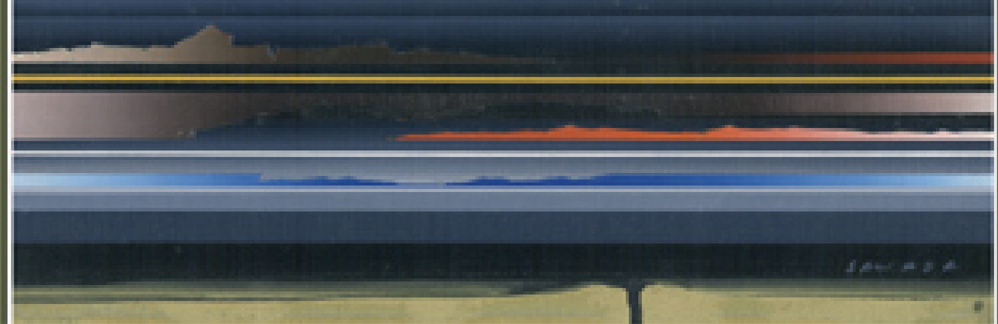
Fundamentals of

Database Systems

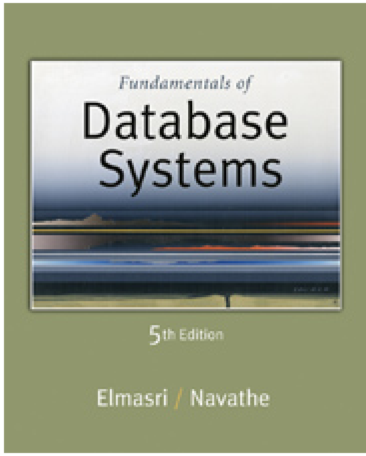


5th Edition

Elmasri / Navathe

Chapter 13

Disk Storage, Basic File Structures, and Hashing



Chapter Outline

- Disk Storage Devices
- Files of Records
- Operations on Files
- Unordered Files
- Ordered Files
- Hashed Files
  - Dynamic and Extendible Hashing Techniques
- RAID Technology

Disk Storage Devices

- Preferred secondary storage device for high storage capacity and low cost.
- Data stored as magnetized areas on magnetic disk surfaces.
- A **disk pack** contains several magnetic disks connected to a rotating spindle.
- Disks are divided into concentric circular **tracks** on each disk **surface**.
  - Track capacities vary typically from 4 to 50 Kbytes or more

Disk Storage Devices (contd.)

- A track is divided into smaller **blocks** or **sectors**
  - because it usually contains a large amount of information
- The division of a track into **sectors** is hard-coded on the disk surface and cannot be changed.
  - One type of sector organization calls a portion of a track that subtends a fixed angle at the center as a sector.
- A track is divided into **blocks**.
  - The block size B is fixed for each system.
    - Typical block sizes range from B=512 bytes to B=4096 bytes.
  - Whole blocks are transferred between disk and main memory for processing.

Disk Storage Devices (contd.)

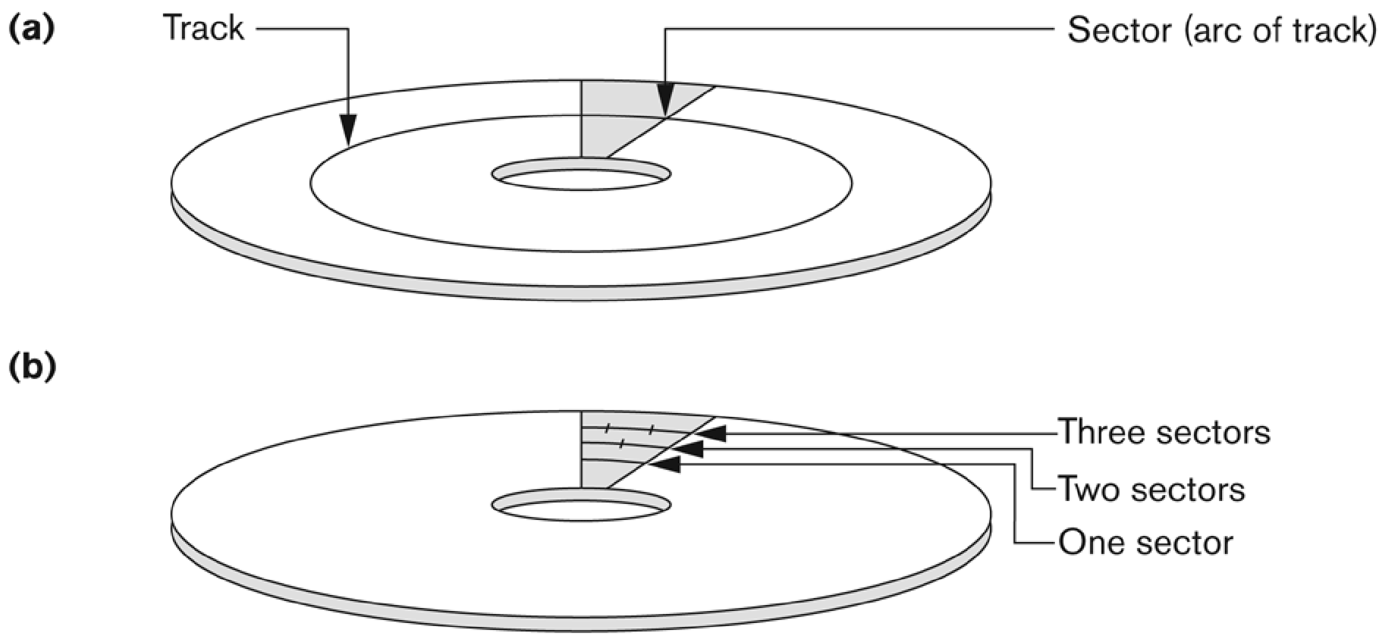


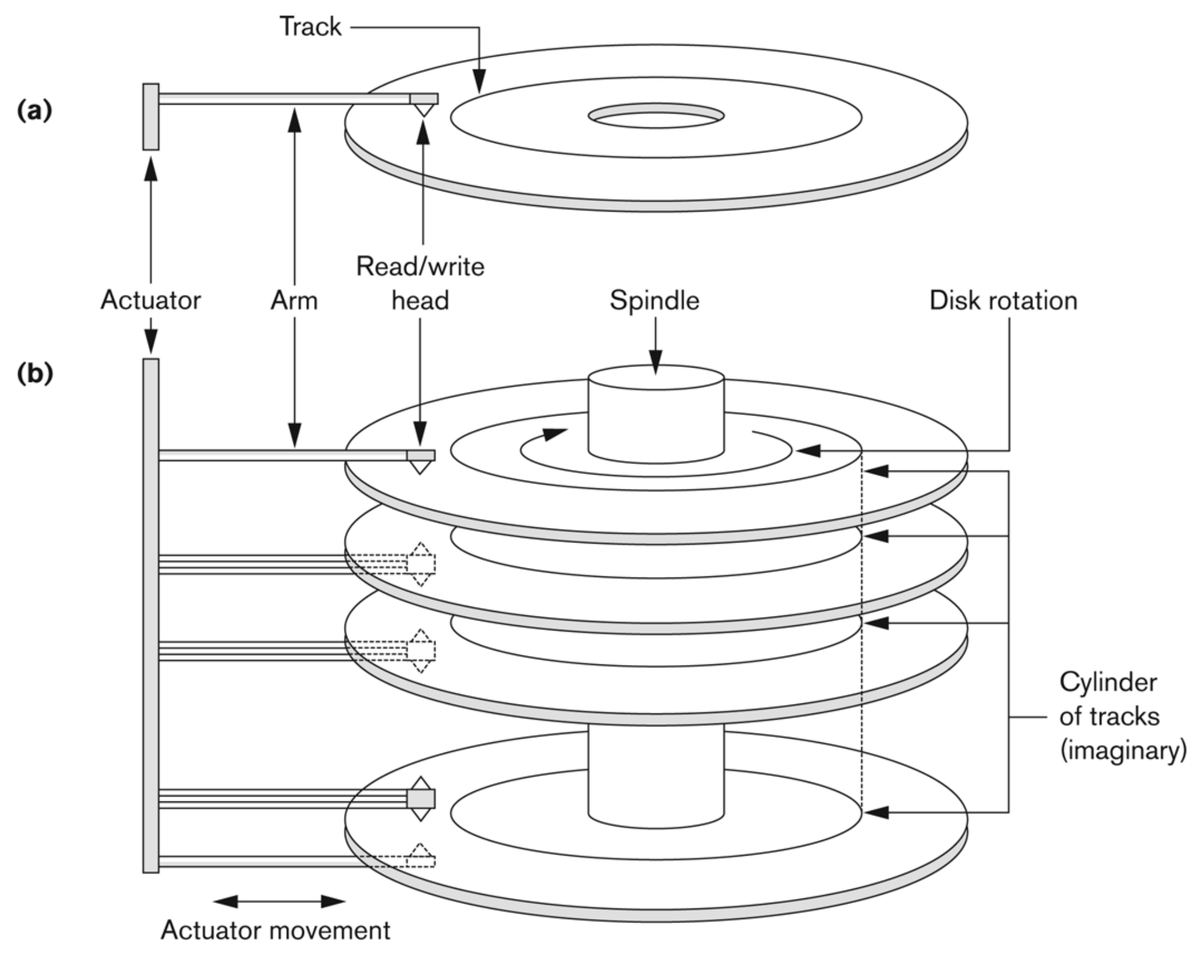
Figure 13.2
Different sector organizations on disk. (a) Sectors subtending a fixed angle. (b) Sectors maintaining a uniform recording density.

Disk Storage Devices (contd.)

- A **read-write head** moves to the track that contains the block to be transferred.
  - Disk rotation moves the block under the read-write head for reading or writing.
- A physical disk block (hardware) address consists of:
  - a cylinder number (imaginary collection of tracks of same radius from all recorded surfaces)
  - the track number or surface number (within the cylinder)
  - and block number (within track).
- Reading or writing a disk block is time consuming because of the seek time s and rotational delay (latency) **rd**.
- Double buffering can be used to speed up the transfer of contiguous disk blocks.

Disk Storage Devices (contd.)

Figure 13.1
(a) A single-sided disk with read/write hardware. (b) A disk pack with read/write hardware.



Typical Disk Parameters

Table 13.1
Specifications of Typical High-end Cheetah Disks from Seagate

Description	Cheetah 10K.6	Cheetah 10K.7
Model Number	ST3146807LC	ST3300007LW
Form Factor (width)	3.5 inch	3.5 inch
Form Factor (height)	1 inch	1 inch
Height	25.4 mm	25.4 mm
Width	101.6 mm	101.6 mm
Length	146.05 mm	146.05 mm
Weight	0.73 Kg	0.726 kg
Capacity/Interface		
Formatted Capacity	146.8 Gbytes	300 Gbytes
Interface Type	80-pin	68-pin
Configuration		
Number of disks (physical)	4	4
Number of heads (physical)	8	8
Number of Cylinders	49,854	90,774
Total Tracks		726,192
Bytes per Sector	512	512
Areal Density	36,000 Mb/sq.inch	
Track Density	64,000 Tracks/inch	105,000 Tracks/inch
Recording Density	570,000 bits/inch	658,000 bits/inch
Bytes/Track (avg)		556
Performance		
Transfer Rates		
Internal Transfer Rate (min)	475 Mb/sec	472 Mb/sec
Internal Transfer Rate (max)	840 Mb/sec	944 Mb/sec
Formated Int. Transfer Rate (min)	43 MB/sec	59 MB/sec
Formated Int. Transfer Rate (max)	78 MB/sec	118 MB/sec
External I/O Transfer Rate (max)	320 MB/sec	320 MB/sec
Average Formatted Transfer Rate	59.9 MB/sec	59.5 MB/sec
Seek Times		
Avg. Seek Time (Read)	4.7 ms (typical)	4.7 ms (typical)
Avg. Seek Time (Write)	5.2 ms (typical)	5.3 ms (typical)
Track-to-track, Seek, Read	0.3 ms (typical)	0.2 ms (typical)
Track-to-track, Seek, Write	0.5 ms (typical)	0.5 ms (typical)
Full Disc Seek, Read		9.5 ms (typical)
Full Disc Seek, Write		10.3 ms (typical)
Average Latency	2.99 ms	3 msec
Other		
Default Buffer (cache) size	8,000 KB	8,192 KB
Spindle Speed	10000 RPM	10000 RPM
Power-on to Ready Time		25 sec

(Courtesy of Seagate Technology)

Records

- Fixed and variable length records
- Records contain fields which have values of a particular type
  - E.g., amount, date, time, age
- Fields themselves may be fixed length or variable length
- Variable length fields can be mixed into one record:
  - Separator characters or length fields are needed so that the record can be "parsed."

Blocking

- **Blocking**:
  - Refers to storing a number of records in one block on the disk.
- Blocking factor (**bfr**) refers to the number of records per block.
- There may be empty space in a block if an integral number of records do not fit in one block.
- **Spanned Records**:
  - Refers to records that exceed the size of one or more blocks and hence span a number of blocks.

Files of Records

- A **file** is a *sequence* of records, where each record is a collection of data values (or data items).
- A **file descriptor** (or **file header**) includes information that describes the file, such as the *field names* and their *data types*, and the addresses of the file blocks on disk.
- Records are stored on disk blocks.
- The **blocking factor bfr** for a file is the (average) number of file records stored in a disk block.
- A file can have **fixed-length** records or **variable-length** records.

Files of Records (contd.)

- File records can be **unspanned** or **spanned**
  - **Unspanned**: no record can span two blocks
  - **Spanned**: a record can be stored in more than one block
- The physical disk blocks that are allocated to hold the records of a file can be *contiguous, linked, or indexed*.
- In a file of fixed-length records, all records have the same format. Usually, unspanned blocking is used with such files.
- Files of variable-length records require additional information to be stored in each record, such as **separator characters** and **field types**.
  - Usually spanned blocking is used with such files.

Operation on Files

- Typical file operations include:
  - **OPEN**: Readies the file for access, and associates a pointer that will refer to a *current* file record at each point in time.
  - **FIND**: Searches for the first file record that satisfies a certain condition, and makes it the current file record.
  - **FINDNEXT**: Searches for the next file record (from the current record) that satisfies a certain condition, and makes it the current file record.
  - **READ**: Reads the current file record into a program variable.
  - **INSERT**: Inserts a new record into the file & makes it the current file record.
  - **DELETE**: Removes the current file record from the file, usually by marking the record to indicate that it is no longer valid.
  - **MODIFY**: Changes the values of some fields of the current file record.
  - **CLOSE**: Terminates access to the file.
  - **REORGANIZE**: Reorganizes the file records.
    - For example, the records marked deleted are physically removed from the file or a new organization of the file records is created.
  - **READ_ORDERED**: Read the file blocks in order of a specific field of the file.

Unordered Files

- Also called a **heap** or a **pile** file.
- New records are inserted at the end of the file.
- A **linear search** through the file records is necessary to search for a record.
  - This requires reading and searching half the file blocks on the average, and is hence quite expensive.
- Record insertion is quite efficient.
- Reading the records in order of a particular field requires sorting the file records.

Ordered Files

- Also called a **sequential** file.
- File records are kept sorted by the values of an *ordering field*.
- Insertion is expensive: records must be inserted in the correct order.
  - It is common to keep a separate unordered *overflow* (or *transaction*) file for new records to improve insertion efficiency; this is periodically merged with the main ordered file.
- A **binary search** can be used to search for a record on its *ordering field* value.
  - This requires reading and searching $\log_2$ of the file blocks on the average, an improvement over linear search.
- Reading the records in order of the ordering field is quite efficient.

Ordered Files (contd.)

	NAME	SSN	BIRTHDATE	JOB	SALARY	SEX
block 1	Aaron, Ed					
	Abbott, Diane					
	⋮					
	Acosta, Marc					
block 2	Adams, John					
	Adams, Robin					
	⋮					
	Akers, Jan					
block 3	Alexander, Ed					
	Alfred, Bob					
	⋮					
	Allen, Sam					
block 4	Allen, Troy					
	Anders, Keith					
	⋮					
	Anderson, Rob					
block 5	Anderson, Zach					
	Angeli, Joe					
	⋮					
	Archer, Sue					
block 6	Arnold, Mack					
	Arnold, Steven					
	⋮					
	Atkins, Timothy					
⋮						
block n –1	Wong, James					
	Wood, Donald					
	⋮					
	Woods, Manny					
block n	Wright, Pam					
	Wyatt, Charles					
	⋮					
	Zimmer, Byron					

Average Access Times

- The following table shows the average access time to access a specific record for a given type of file

TABLE 13.2 AVERAGE ACCESS TIMES FOR BASIC FILE ORGANIZATIONS

TYPE OF ORGANIZATION	ACCESS/SEARCH METHOD	AVERAGE TIME TO ACCESS A SPECIFIC RECORD
Heap (Unordered)	Sequential scan (Linear Search)	$b/2$
Ordered	Sequential scan	$b/2$
Ordered	Binary Search	$\log_2 b$

Hashed Files

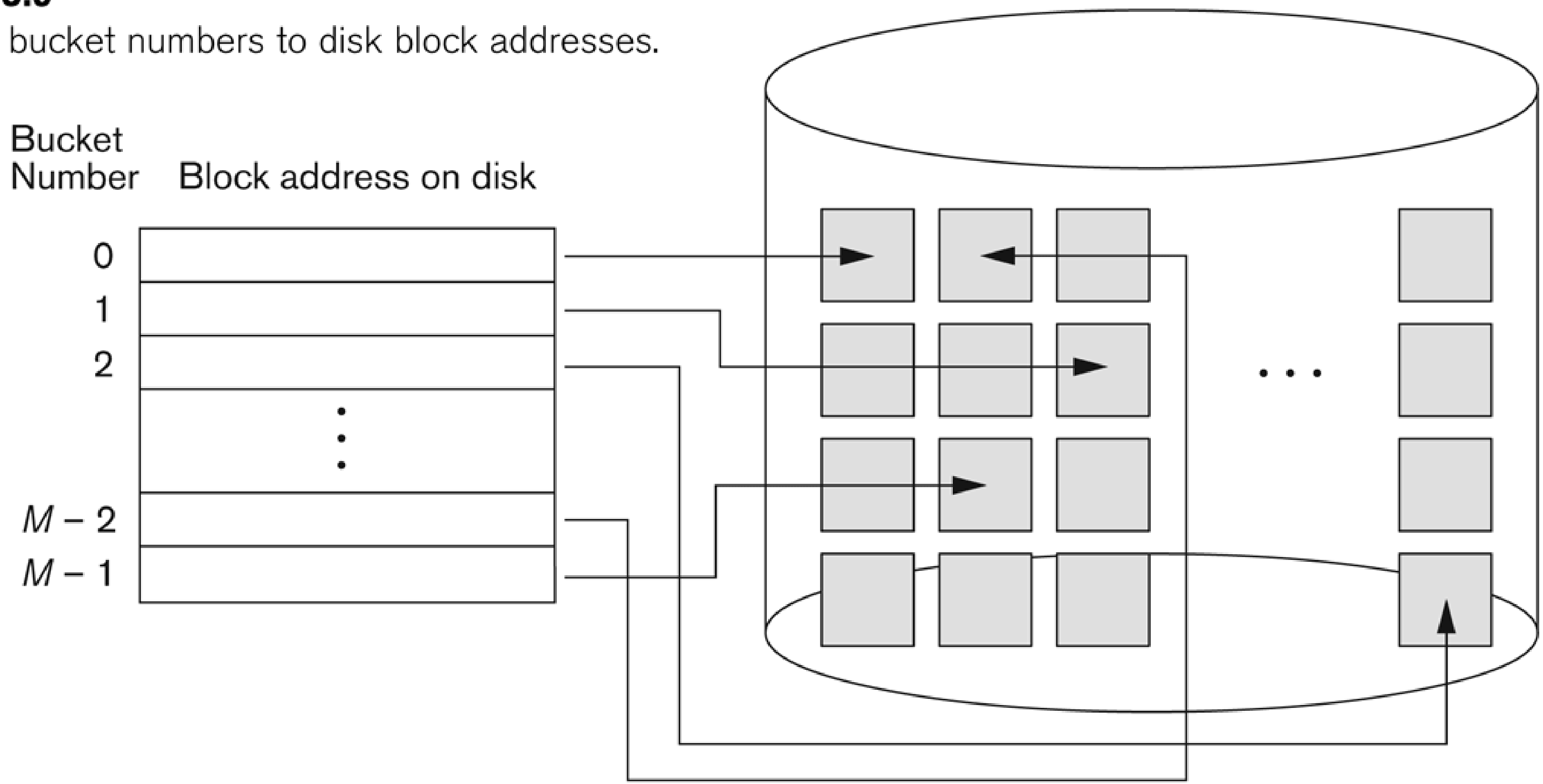
- Hashing for disk files is called **External Hashing**
- The file blocks are divided into M equal-sized **buckets**, numbered $bucket_0$, $bucket_1$, ..., $bucket_{M-1}$.
  - Typically, a bucket corresponds to one (or a fixed number of) disk block.
- One of the file fields is designated to be the **hash key** of the file.
- The record with hash key value K is stored in bucket i, where i=h(K), and h is the **hashing function**.
- Search is very efficient on the hash key.
- Collisions occur when a new record hashes to a bucket that is already full.
  - An overflow file is kept for storing such records.
  - Overflow records that hash to each bucket can be linked together.

Hashed Files (contd.)

- There are numerous methods for collision resolution, including the following:
  - **Open addressing**: Proceeding from the occupied position specified by the hash address, the program checks the subsequent positions in order until an unused (empty) position is found.
  - **Chaining**: For this method, various overflow locations are kept, usually by extending the array with a number of overflow positions. In addition, a pointer field is added to each record location. A collision is resolved by placing the new record in an unused overflow location and setting the pointer of the occupied hash address location to the address of that overflow location.
  - **Multiple hashing**: The program applies a second hash function if the first results in a collision. If another collision results, the program uses open addressing or applies a third hash function and then uses open addressing if necessary.

Hashed Files (contd.)

Figure 13.9
Matching bucket numbers to disk block addresses.



Hashed Files (contd.)

- To reduce overflow records, a hash file is typically kept 70-80% full.
- The hash function h should distribute the records uniformly among the buckets
  - Otherwise, search time will be increased because many overflow records will exist.
- Main disadvantages of static external hashing:
  - Fixed number of buckets M is a problem if the number of records in the file grows or shrinks.
  - Ordered access on the hash key is quite inefficient (requires sorting the records).

Hashed Files - Overflow handling

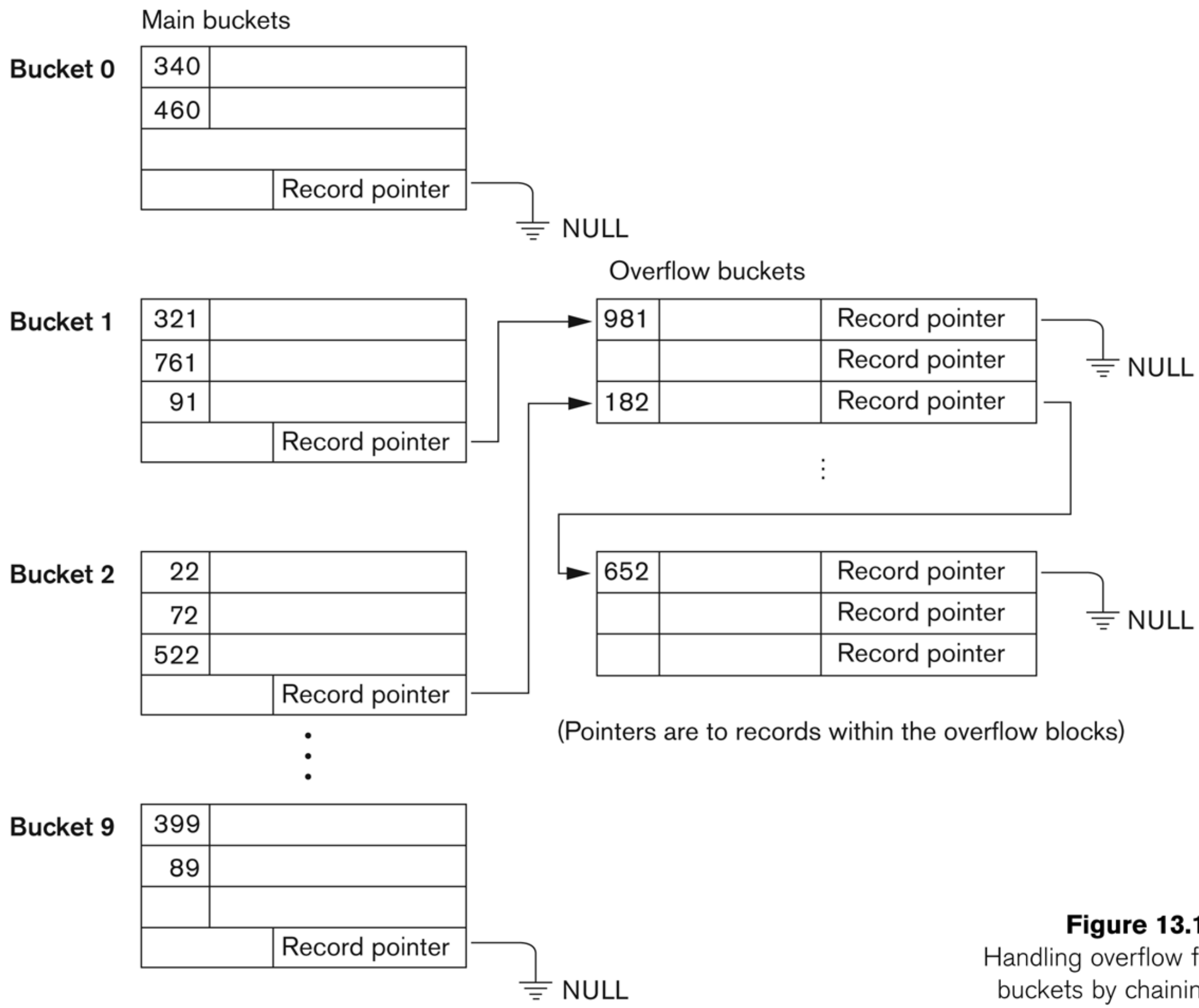


Figure 13.10
Handling overflow for buckets by chaining.

Dynamic And Extendible Hashed Files

- Dynamic and Extendible Hashing Techniques
  - Hashing techniques are adapted to allow the dynamic growth and shrinking of the number of file records.
  - These techniques include the following: **dynamic hashing, extendible hashing**, and **linear hashing.**
- Both dynamic and extendible hashing use the **binary representation** of the hash value h(K) in order to access a **directory**.
  - In dynamic hashing the directory is a binary tree.
  - In extendible hashing the directory is an array of size 2^d where d is called the **global depth**.

Dynamic And Extendible Hashing (contd.)

- The directories can be stored on disk, and they expand or shrink dynamically.
  - Directory entries point to the disk blocks that contain the stored records.
- An insertion in a disk block that is full causes the block to split into two blocks and the records are redistributed among the two blocks.
  - The directory is updated appropriately.
- Dynamic and extendible hashing do not require an overflow area.
- Linear hashing does require an overflow area but does not use a directory.
  - Blocks are split in *linear order* as the file expands.

Extendible Hashing

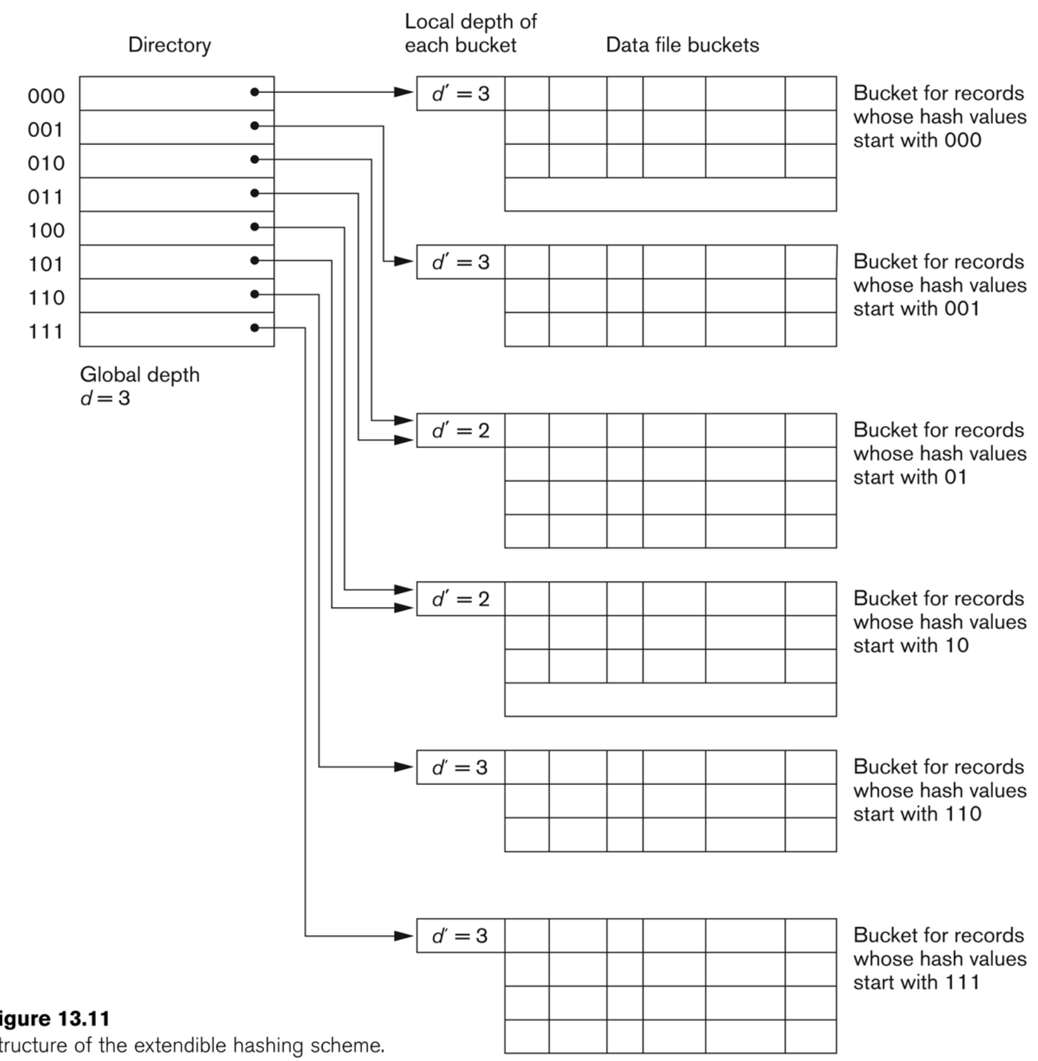


Figure 13.11
Structure of the extendible hashing scheme.

Parallelizing Disk Access using RAID Technology.

- Secondary storage technology must take steps to keep up in performance and reliability with processor technology.
- A major advance in secondary storage technology is represented by the development of **RAID**, which originally stood for **Redundant Arrays of Inexpensive Disks**.
- The main goal of RAID is to even out the widely different rates of performance improvement of disks against those in memory and microprocessors.

RAID Technology (contd.)

- A natural solution is a large array of small independent disks acting as a single higher-performance logical disk.
- A concept called **data striping** is used, which utilizes parallelism to improve disk performance.
- Data striping distributes data transparently over multiple disks to make them appear as a single large, fast disk.

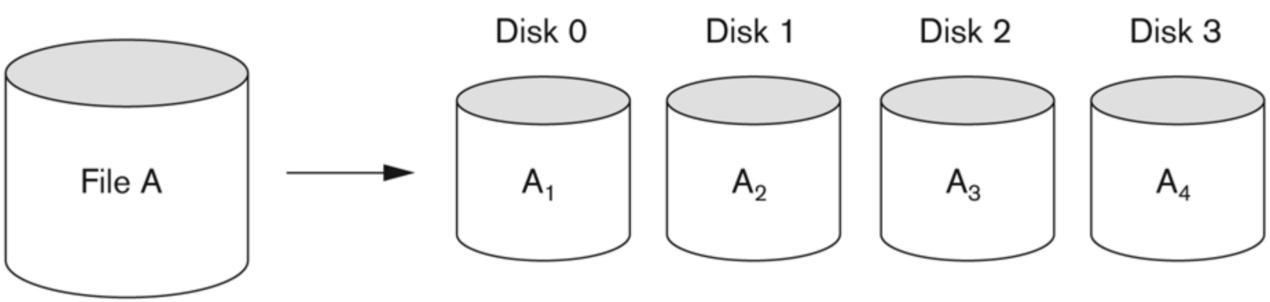


Figure 13.12
Data striping. File A is striped across four disks.

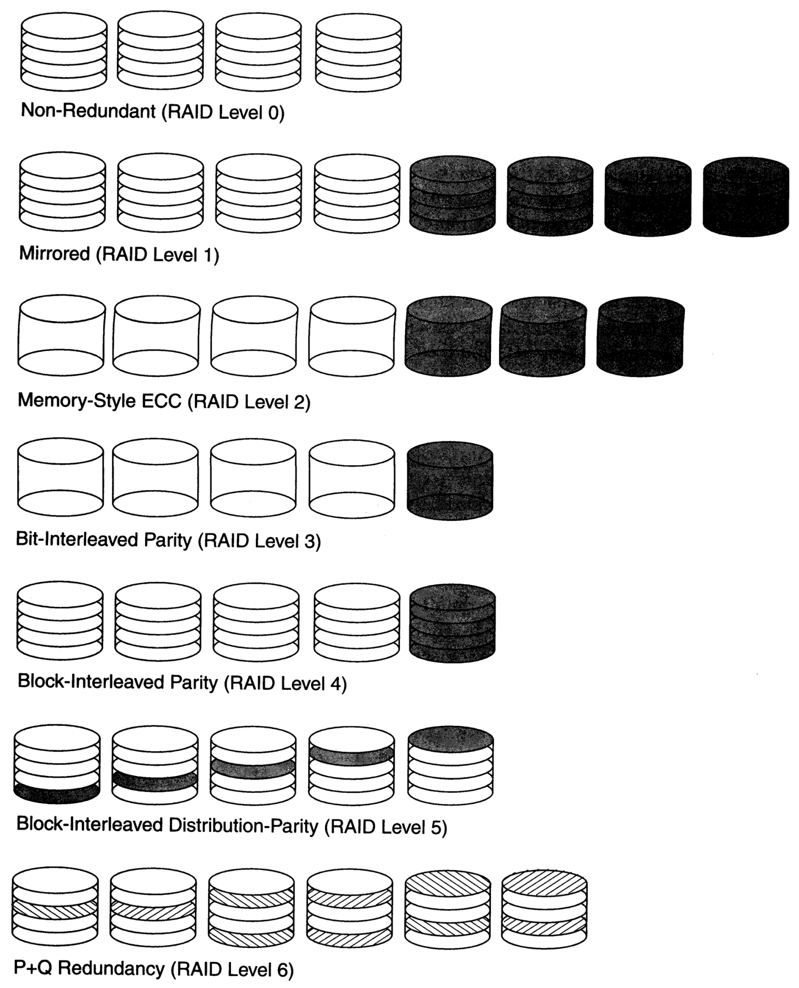
RAID Technology (contd.)

- Different raid organizations were defined based on different combinations of the two factors of granularity of data interleaving (striping) and pattern used to compute redundant information.
  - Raid level 0 has no redundant data and hence has the best write performance at the risk of data loss
  - Raid level 1 uses mirrored disks.
  - Raid level 2 uses memory-style redundancy by using Hamming codes, which contain parity bits for distinct overlapping subsets of components. Level 2 includes both error detection and correction.
  - Raid level 3 uses a single parity disk relying on the disk controller to figure out which disk has failed.
  - Raid Levels 4 and 5 use block-level data striping, with level 5 distributing data and parity information across all disks.
  - Raid level 6 applies the so-called P + Q redundancy scheme using Reed-Soloman codes to protect against up to two disk failures by using just two redundant disks.

Use of RAID Technology (contd.)

- Different raid organizations are being used under different situations
  - Raid level 1 (mirrored disks) is the easiest for rebuild of a disk from other disks
    - It is used for critical applications like logs
  - Raid level 2 uses memory-style redundancy by using Hamming codes, which contain parity bits for distinct overlapping subsets of components.
    - Level 2 includes both error detection and correction.
  - Raid level 3 (single parity disks relying on the disk controller to figure out which disk has failed) and level 5 (block-level data striping) are preferred for Large volume storage, with level 3 giving higher transfer rates.
- Most popular uses of the RAID technology currently are:
  - Level 0 (with striping), Level 1 (with mirroring) and Level 5 with an extra drive for parity.
- Design Decisions for RAID include:
  - Level of RAID, number of disks, choice of parity schemes, and grouping of disks for block-level striping.

Use of RAID Technology (contd.)



Trends in Disk Technology

TABLE 13.3 TRENDS IN DISK TECHNOLOGY

	1993 PARAMETER VALUES*	HISTORICAL RATE OF IMPROVEMENT PER YEAR (%)*	CURRENT (2003) VALUES**
Areal density	50–150 Mbits/sq. inch	27	36 Gbits/sq. inch
Linear density	40,000–60,000 bits/inch	13	570 Kbits/inch
Inter-track density	1500–3000 tracks/inch	10	64,000 tracks/inch
Capacity (3.5" form factor)	100–2000 MB	27	146 GB
Transfer rate	3–4 MB/s	22	43–78 MB/sec
Seek time	7–20 ms	8	3.5–6 msec

**Source:* From Chen, Lee, Gibson, Katz, and Patterson (1994), ACM *Computing Surveys*, Vol. 26, No. 2 (June 1994). Reprinted by permission.

***Source:* IBM Ultrastar 36XP and 18ZX hard disk drives.

Storage Area Networks

- The demand for higher storage has risen considerably in recent times.
- Organizations have a need to move from a static fixed data center oriented operation to a more flexible and dynamic infrastructure for information processing.
- Thus they are moving to a concept of Storage Area Networks (SANs).
  - In a SAN, online storage peripherals are configured as nodes on a high-speed network and can be attached and detached from servers in a very flexible manner.
- This allows storage systems to be placed at longer distances from the servers and provide different performance and connectivity options.

Storage Area Networks (contd.)

- Advantages of SANs are:
  - Flexible many-to-many connectivity among servers and storage devices using fiber channel hubs and switches.
  - Up to 10km separation between a server and a storage system using appropriate fiber optic cables.
  - Better isolation capabilities allowing non-disruptive addition of new peripherals and servers.
- SANs face the problem of combining storage options from multiple vendors and dealing with evolving standards of storage management software and hardware.

Summary

- Disk Storage Devices
- Files of Records
- Operations on Files
- Unordered Files
- Ordered Files
- Hashed Files
  - Dynamic and Extendible Hashing Techniques
- RAID Technology