

Source: Pearson

RAID Level 3

- **Distribute each byte/word over multiple disks**
- **Add parity bit (bit-interleaved parity)**
  - Requires only a single redundant disk, no matter how large the disk array
  - In case of a disk failure, the parity drive is accessed and data is reconstructed from the remaining devices.
- **Can achieve very high data transfer rates**

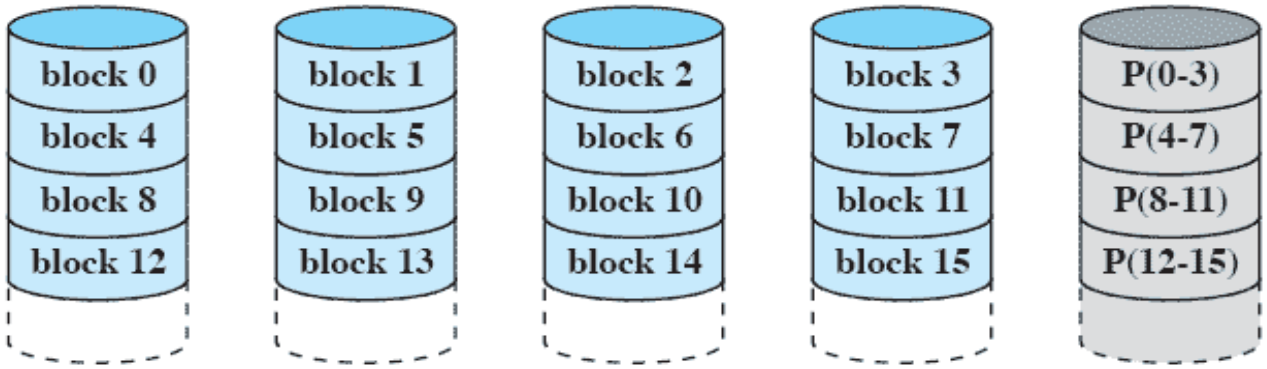


(d) RAID 3 (bit-interleaved parity)

Source: Pearson

RAID Level 4

- **RAID 4~6 make use of an *independent access technique***
  - Each member disk operates independently. Separate IO requests can be satisfied in parallel.
  - Suitable for applications with high IO request rates but not suitable for applications with high data transfer rates
- **Block-interleaved parity**
  - A bit-by-bit parity strip is calculated across corresponding strips on each data disk, and the parity bits are stored in the corresponding strip on the parity disk
- **A write to disk X1 requires 2 reads of disk X1 and X4(parity) and 2 writes of disk X1 and X4**



(e) RAID 4 (block-level parity)

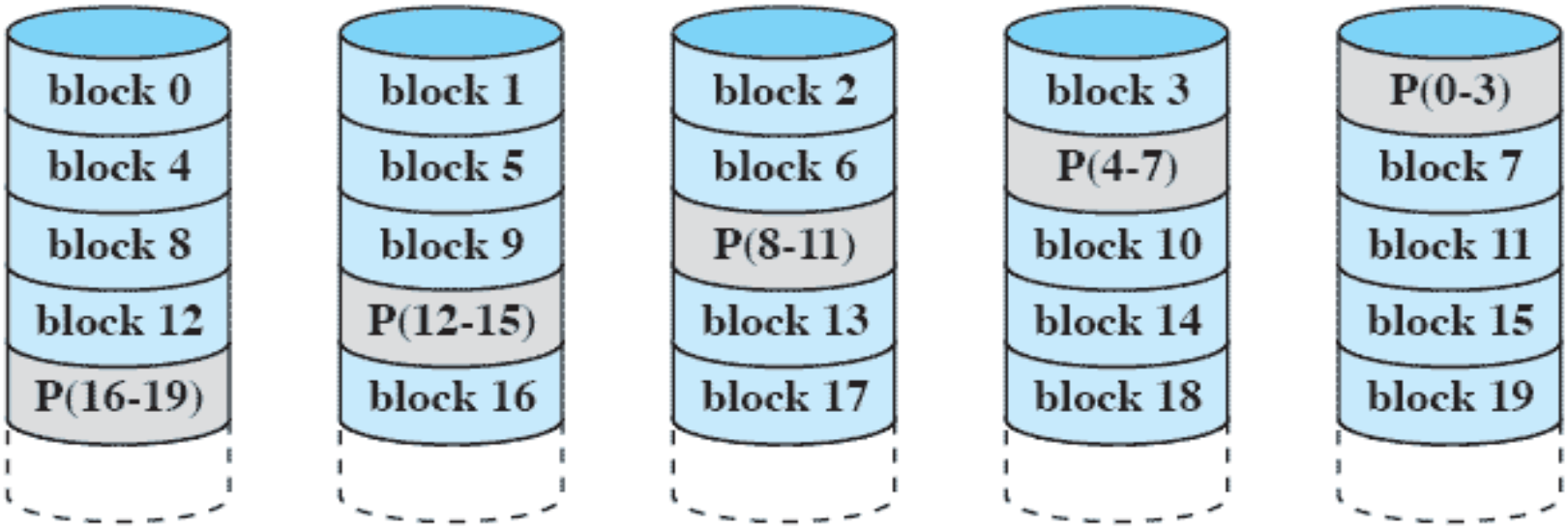
Source: Pearson

RAID 4 Level

- **Initially, the following relationship holds for each bit I**
  - $X4(i) = X3(i) \oplus X2(i) \oplus X1(i) \oplus X0(i)$
- **After the write**
  - $X4'(i) = X3(i) \oplus X2(i) \oplus X1'(i) \oplus X0(i)$
    $= X3(i) \oplus X2(i) \oplus X1'(i) \oplus X0(i) \oplus X1(i) \oplus X1(i)$
    $= X3(i) \oplus X2(i) \oplus X1(i) \oplus X0(i) \oplus X1(i) \oplus X1'(i)$
    $= X4(i) \oplus X1(i) \oplus X1'(i)$
- **Therefore, to calculate the new parity, it must read the old user data and the old user parity**
  - Every write operation must involve the parity disk, which can become a bottleneck.

RAID Level 5

- Similar to RAID-4 but distributes the parity bits across all disks
- Typical allocation is a round-robin scheme
- Has the characteristic that the loss of any one disk does not result in data loss
- Widely used

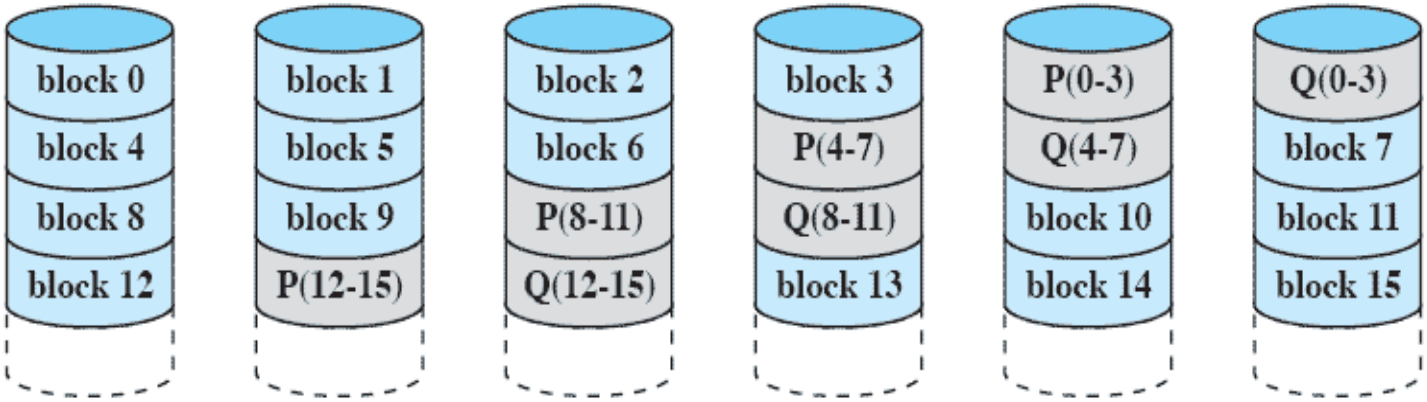


(f) RAID 5 (block-level distributed parity)

Source: Pearson

RAID Level 6

- **Two different parity calculations are carried out and stored in separate blocks on different disks**
  - One may use parity (exclusive-OR) and the other can be an independent algorithm
- **Provides extremely high data availability**
- **Incurs a substantial write penalty because each write affects two parity blocks**
  - Compared to RAID5, RAID6 can suffer more than a 30% drop in write performance



(g) RAID 6 (dual redundancy)

Source: Pearson

Disk Cache

- ***Disk cache* is a buffer in main memory for disk sectors**
  - Contains a copy of some of the sectors on the disk
- **When an I/O request is made for a particular sector, a check is made to determine if the sector is in the disk cache**
  - If Yes, the request is satisfied via the cache
  - If No, the requested sector is read into the disk cache from the disk

LRU

- **The most commonly used algorithm**
- **The block that has not been referenced for the longest time is replaced**
- **A stack of pointers reference the cache**
  - Most recently referenced block is on the top of the stack
  - When a block is referenced or brought into the cache, it is placed on the top of the stack

LFU (Least Frequently Used)

- **The block that has experienced the fewest references is replaced**
- **A counter is associated with each block**
- **Counter is incremented each time block is accessed**
- **When replacement is required, the block with the smallest count is selected**
- **Problematic when**
  - Certain blocks are referenced relatively infrequently overall, but when they are referenced, there are short intervals of repeated references due to locality, building up high reference counts. After such interval is over, the reference count may be misleading.

Homework 10

- Exercise 11.1
- Exercise 11.4
- Exercise 11.6
- Exercise 11.8

Operating System

Chapter 12. File Management

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Files

- **In most applications, files are key elements**
  - For most systems except some real-time systems, files are used as inputs and outputs
  - Virtually all the operating systems provide file systems
- **Desirable properties of files:**
  - Long-term existence
    - Files are stored on disk or other secondary storage
  - Sharable between processes
    - Files have names and can have associated access permissions that permit controlled sharing
  - Structure
    - A file can have an internal structure tailored for a particular application. Also, files can be organized into hierarchical structure to reflect the relationships among files

File System

- **File system**
  - Provide a means to store data organized as files and it also provides a collection of functions that can be performed on files
  - Typical operations include
    - Create, delete, open, close, read, write
  - Maintain a set of attributes associated with the file
    - Owner, creation time, time last modified, access privileges, and so on.
- **File structure**
  - Four terms are commonly used
    - Field
    - Record
    - File
    - Database

Structure Terms

- **Field**
  - Basic element of data
  - Contain a single value, such as name, date
  - Fixed or variable length
- **Record**
  - A collection of related fields that can be treated as a unit by an application program
  - Example: employee record contains name, social security number, job, date of hire, etc.
  - Fixed or variable length
- **File**
  - A collection of similar records
  - Treated as a single entity by users and applications
  - Maybe referenced by a name
  - Access control restrictions usually apply at the file level
- **Database**
  - A collection of related data
    - It may contain all the information related to an organization or project
    - Consist of one or more files
  - Relationships among elements of data are explicit
  - Designed for use by a number of different applications

File System Objectives

- **File system**
  - A set of system software that provides service to users and applications in the use of files
  - Typically, the only way that a user or application may access file is through the file system
- **File system objectives**
  - Meet the data management needs of the user
  - Guarantee that the data in the file are valid
  - Optimize performance for throughput and response time
  - Provide I/O support for various storage device types
  - Minimize 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

File System Requirements

- **Each user**
  - Should be able to create, delete, read, write and modify files
  - May have controlled access to other users' files
  - May control what type of accesses are allowed to each file
  - Should be able to restructure the files in a form appropriate to the problem
  - Should be able to move data between files
  - Should be able to back up and recover files in case of damage
  - Should be able to access files by name than by numeric identifier

File System Architecture

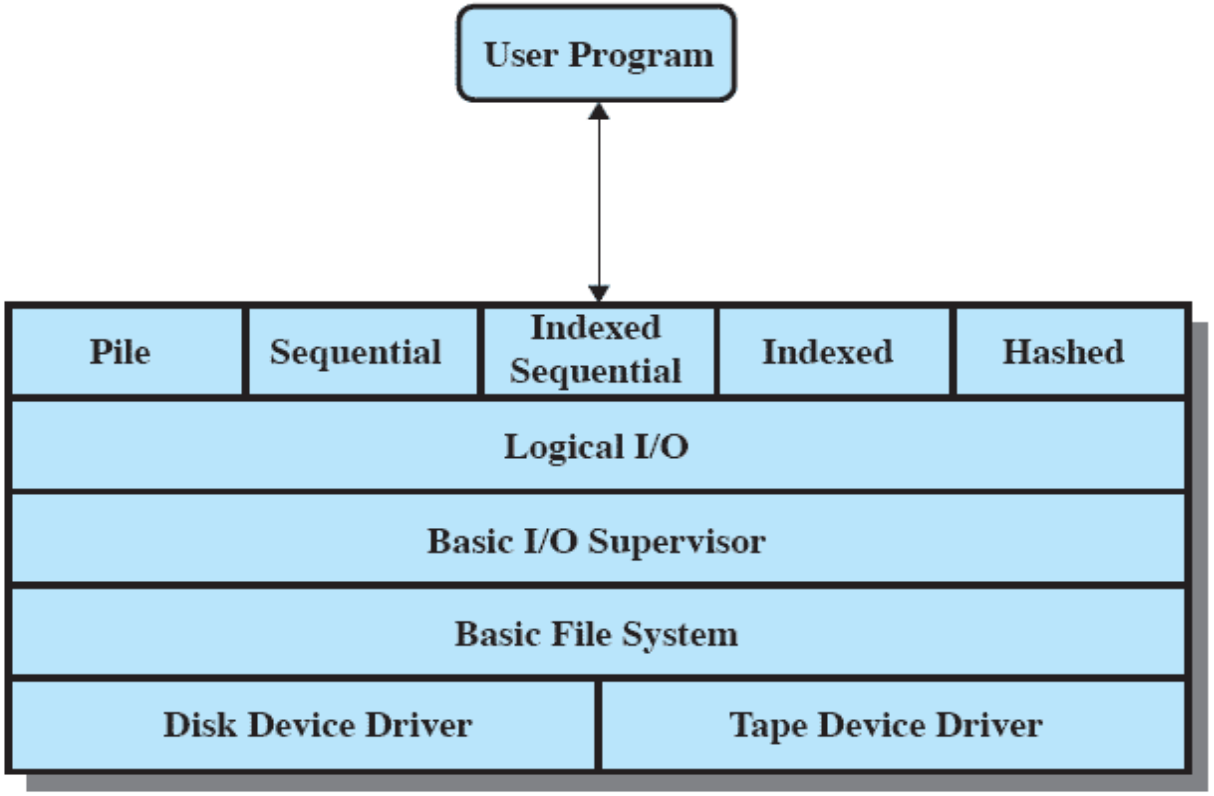


Figure 12.1 File System Software Architecture

Source: Pearson

File System Architecture

- **Device drivers**
  - Lowest level
  - Communicates directly with peripheral devices
  - Responsible for starting/completion of I/O operations on a device
  - Part of OS

- **Basic file system**
  - Also referred to as the *physical I/O*
  - Primary interface with the environment outside the computer system
  - Deals with data blocks that are exchanged with disk systems
  - Deals with the placement of blocks on the secondary storage device
  - Deals with buffering blocks in main memory
  - Part of OS

File System Architecture

- **Basic I/O supervisor**
  - Responsible for file I/O initiation and termination
  - Maintain control structures that deal with device I/O, scheduling, and file status
  - Deals with disk scheduling to optimize performance
  - Assign I/O buffers and allocate secondary memory
  - Part of OS
- **Logical IO**
  - While basic file system deals with blocks, the logical I/O deals with file records
  - Provide general-purpose record I/O capability and maintain basic data about files
- **Access method**
  - Level of the file system closest to the user
  - Different access methods reflect different file structures and different ways of accessing and processing the data
  - Provides a standard interface between applications and the file systems and devices

File System in Different Perspective

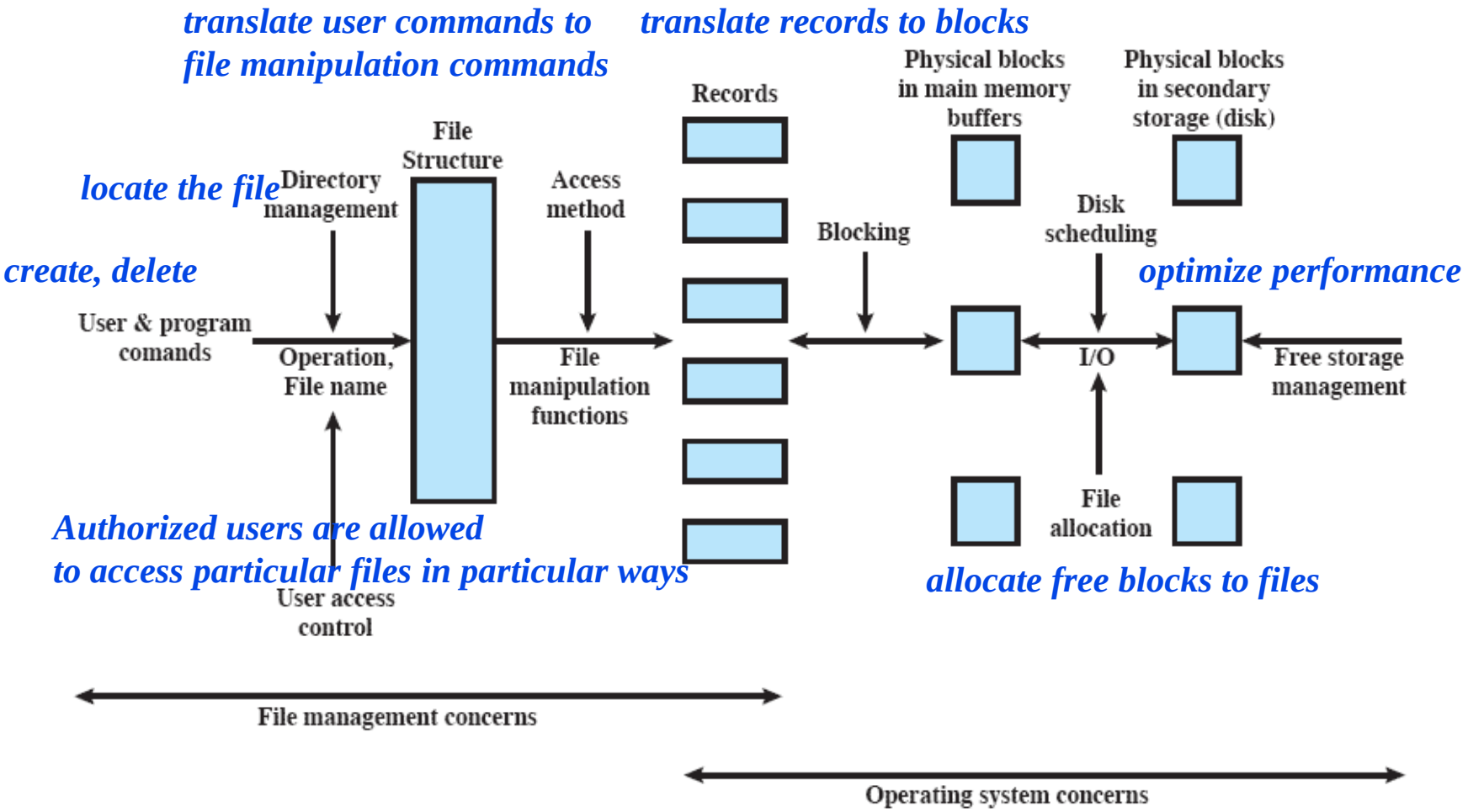


Figure 12.2 Elements of File Management

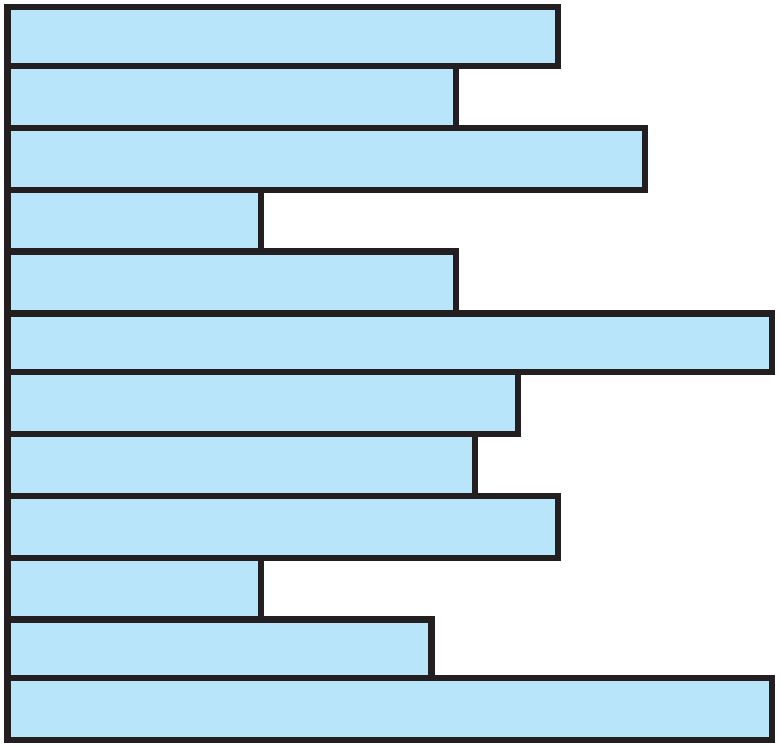
Source: Pearson

File Organization

- ***File organization* is the logical structuring of the records**
- **In choosing a file organization, several criteria are important**
  - Short access time
  - Ease of update
  - Economy of storage
  - Simple maintenance
  - Reliability
- **Priority of criteria depends on the application**
  - If a file is used only in batch mode, the rapid access of a single record is not important
  - For a file on CD-ROM, the ease of update is not an issue
- **Five common file organization types are**
  - Pile
  - Sequential file
  - Direct, or hashed file
  - Indexed file
  - Indexed sequential file

Pile

- **The least complicated form of file organization**
  - There is no file structure
- **Data are collected in the order in which they arrive**
- **The purpose is simply to accumulate the mass of data and save it**
- **Records may have different fields, or similar fields in different order**
- **Record access is by exhaustive search**



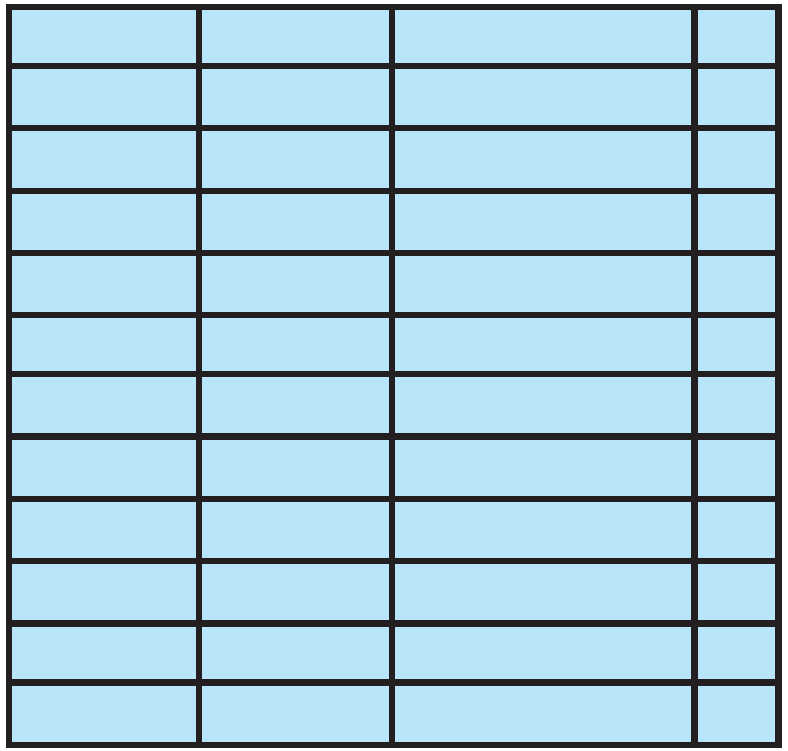
Variable-length records
Variable set of fields
Chronological order

(a) Pile File

Source: Pearson

Sequential File

- **The most common form of file structure**
- **A fixed format is used for records**
  - All records have the same length, consisting of the same number of fixed-size fields
- **Key field**
  - Uniquely identifies the record
  - Records are stored sequentially based on the key field
- **Good for batch applications**
- **Bad for interactive apps.**
  - Random access is slow due to sequential search
  - Addition to a file is also slow



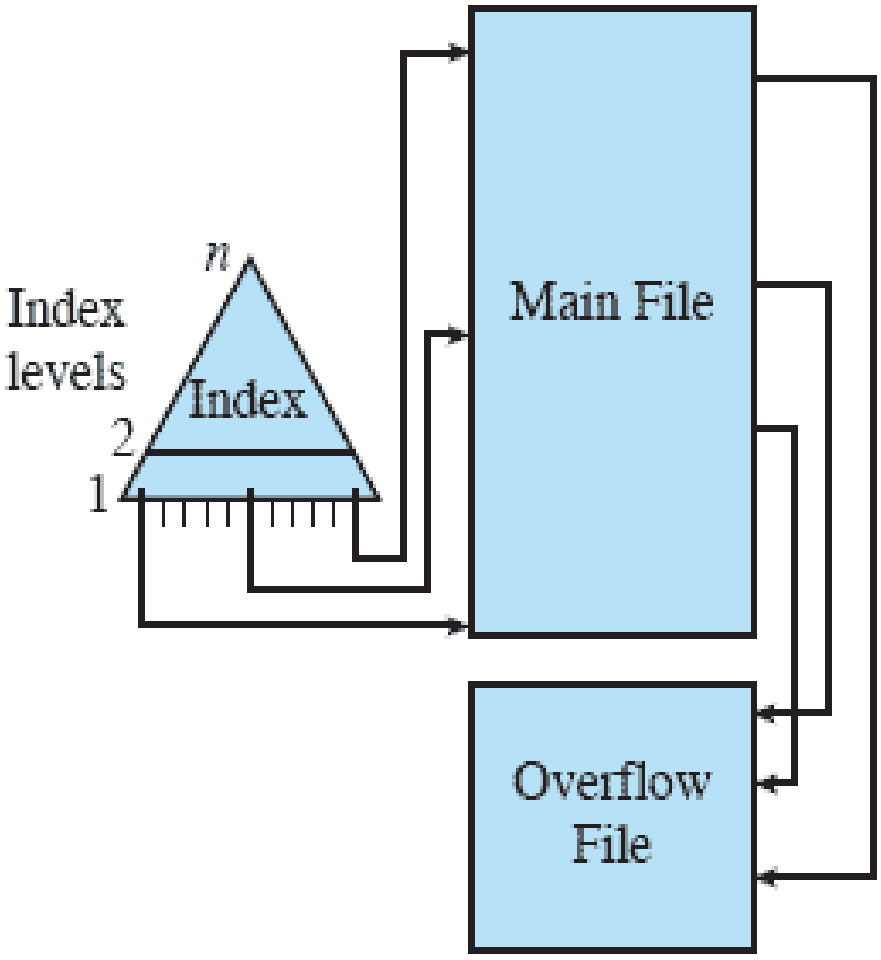
Fixed-length records
Fixed set of fields in fixed order
Sequential order based on key field

Source: Pearson

(b) Sequential File

Indexed Sequential File

- **Two new features**
  - Adds an index to the file to support random access
  - Adds an overflow file to speed up addition
- **Greatly reduces the time required to access a single record**
  - A sequential file with 1M records and1000-entry index requires
    - 500 accesses to the index file + 500 accesses to the main file compared to half million accesses in a sequential file
- **Multiple levels of indexing can be used to provide greater efficiency in access**

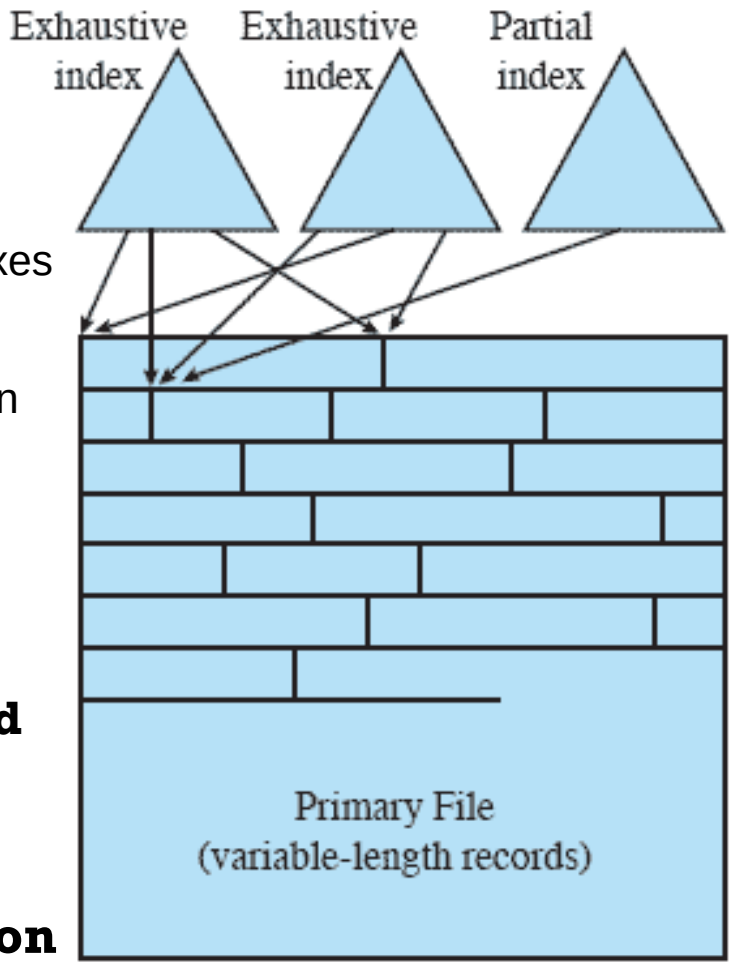


(c) Indexed Sequential File

Source: Pearson

Indexed File

- **Problems of indexed sequential file**
  - Efficient processing is limited to the key field
- **Indexed file**
  - Multiple indexes for each field
  - Records are accessed only through their 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
- **Variable-length records can be employed**
- **Used mostly in applications where timeliness of information is critical**
- **Examples would be airline reservation systems and inventory control systems**



(d) Indexed File

Source: Pearson

Direct or Hashed File

- **Access directly any block of a known address**
- **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

File Directories

- **File directory**
  - Contains information about the files, including attributes, location, and ownership
  - The directory itself is a file
- **Directory operations**
  - Search
    - Search the directory to find an entry for the file
  - Create/delete file
    - Add/delete an entry to the directory
  - List directory
  - Update director
    - A change in some file attribute requires a change in the 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

Source: Pearson

Directory Structure

❑ Two-level scheme

- There is one directory for each user and a master directory
- Master directory
  - Has an entry for each user directory
  - Provide address and access control information
- User directory
  - 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

❑ Tree-structured directory

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

❑ Each directory can be organized as

- A sequential file or a hashed file (if the directory contains a very large number of entries

Tree Structured Directory

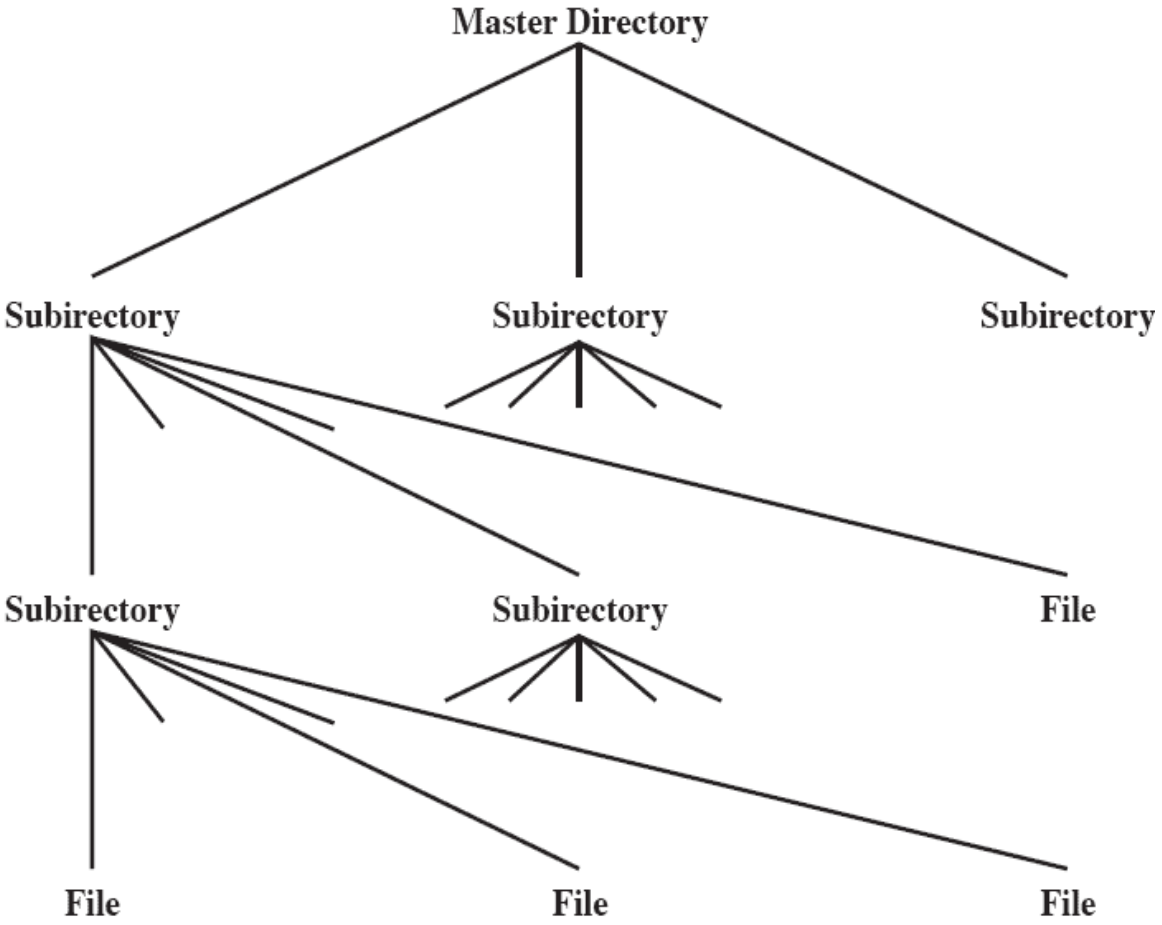


Figure 12.4 Tree-Structured Directory

Source: Pearson

Example of Tree-Structured Directory

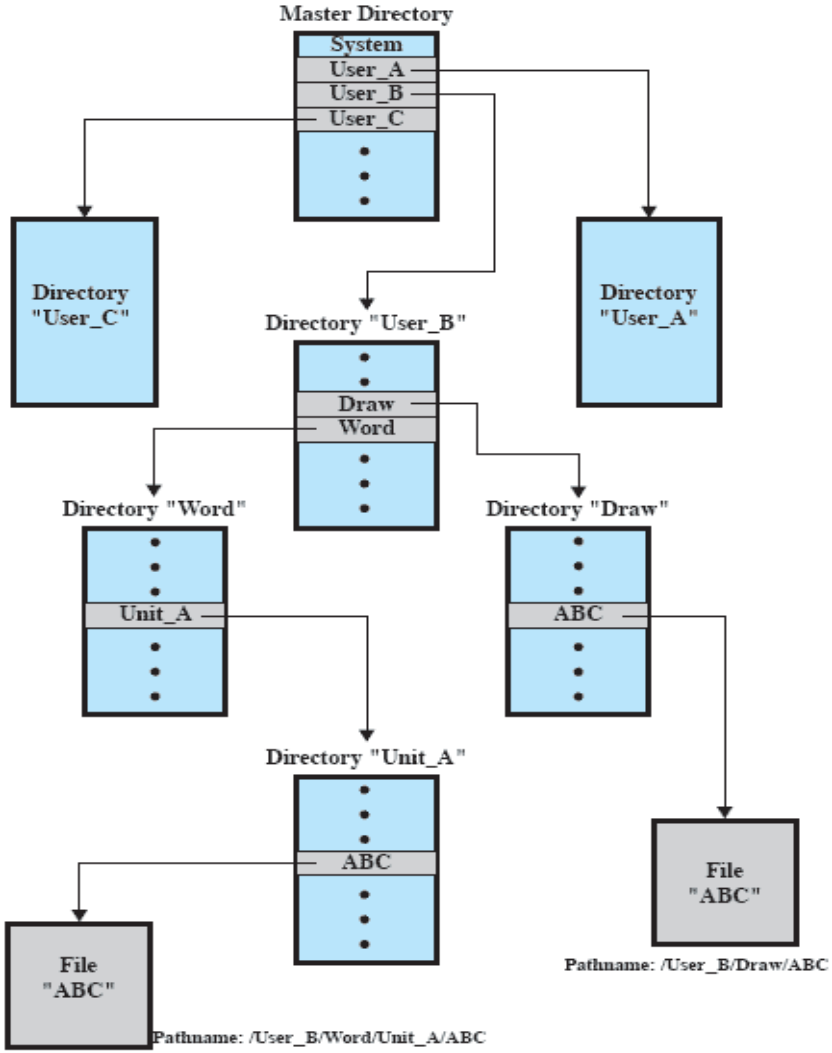


Figure 12.5 Example of Tree-Structured Directory

Source: Pearson

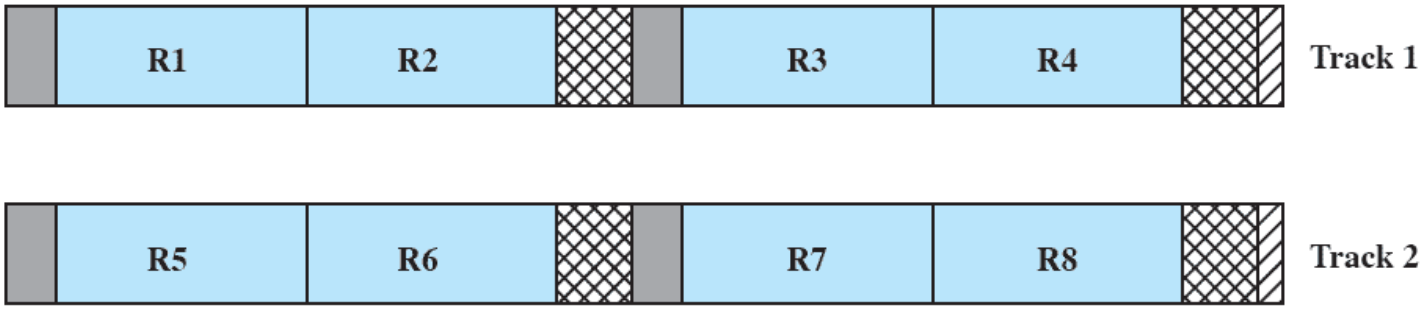
File Sharing

- **Two issues arise**
  - Access rights and the management of simultaneous access (mutual exclusion/deadlock)
- **Access rights**
  - Constitute a hierarchy with each right implying those preceding it
  - None – May not even know the existence of the file. Cannot read the directory
  - Knowledge – Know the file exists and who the owner is. Must ask the owner for access
  - Execute – Can execute the program but cannot copy it
  - Read – Can read the file, including copying and execution
  - Append – Can add data to the file but cannot modify or delete
  - Update – Can modify, delete, and add to the file's data
  - Change protection – Can change the access rights
  - Delete – Can delete the file
- **Access can be provided to different class of users**
  - Owner – The person who initially created the file. Has all the access rights
  - Specific user – Individual user designated by user ID
  - User groups – A group of users
  - All – All users

Record Blocking

- **Records are the logical unit of access for a structured file whereas blocks are the unit of I/O**
  - Thus, to perform I/O, records must be organized as blocks
- **Several issues to consider**
  - Should blocks be of fixed or variable length?
    - In most systems, blocks are of fixed size, which simplify IO
  - What should be the relative size of a block compared to an average record size?
    - The larger the block, can speed up IO but may include unnecessary records
- **Three blocking methods can be used**
  - **Fixed-Length Blocking** – fixed-length records are used, and an integral number of records are stored in a block
  - **Variable-Length Spanned Blocking –** variable-length records are used and are packed into blocks with no unused space
    - Some records may span two blocks
  - **Variable-Length Unspanned Blocking** – variable-length records are used, but spanning is not employed

Fixed Blocking



Fixed Blocking

Data

Gaps due to hardware design

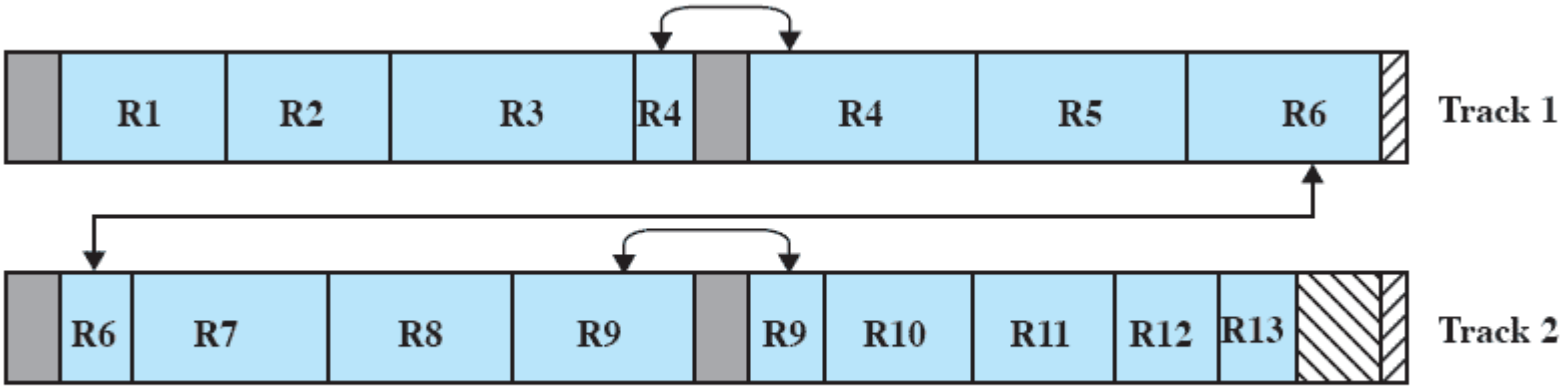
Waste due to block fit to track size

Waste due to record fit to block size

Waste due to block size constraint from fixed record size

Source: Pearson

Variable Blocking: Spanned



Variable Blocking: Spanned

Data

Gaps due to hardware design

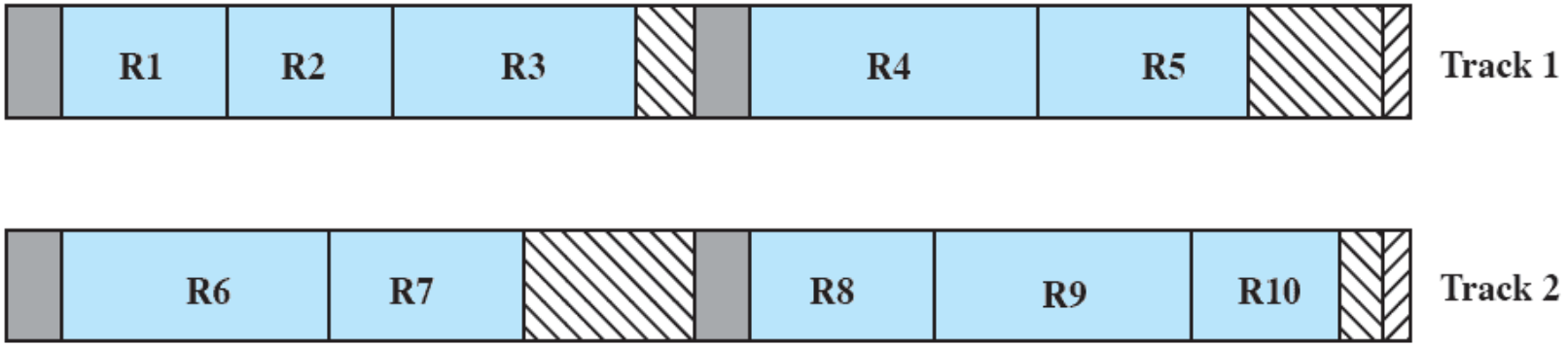
Waste due to block fit to track size

Waste due to record fit to block size

Waste due to block size constraint from fixed record size

Source: Pearson

Variable Blocking: Unspanned



Variable Blocking: Unspanned

- Data
- Gaps due to hardware design
- Waste due to block fit to track size
- Waste due to record fit to block size
- Waste due to block size constraint from fixed record size

Source: Pearson

File Allocation

- **A file consists of a collection of blocks**
- **OS (file system) is responsible for the file allocation**
  - OS allocates free space on secondary storage to files
  - OS needs to keep track of free spaces
- **File allocation issues**
  - When a new file is created, should we allocate the maximum space for the file at once?
  - OS assigns a contiguous set of free blocks (called a portion) to a file. What size should we use for the portion? It can range from a single block to the entire file.
  - What kind of data structure is used to keep track of the portions assigned to a file?
    - Example: FAT (File Allocation Table) on DOS

Preallocation vs. Dynamic Allocation

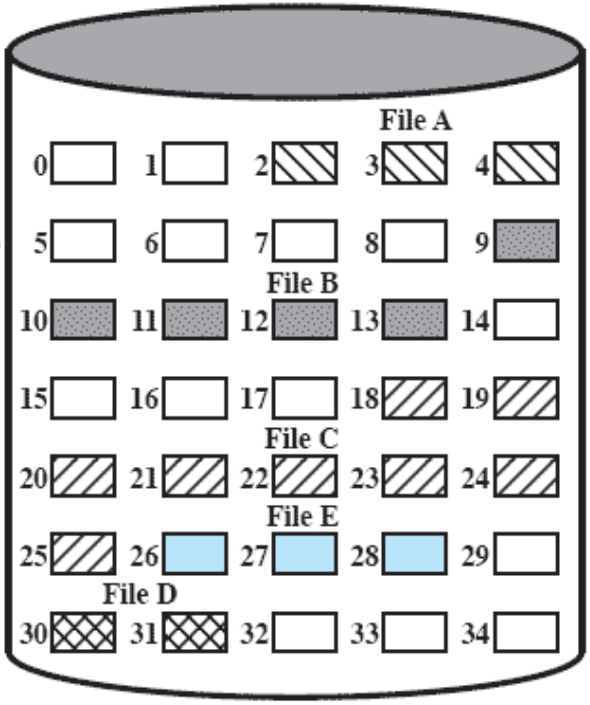
- **Preallocation**
  - Require the maximum file size to be declared at the file creation time
  - For some applications, it is possible to estimate the maximum size
    - Program compile, file transfer over the network
  - But, for many applications, it is impossible to estimate the max. size
    - Users and applications tend to overestimate the size, which results in storage waste
- **Dynamic allocation**
  - Allocate space as needed

Portion Size

- **The portion size ranges from a single block to the entire file**
- **Need to consider the following:**
  - Contiguity of space increases the performance
  - A large number of small portions increases the size of tables needed to manage the allocation information
  - Fixed size portions simplifies the reallocation of spaces
  - Variable size or small fixed-size portions minimizes the storage waste
- **Two alternatives**
  - **Variable, large contiguous portions**
    - (+) Better performance, avoid waste, small tables
    - (-) Hard to reuse space
  - **Blocks**
    - (+) Greater flexibility, don't have to be contiguous, blocks are allocated on demand, easy to reuse space
    - (-) Large tables

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**
- **Advantages**
  - Improve I/O performance for sequential processing
  - FAT needs a single entry for each file
- **Disadvantages**
  - External fragmentation
    - Compaction required



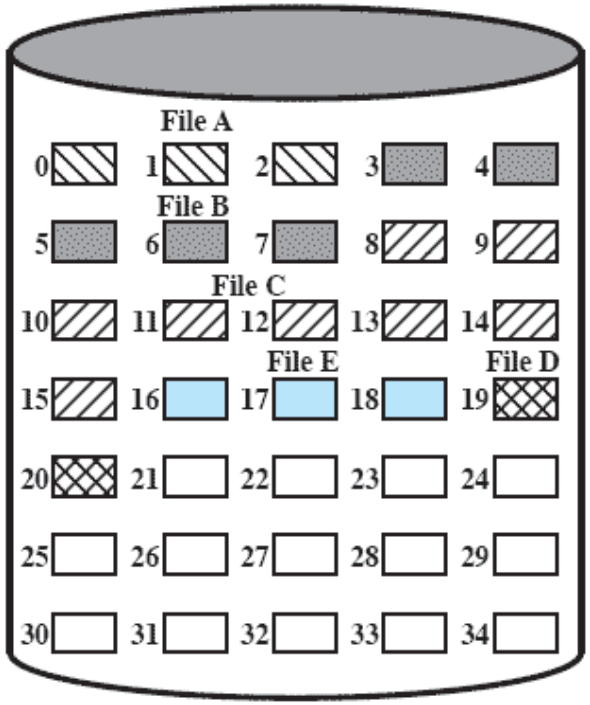
File Allocation Table

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 12.7 Contiguous File Allocation

Source: Pearson

After Compaction



File Allocation Table

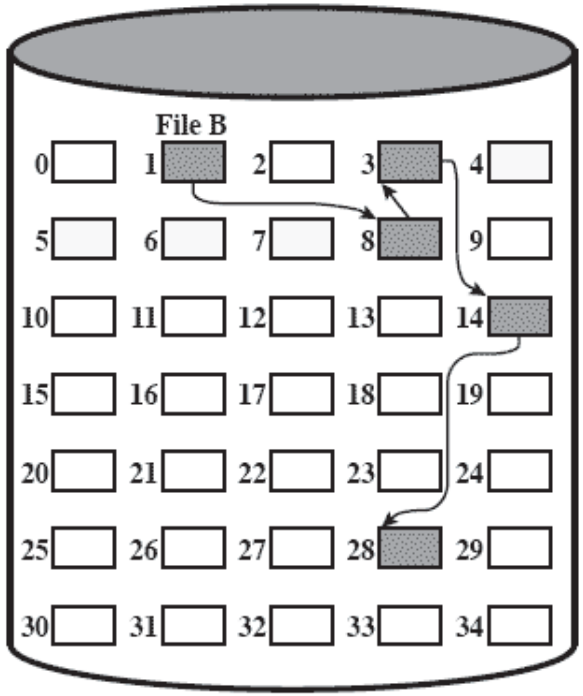
File Name	Start Block	Length
File A	0	3
File B	3	5
File C	8	8
File D	19	2
File E	16	3

Figure 12.8 Contiguous File Allocation (After Compaction)

Source: Pearson

Chained Allocation

- **Allocation is on an individual block basis**
- **Each block contains a pointer to the next block in the chain**
- **FAT needs just a single entry for each file**
- **No external fragmentation**
- **Not good when we need to bring in multiple blocks since it requires a series of accesses to different parts of disk storage**
  - Require periodic consolidation



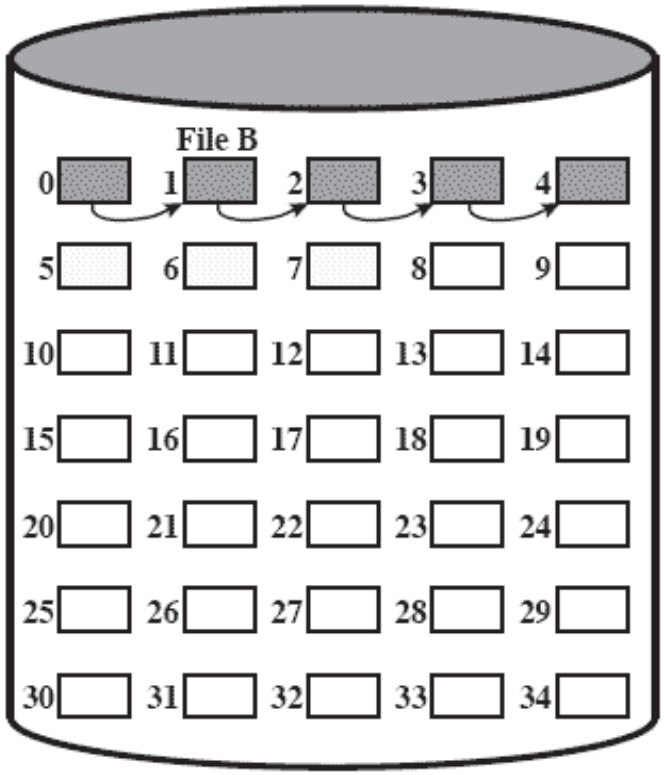
File Allocation Table

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

Source: Pearson

Figure 12.9 Chained Allocation

Chained Allocation After Consolidation



File Allocation Table

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

Figure 12.10 Chained Allocation (After Consolidation)

Source: Pearson

Indexed Allocation with Block Portions

- Address the problems of contiguous and chained allocation
- FAT entry for each file points to an index block, which has one entry for each portion allocated to the file

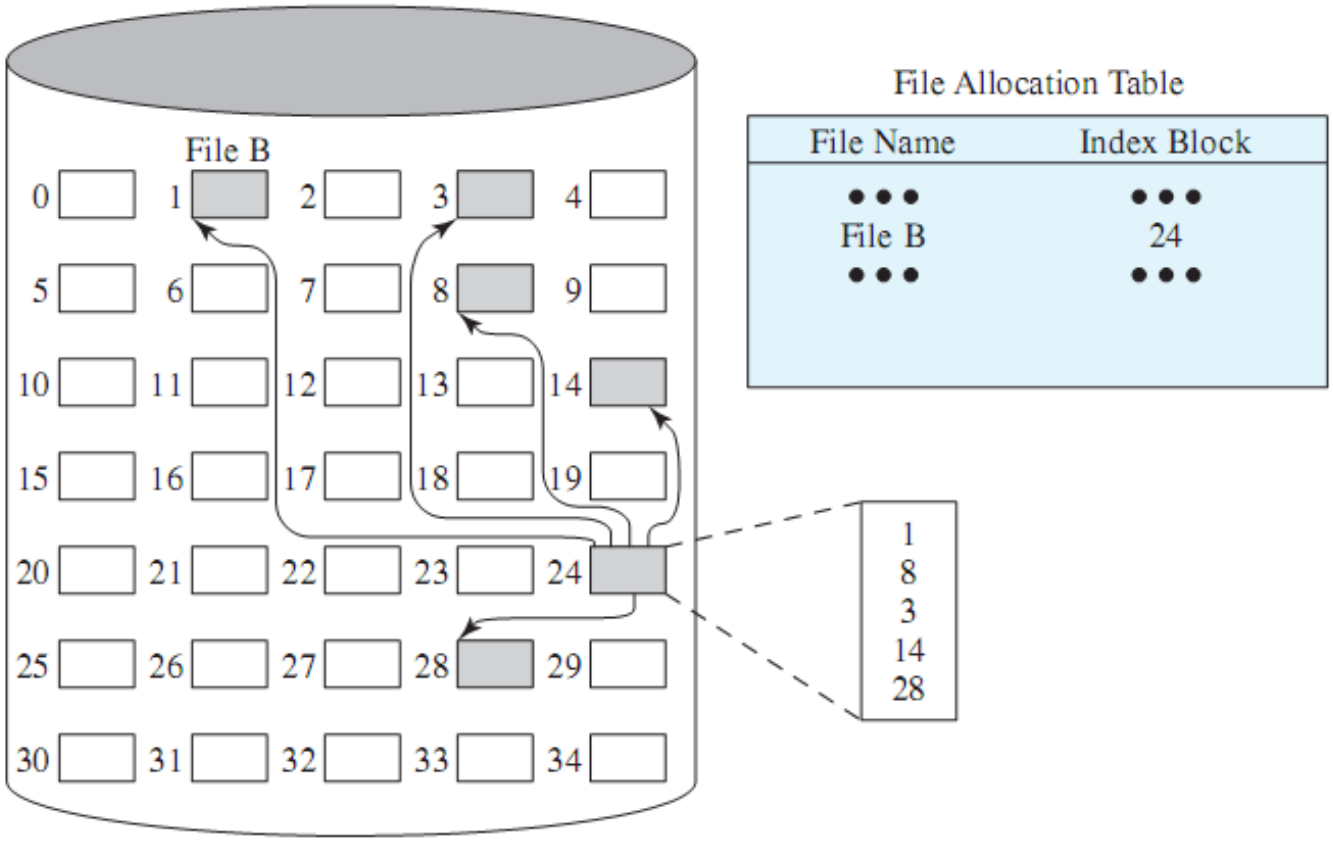


Figure 12.11 Indexed Allocation with Block Portions

Source: Pearson

Indexed Allocation with Variable Length Portions

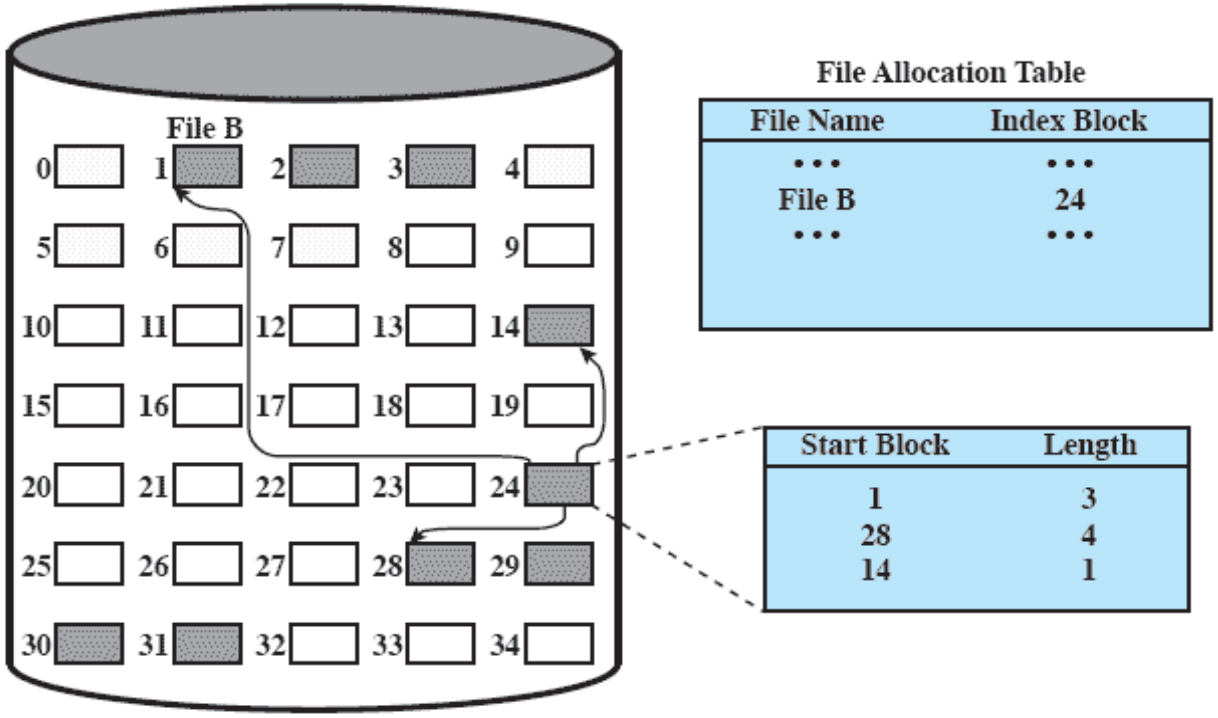


Figure 12.12 Indexed Allocation with Variable-Length Portions

Source: Pearson

Free Space Management

- **Just as the allocated space must be managed, so the unallocated space must be managed.**
- **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 table**
  - A bit vector containing one bit for each block on the disk
  - 00110000111110000011111101100
  - Each entry of a 0 corresponds to a free block, and each 1 corresponds to a block in use
  - Works well with any file allocation method
  - The size of the bit table is relatively small but can be still big!
    - 16GB disk with 512B blocks needs 4MB bit table, which requires 8000 disk blocks!

Chained Free Portions

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

Volumes

- **A collection of addressable sectors in secondary memory that an OS or application can use for data storage**
- **The sectors in a volume need not be consecutive on a physical storage device**
  - They need only appear that way to the OS or application
- **A volume may be the result of assembling and merging smaller volumes**
- **Examples**
  - In the simplest case, a single disk is one volume
  - Frequently, a disk is divided into partitions, with each partition functioning as a separate volume
  - Partitions on multiple disks as a single volume