CHAPTER 10

Disk Storage, Basic File Structures, Hashing, and Modern Storage Architectures

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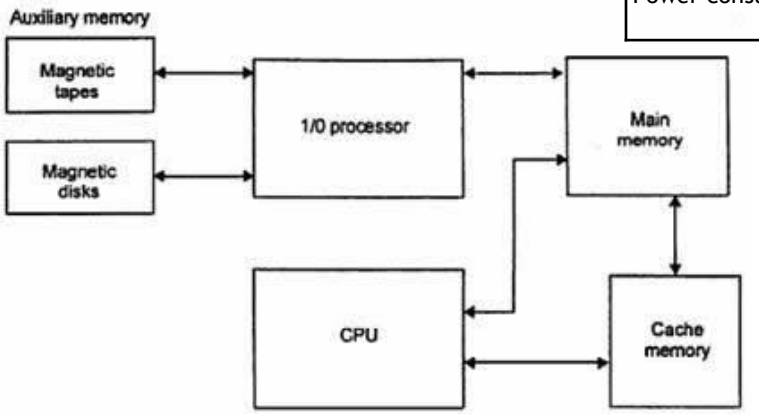
10.1 Introduction

- Databases typically stored on magnetic disks
  - Accessed using physical database file structures
- Storage hierarchy
  - Primary storage
    - CPU main memory, cache memory
  - Secondary storage
    - Magnetic disks, flash memory, solid-state drives
  - Tertiary storage
    - Removable media

BASIS FOR COMPARISON	Main Memory (RAM)	Cache Memory
Definition	Main memory is also known as Random Access Memory. It is a memory unit that directly interacts with the central processing unit (CPU)	Cache memory is used to store frequently accessed data in order to quickly access the data whenever it is required.
Proximity with CPU	Comparatively far	Comparatively closer
Speed	Comparatively slow	Comparatively fast
Capacity	Larger	Comparatively less
Component	It is a part of the hard drive (secondary storage)	Located on the processor itself

BASIS FOR COMPARISON	SRAM	DRAM
Speed	Faster	Slower
Size	Small	Large
Cost	Expensive	Cheap
Used in	Cache memory	Main memory
Density	Less dense	Highly dense
Construction	Complex and uses transistors and latches.	Simple and uses capacitors and very few transistors.
Single block of memory requires	6 transistors	Only one transistor.
Charge leakage property	Not present	Present hence require power refresh circuitry
Power consumption	Low	High



Memory Hierarchies and Storage Devices

- Cache memory
  - Static RAM
  - DRAM
- Mass storage
  - Magnetic disks
    - CD-ROM, DVD, tape drives
- Flash memory
  - Nonvolatile

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Storage Types and Characteristics

Type	Capacity*	Access Time	Max Bandwidth	Commodity Prices (2014)**
Main Memory- RAM	4GB–1TB	30ns	35GB/sec	$100–$20K
Flash Memory- SSD	64 GB–1TB	50µs	750MB/sec	$50–$600
Flash Memory- USB stick	4GB–512GB	100µs	50MB/sec	$2–$200
Magnetic Disk	400 GB–8TB	10ms	200MB/sec	$70–$500
Optical Storage	50GB–100GB	180ms	72MB/sec	$100
Magnetic Tape	2.5TB–8.5TB	10s–80s	40–250MB/sec	$2.5K–$30K
Tape jukebox	25TB–2,100,000TB	10s–80s	250MB/sec–1.2PB/sec	$3K–$1M+

*Capacities are based on commercially available popular units in 2014.

**Costs are based on commodity online marketplaces.

Table 10.1 Types of Storage with Capacity, Access Time, Max Bandwidth (Transfer Speed), and Commodity Cost

Storage Organization of Databases

- Persistent data
  - Most databases
- Transient data
  - Exists only during program execution
- File organization
  - Determines how records are physically placed on the disk
  - Determines how records are accessed

10.2 Secondary Storage Devices

- Hard disk drive
- Bits (ones and zeros)
  - Grouped into bytes or characters
- Disk capacity measures storage size
- Disks may be single or double-sided
- Concentric circles called tracks
  - Tracks divided into blocks or sectors
- Disk packs
  - Cylinder

Single-Sided Disk and Disk Pack

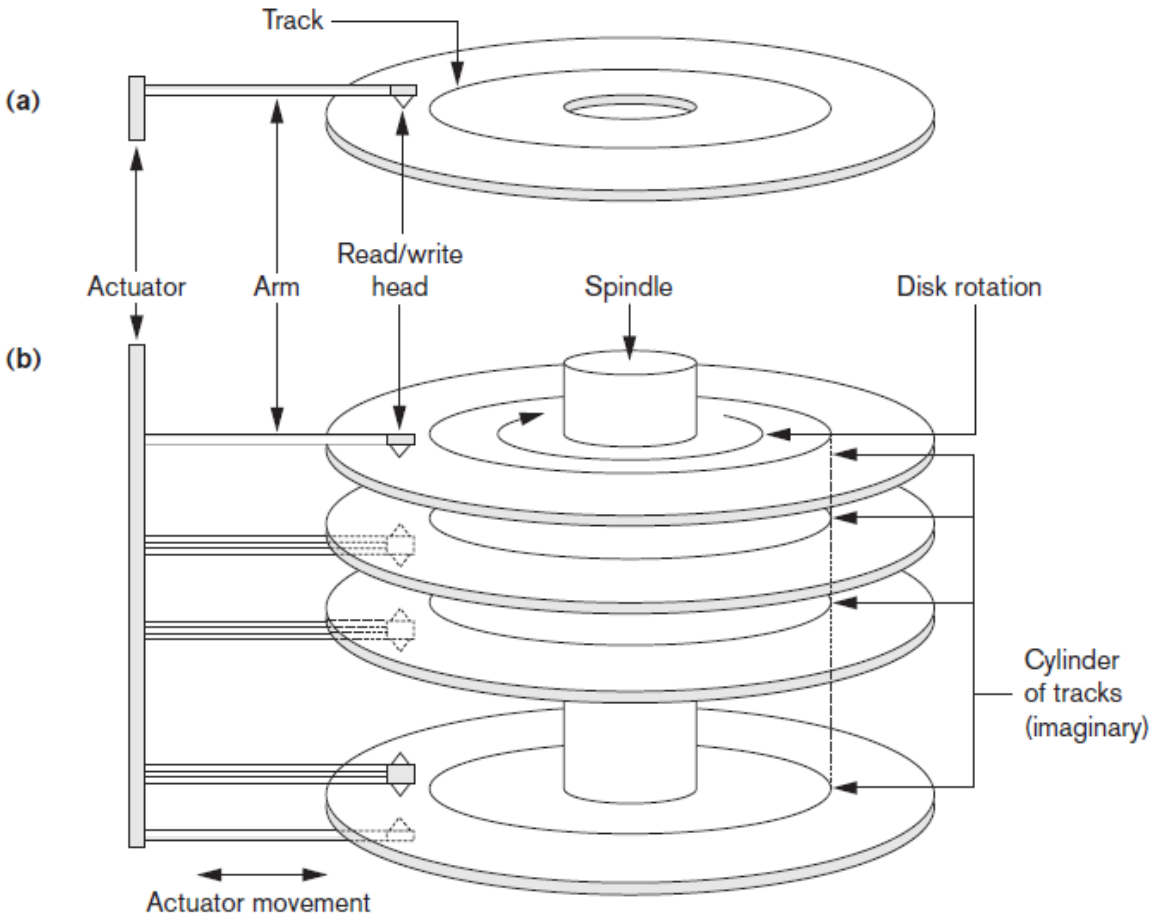

Figure 10.1 (a) A single-sided disk with read/write hardware (b) A disk pack with read/write hardware

Sectors on a Disk

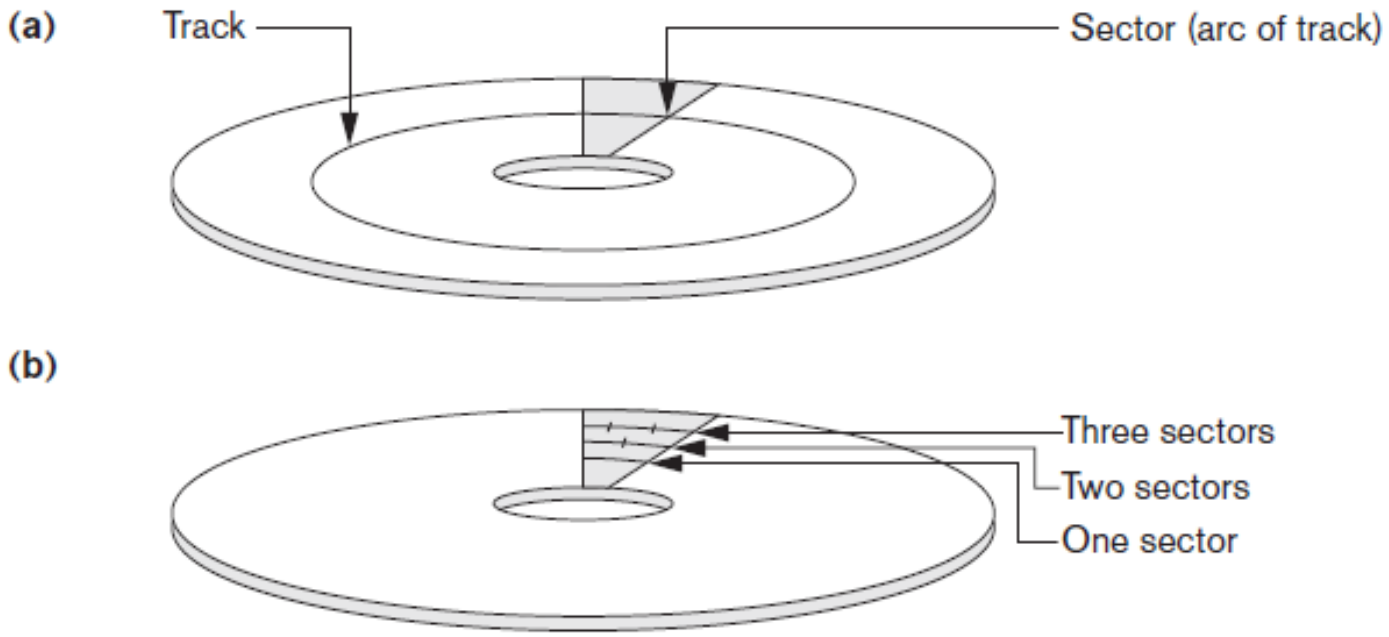

Figure 10.2 Different sector organizations on disk (a) Sectors subtending a fixed angle (b) Sectors maintaining a uniform recording density

Secondary Storage Devices (cont'd.)

- Formatting
  - Divides tracks into equal-sized disk blocks
  - Blocks separated by interblock gaps
- Data transfer in units of disk blocks
  - Hardware address supplied to disk I/O hardware
- Buffer
  - Used in read and write operations
- Read/write head
  - Hardware mechanism for read and write operations

Secondary Storage Devices (cont'd.)

- Disk controller
  - Interfaces disk drive to computer system
  - Standard interfaces
    - SCSI (Small Computer System Interface)
    - SATA (Serial Advanced Technology Attachment)
    - SAS (Serial Attached SCSI)

Secondary Storage Devices (cont'd.)

- Techniques for efficient data access
  - Data buffering
  - Proper organization of data on disk
  - Reading data ahead of request
  - Proper scheduling of I/O requests
  - Use of log disks to temporarily hold writes
  - Use of SSDs or flash memory for recovery purposes

Solid State Device Storage

- Sometimes called flash storage
- Main component: controller
- Set of interconnected flash memory cards
- No moving parts
- Data less likely to be fragmented
- More costly than HDDs
- DRAM-based SSDs available
  - Faster access times compared with flash

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Magnetic Tape Storage Devices

- Sequential access
  - Must scan preceding blocks
- Tape is mounted and scanned until required block is under read/write head
- Important functions
  - Backup
  - Archive

10.3 Buffering of Blocks

- Buffering most useful when processes can run concurrently in parallel

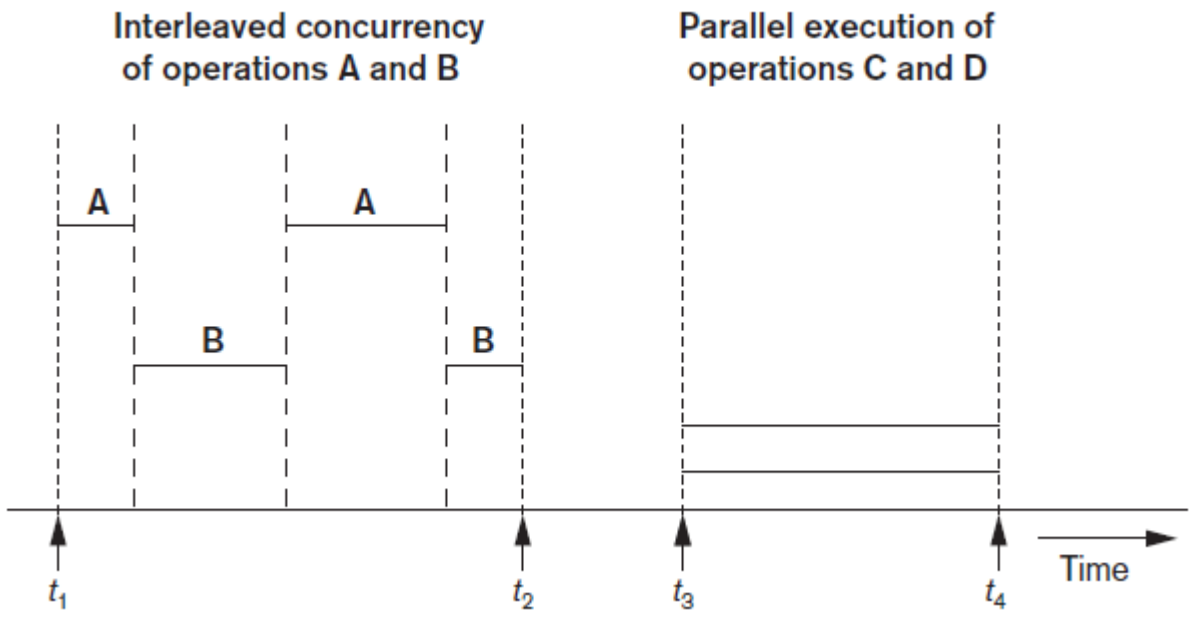

Figure 10.3 Interleaved concurrency versus parallel execution

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Buffering of Blocks (cont'd.)

- Double buffering can be used to read continuous stream of blocks

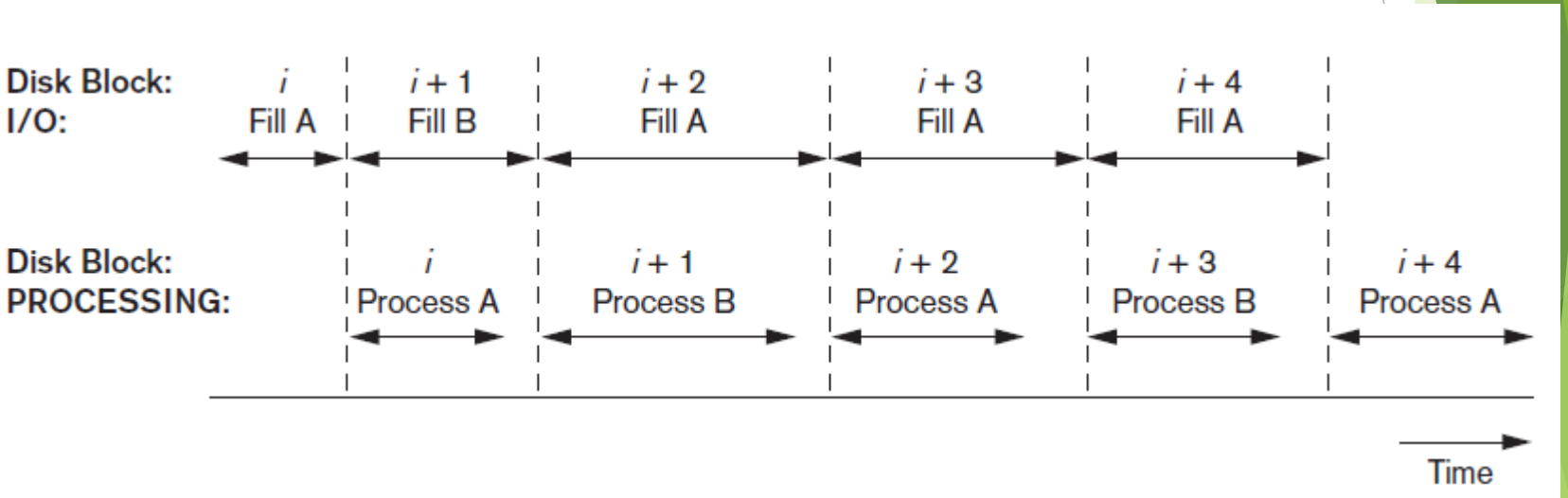

Figure 10.4 Use of two buffers, A and B, for reading from disk

Buffer Management and Replacement Strategies

- Buffer management information
  - Pin count
  - Dirty bit
- Buffer replacement strategies
  - Least recently used (LRU)
  - Clock policy
  - First-in-first-out (FIFO)

16.4 Placing File Records on Disk

- Record: collection of related data values or items
  - Values correspond to record field
- Data types
  - Numeric
  - String
  - Boolean
  - Date/time
- Binary large objects (BLOBs)
  - Unstructured objects

Placing File Records on Disk (cont'd.)

- Reasons for variable-length records
  - One or more fields have variable length
  - One or more fields are repeating
  - One or more fields are optional
  - File contains records of different types

Record Blocking and Spanned Versus Unspanned Records

- File records allocated to disk blocks
- Spanned records
  - Larger than a single block
  - Pointer at end of first block points to block containing remainder of record
- Unspanned
  - Records not allowed to cross block boundaries

Record Blocking and Spanned Versus Unspanned Records (cont'd.)

- Blocking factor
  - Average number of records per block for the file

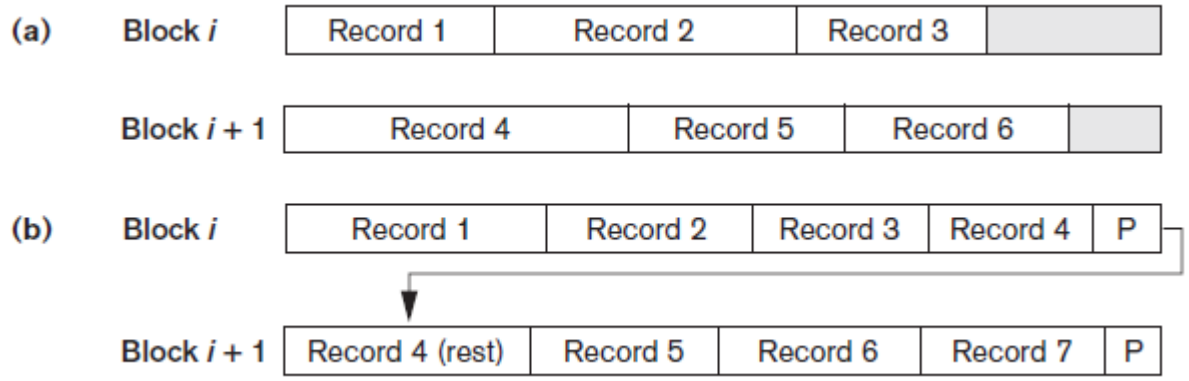

Figure 10.6 Types of record organization (a) Unspanned (b) Spanned

Record Blocking and Spanned Versus Unspanned Records (cont'd.)

- Allocating file blocks on disk
  - Contiguous allocation
  - Linked allocation
  - Indexed allocation
- File header (file descriptor)
  - Contains file information needed by system programs
    - Disk addresses
    - Format descriptions

10.5 Operations on Files

- Retrieval operations
  - No change to file data
- Update operations
  - File change by insertion, deletion, or modification
- Records selected based on selection condition

Operations on Files (cont'd.)

- Examples of operations for accessing file records
  - Open
  - Find
  - Read
  - FindNext
  - Delete
  - Insert
  - Close
  - Scan

10.6 Files of Unordered Records (Heap Files)

- Heap (or pile) file
  - Records placed in file in order of insertion
- Inserting a new record is very efficient
- Searching for a record requires linear search
- Deletion techniques
  - Rewrite the block
  - Use deletion marker

10.7 Files of Ordered Records (Sorted Files)

- Ordered (sequential) file
  - Records sorted by ordering field
    - Called ordering key if ordering field is a key field
- Advantages
  - Reading records in order of ordering key value is extremely efficient
  - Finding next record
  - Binary search technique

Access Times for Various File Organizations

Type of Organization	Access/Search Method	Average Blocks to Access a Specific Record
Heap (unordered)	Sequential scan (linear search)	$b/2$
Ordered	Sequential scan	$b/2$
Ordered	Binary search	$\log_2 b$

Table 10.3 Average access times for a file of *b* blocks under basic file organizations

10.8 Hashing Techniques

- Hash function (randomizing function)
  - Applied to hash field value of a record
  - Yields address of the disk block of stored record
- Organization called hash file
  - Search condition is equality condition on the hash field
  - Hash field typically key field
- Hashing also internal search structure
  - Used when group of records accessed exclusively by one field value

Hashing Techniques (cont'd.)

- Internal hashing
  - Hash table
- Collision
  - Hash field value for inserted record hashes to address already containing a different record
- Collision resolution
  - Open addressing
  - Chaining
  - Multiple hashing

Hashing Techniques (cont'd.)

- External hashing for disk files
  - Target address space made of buckets
  - Bucket: one disk block or contiguous blocks
- Hashing function maps a key into relative bucket
  - Table in file header converts bucket number to disk block address
- Collision problem less severe with buckets
- Static hashing
  - Fixed number of buckets allocated

Hashing Techniques (cont'd.)

- Hashing techniques that allow dynamic file expansion
  - Extendible hashing
    - File performance does not degrade as file grows
  - Dynamic hashing
    - Maintains tree-structured directory
  - Linear hashing
    - Allows hash file to expand and shrink buckets without needing a directory

10.9 Other Primary File Organizations

- Files of mixed records
  - Relationships implemented by logical field references
  - Physical clustering
- B-tree data structure
- Column-based data storage

10.10 Parallelizing Disk Access Using RAID Technology

- Redundant arrays of independent disks (RAID)
  - Goal: improve disk speed and access time
- Set of RAID architectures (0 through 6)
- Data striping
  - Bit-level striping
  - Block-level striping
- Improving Performance with RAID
  - Data striping achieves higher transfer rates

Parallelizing Disk Access Using RAID Technology (cont'd.)

- Improving reliability with RAID
  - Redundancy techniques: mirroring and shadowing
- RAID organizations and levels
  - Level 0
    - Data striping, no redundant data
    - Spits data evenly across two or more disks
  - Level 1
    - Uses mirrored disks

Parallelizing Disk Access Using RAID Technology (cont'd.)

- RAID organizations and levels (cont'd.)
  - Level 2
    - Hamming codes for memory-style redundancy
    - Error detection and correction
  - Level 3
    - Single parity disk relying on disk controller
  - Levels 4 and 5
    - Block-level data striping
    - Data distribution across all disks (level 5)

Parallelizing Disk Access Using RAID Technology (cont'd.)

- RAID organizations and levels (cont'd.)
  - Level 6
    - Applies P+Q redundancy scheme
    - Protects against up to two disk failures by using just two redundant disks
- Rebuilding easiest for RAID level 1
  - Other levels require reconstruction by reading multiple disks
- RAID levels 3 and 5 preferred for large volume storage

RAID Levels

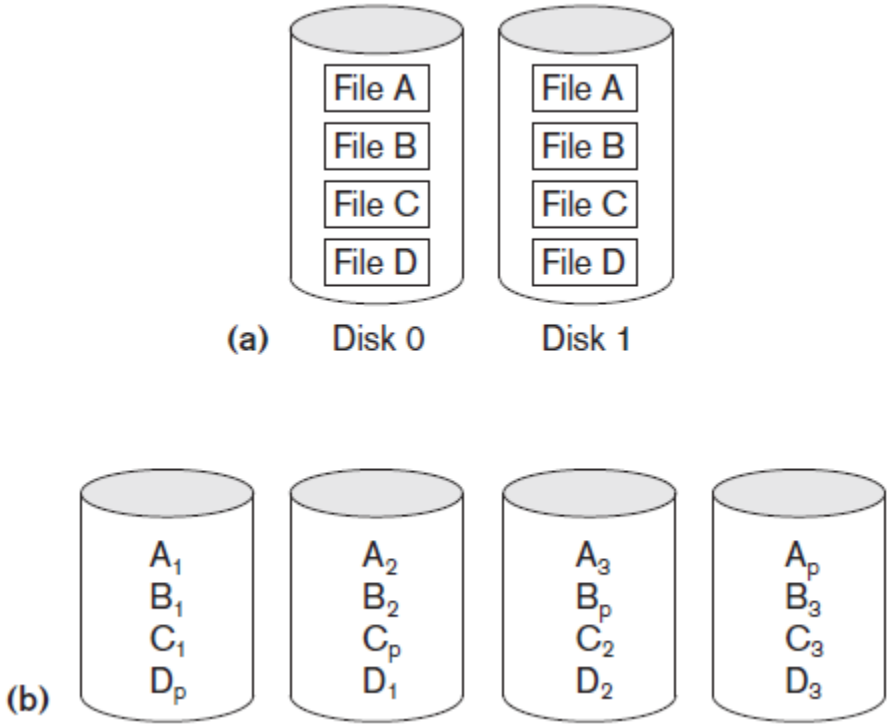

Figure 10.14 Some popular levels of RAID (a) RAID level 1: Mirroring of data on two disks (b) RAID level 5: Striping of data with distributed parity across four disks

10.11 Modern Storage Architectures

- Storage area networks
  - Online storage peripherals configured as nodes on high-speed network
- Network-attached storage
  - Servers used for file sharing
  - High degree of scalability, reliability, flexibility, performance
- iSCSI
  - Clients send SCSI commands to SCSI storage devices on remote channels

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Modern Storage Architectures (cont'd.)

- Fibre Channel over IP (FCIP)
  - Fibre Channel control codes and data translated into IP packets
  - Transmitted between geographically distant Fibre Channel SANs
- Fibre Channel over Ethernet (FCoE)
  - Similar to iSCSI without the IP

Modern Storage Architectures (cont'd.)

- Automated storage tiering
  - Automatically moves data between different storage types depending on need
    - Frequently-used data moved to solid-state drives
- Object-based storage
  - Data managed in form of objects rather than files made of blocks
  - Objects carry metadata and global identifier
  - Ideally suited for scalable storage of unstructured data

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10.12 Summary

- Magnetic disks
  - Accessing a disk block is expensive
- Commands for accessing file records
- File organizations: unordered, ordered, hashed
- RAID
- Modern storage trends