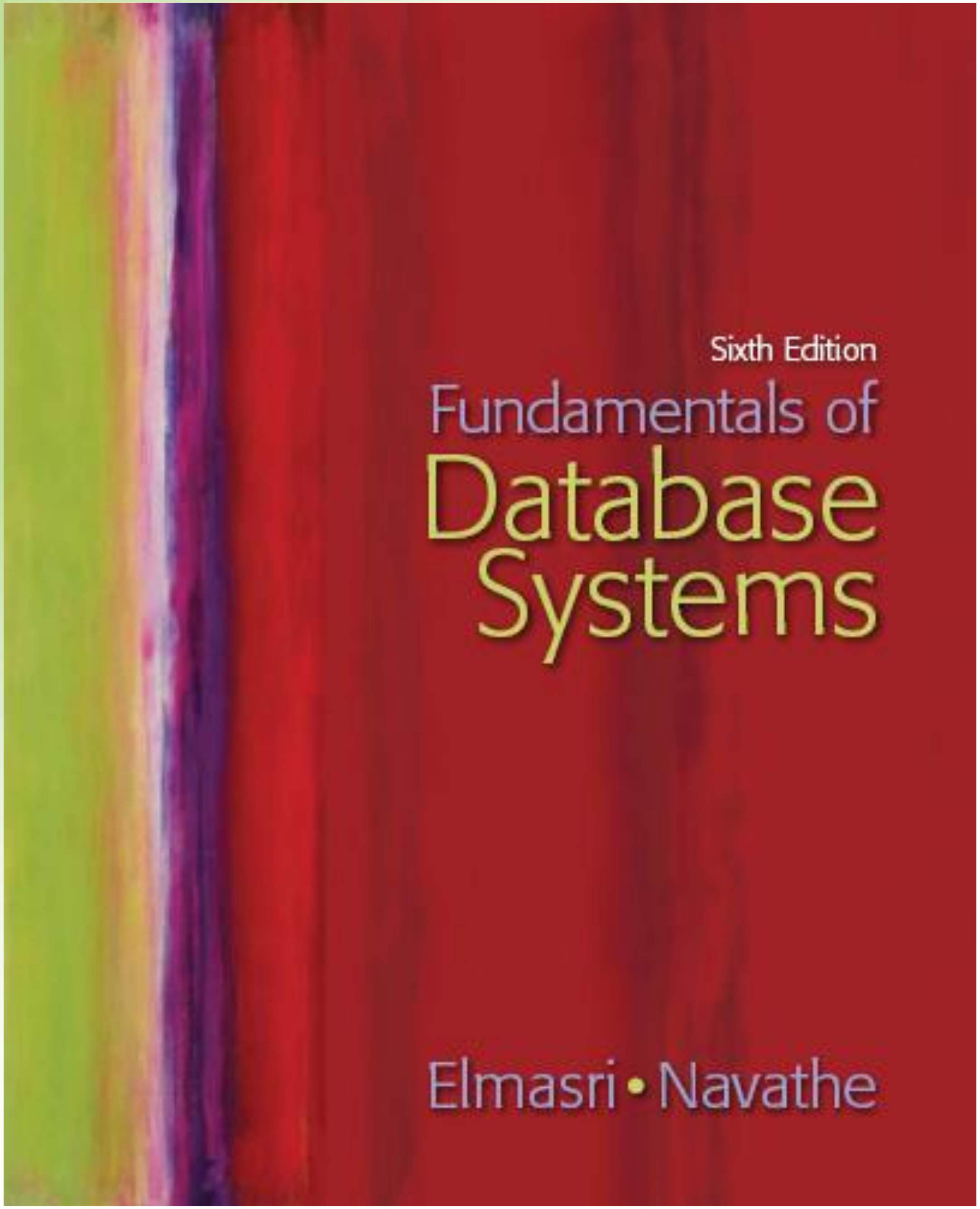
Chapter 17

Disk Storage, Basic File Structures, and Hashing



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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 (cont.)

- 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 (cont.)

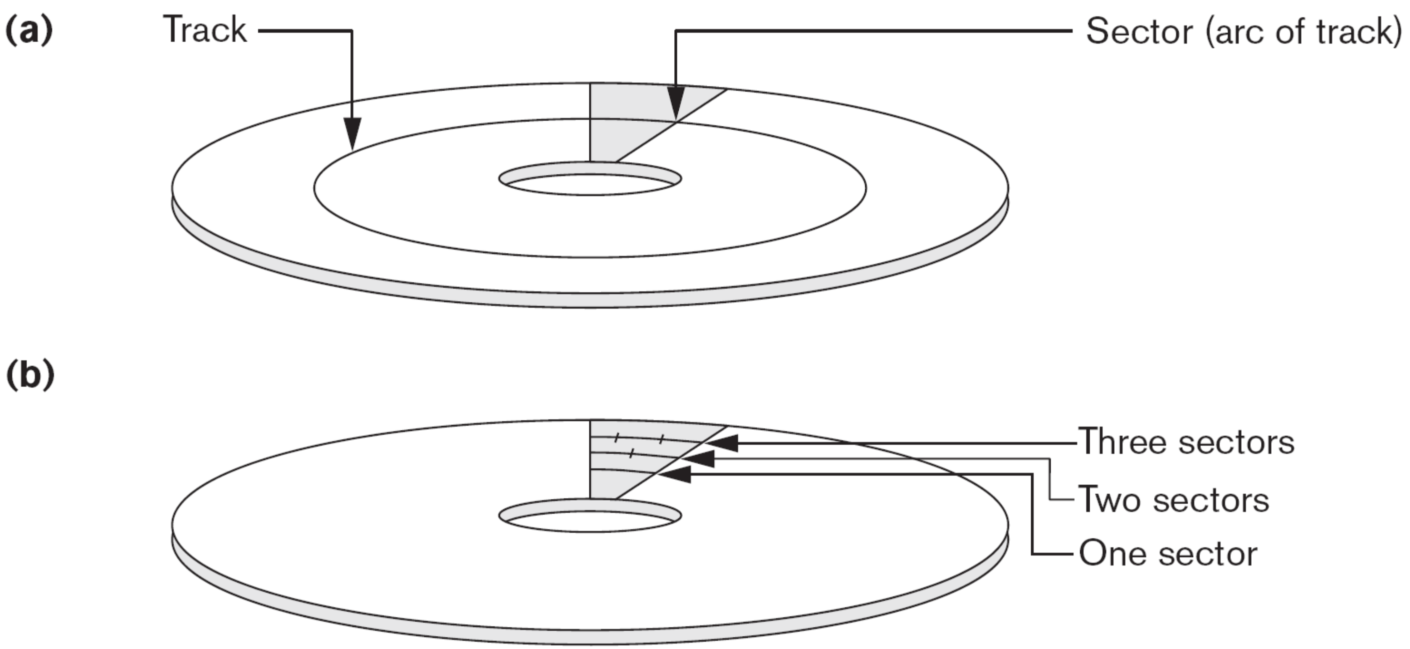


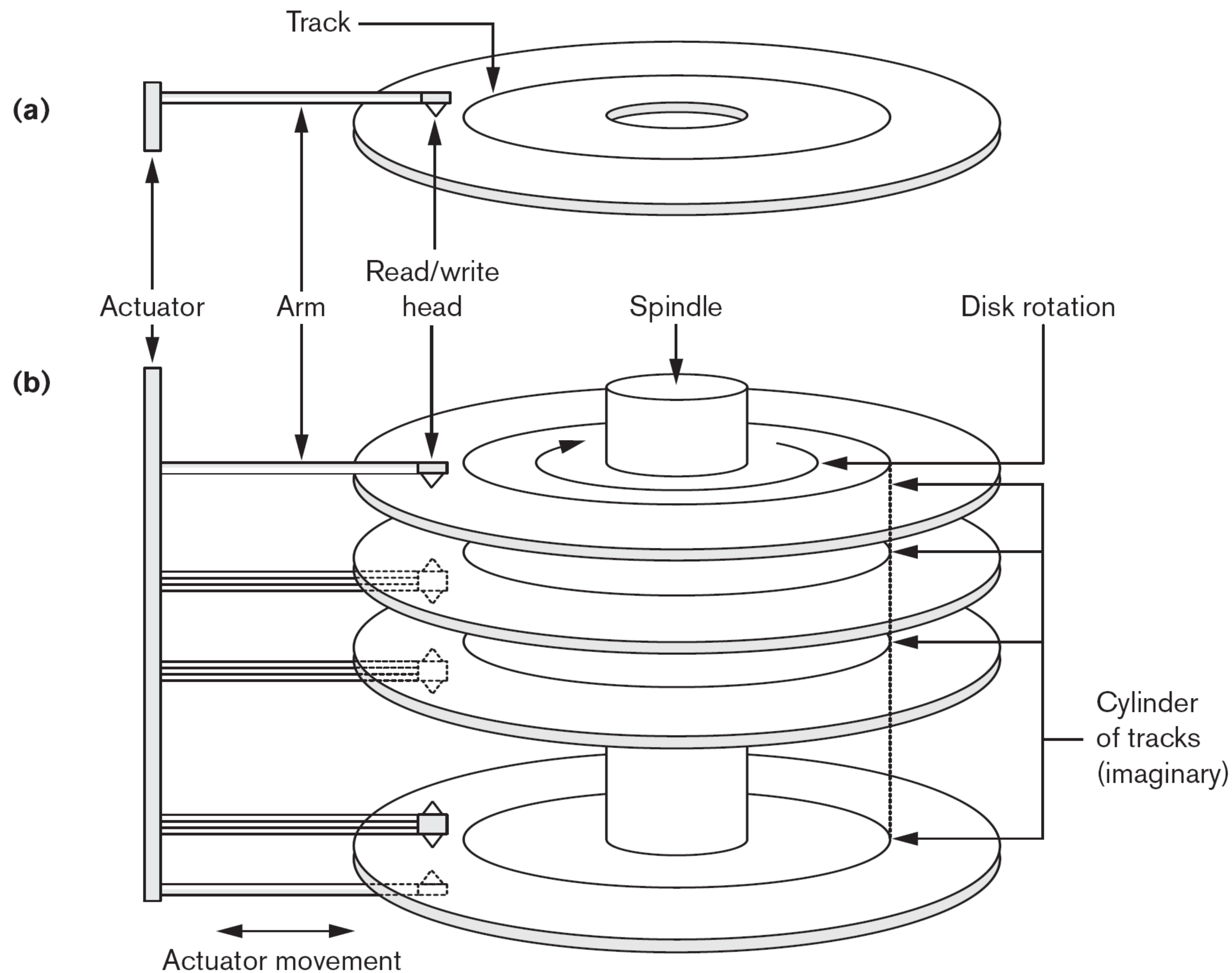
Figure 17.2
Different sector organizations on disk. (a) Sectors subtending a fixed angle. (b) Sectors maintaining a uniform recording density.

Disk Storage Devices (cont.)

- 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 (cont.)

Figure 17.1
(a) A single-sided disk with read/write hardware.
(b) A disk pack with read/write hardware.



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Typical Disk Parameters

Table 17.1 Specifications of Typical High-End Cheetah Disks from Seagate

Description	**Cheetah 15K.6**	**Cheetah NS 10K**
Model Number	ST3450856SS/FC	ST3400755FC
Height	25.4 mm	26.11 mm
Width	101.6 mm	101.85 mm
Length	146.05 mm	147 mm
Weight	0.709 kg	0.771 kg
Capacity		
Formatted Capacity	450 Gbytes	400 Gbytes
Configuration		
Number of disks (physical)	4	4
Number of heads (physical)	8	8
Performance		
Transfer Rates		
Internal Transfer Rate (min)	1051 Mb/sec	
Internal Transfer Rate (max)	2225 Mb/sec	1211 Mb/sec
Mean Time Between Failure (MTBF)		1.4 M hours
Seek Times		
Avg. Seek Time (Read)	3.4 ms (typical)	3.9 ms (typical)
Avg. Seek Time (Write)	3.9 ms (typical)	4.2 ms (typical)
Track-to-track, Seek, Read	0.2 ms (typical)	0.35 ms (typical)
Track-to-track, Seek, Write	0.4 ms (typical)	0.35 ms (typical)
Average Latency	2 ms	2.98 msec

Courtesy 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 (cont.)

- 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.

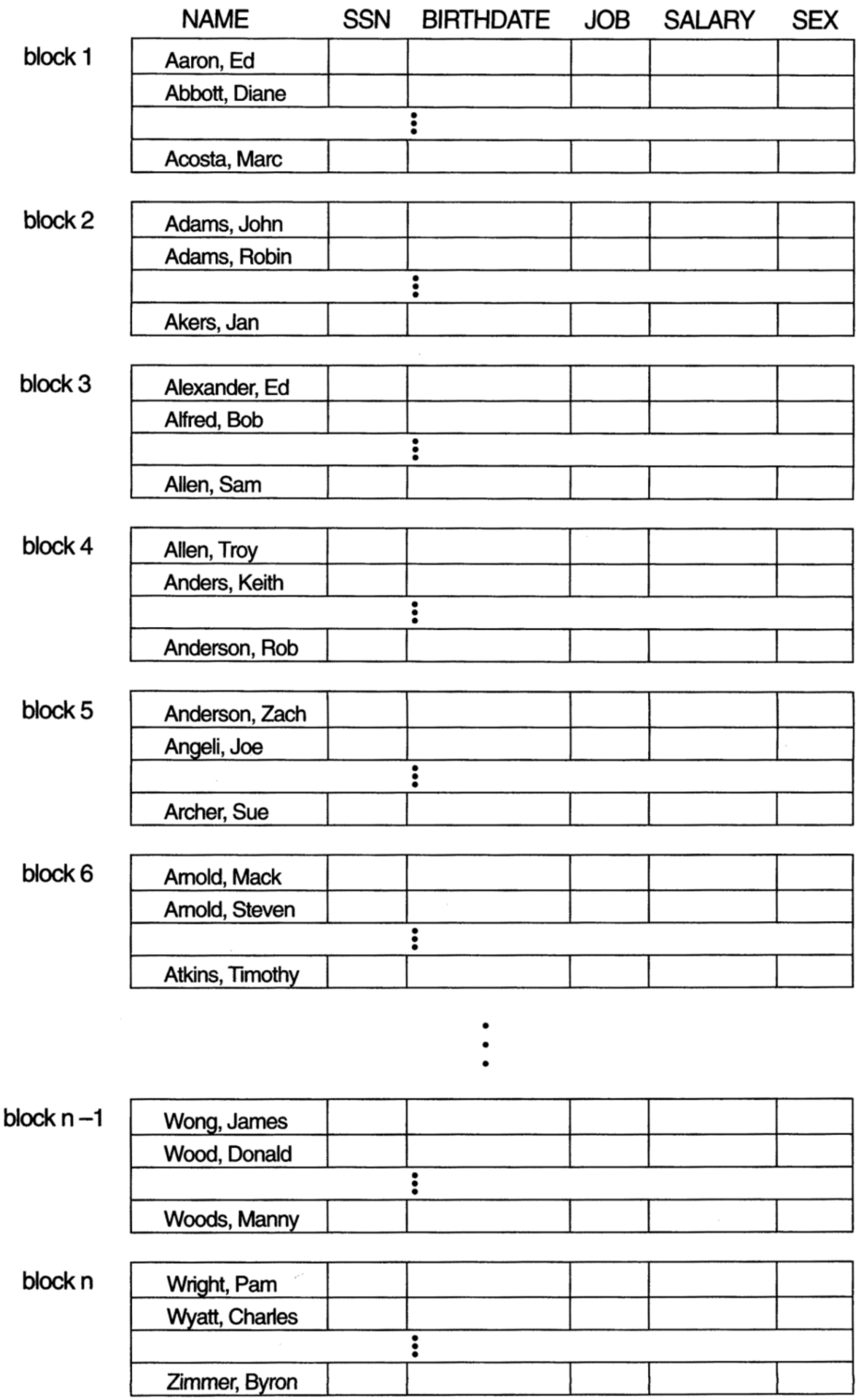
Unordered Files

- 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 (cont.)



Average Access Times

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

Table 17.2 Average Access Times for a File of *b* Blocks under Basic 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	$\log_2 b$

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 (cont.)

- 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 (cont.)

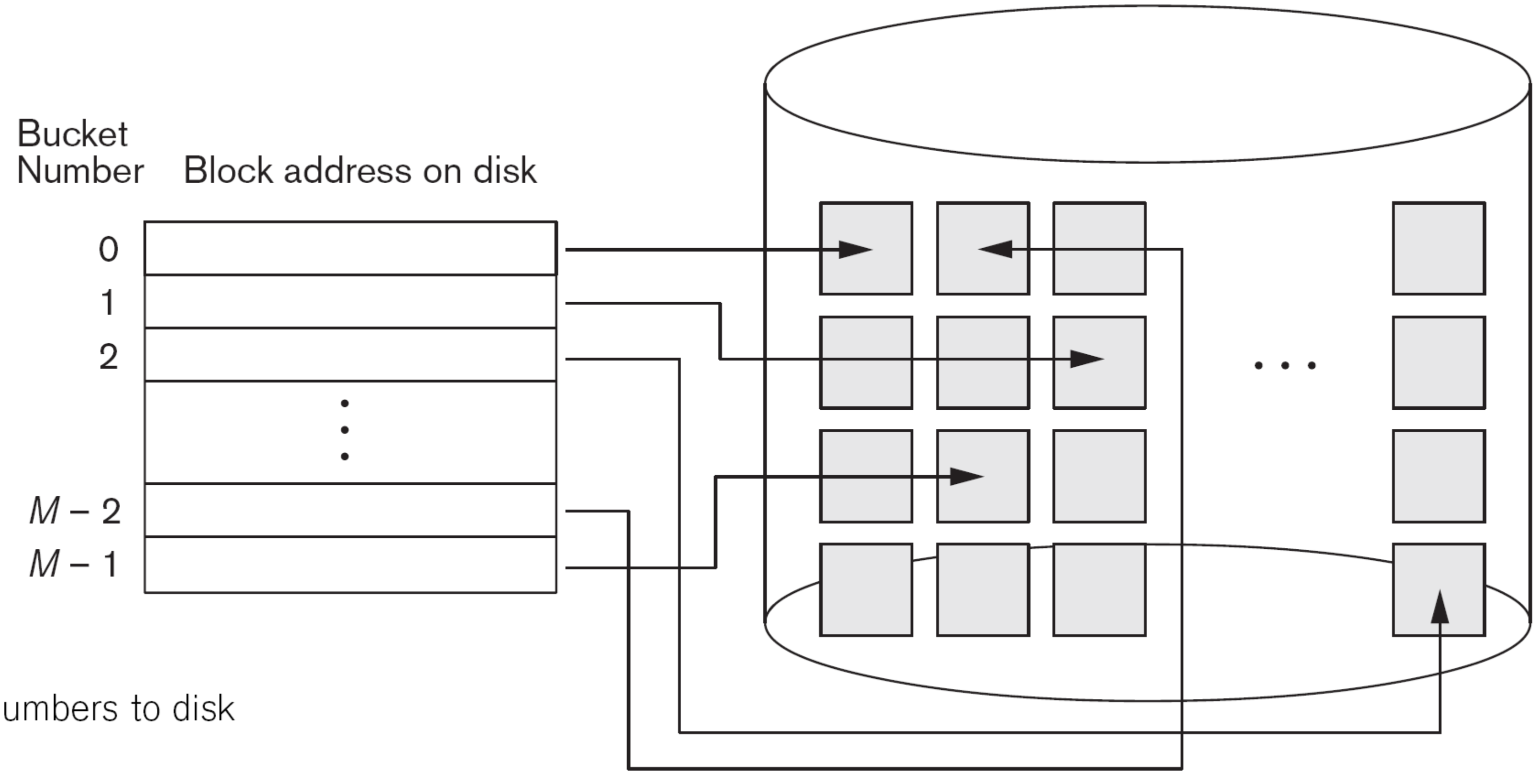


Figure 17.9
Matching bucket numbers to disk block addresses.

Hashed Files (cont.)

- 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

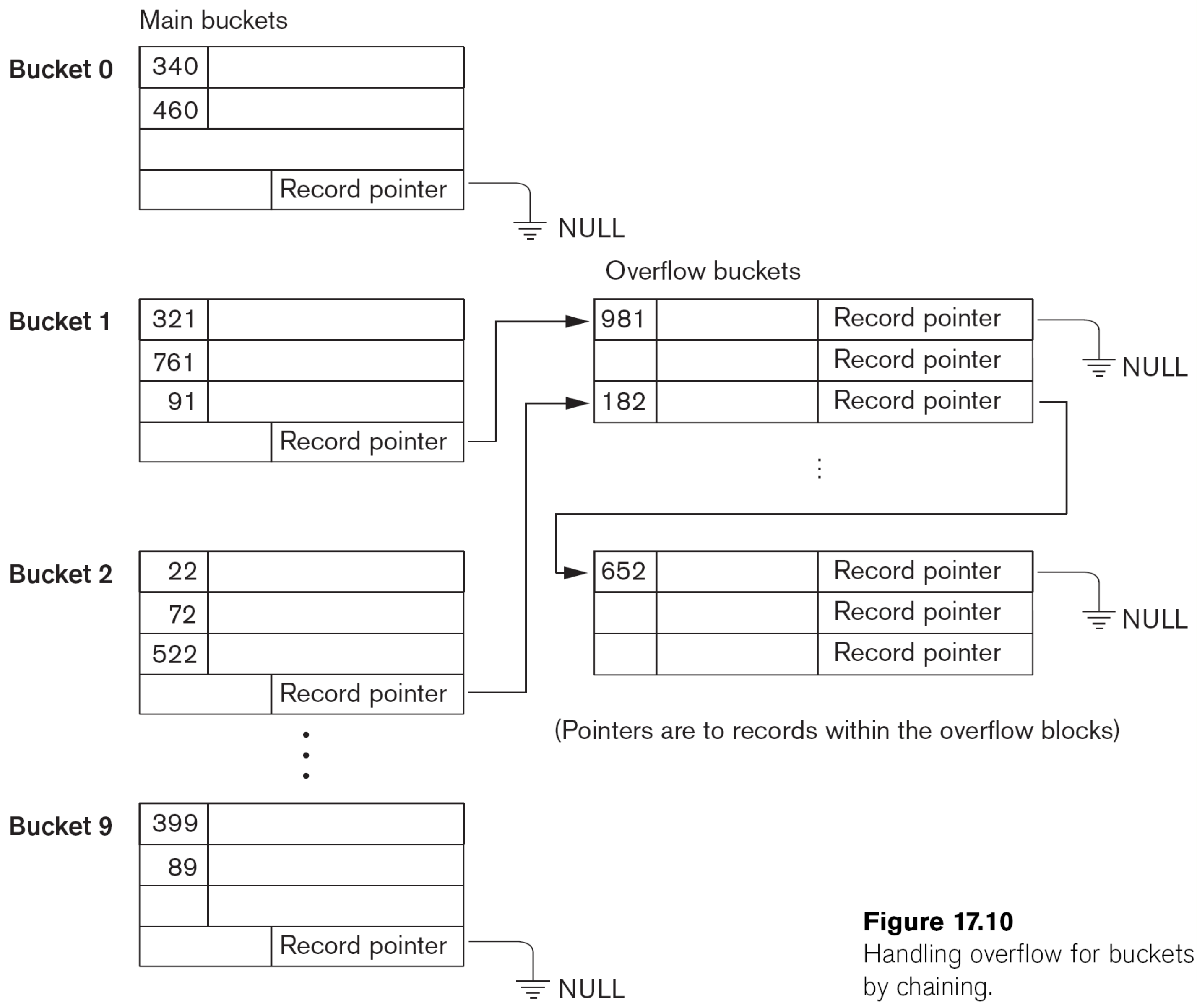


Figure 17.10
Handling overflow for buckets by chaining.

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 (cont.)

- 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

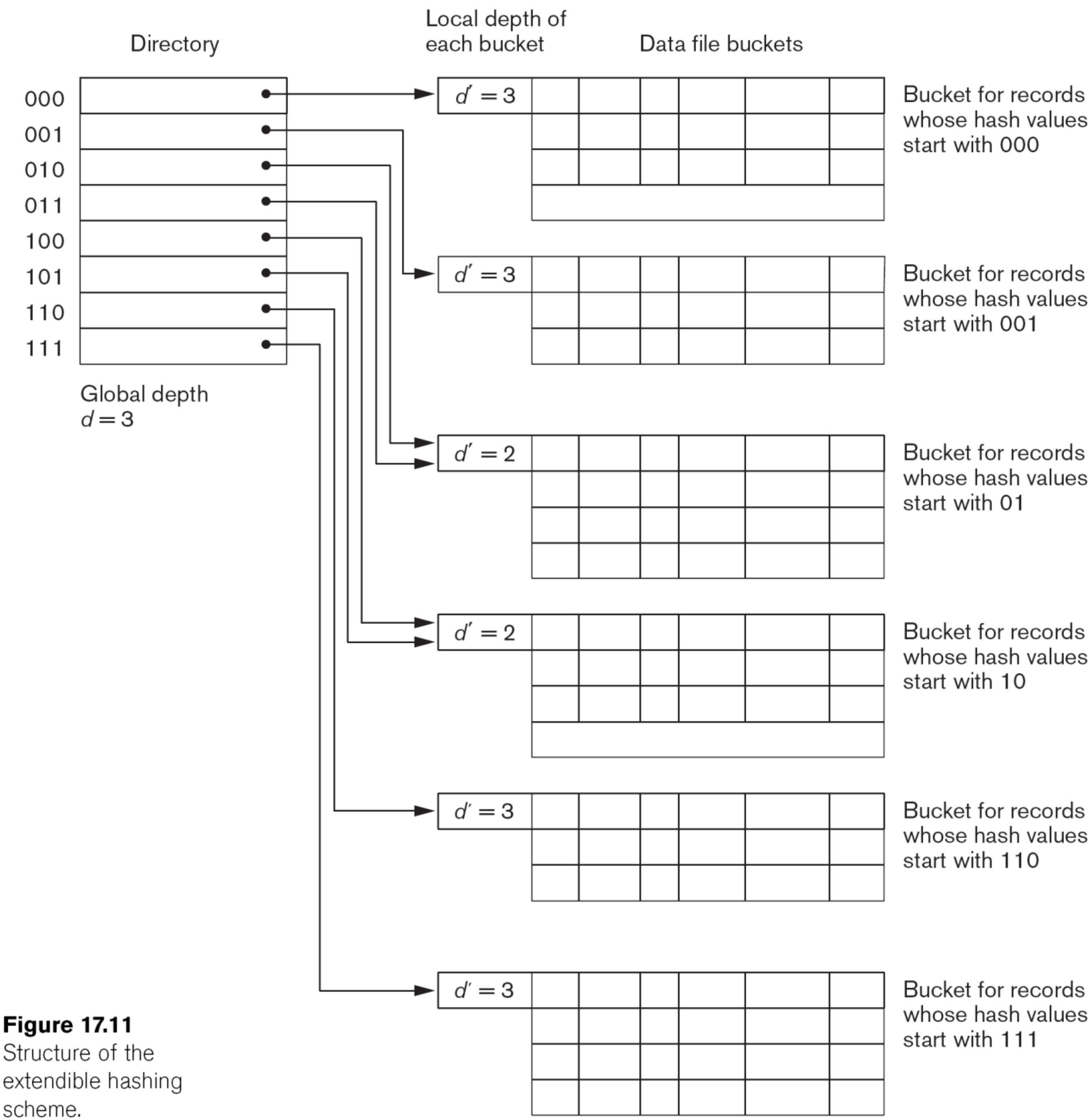


Figure 17.11
Structure of the extendible hashing scheme.

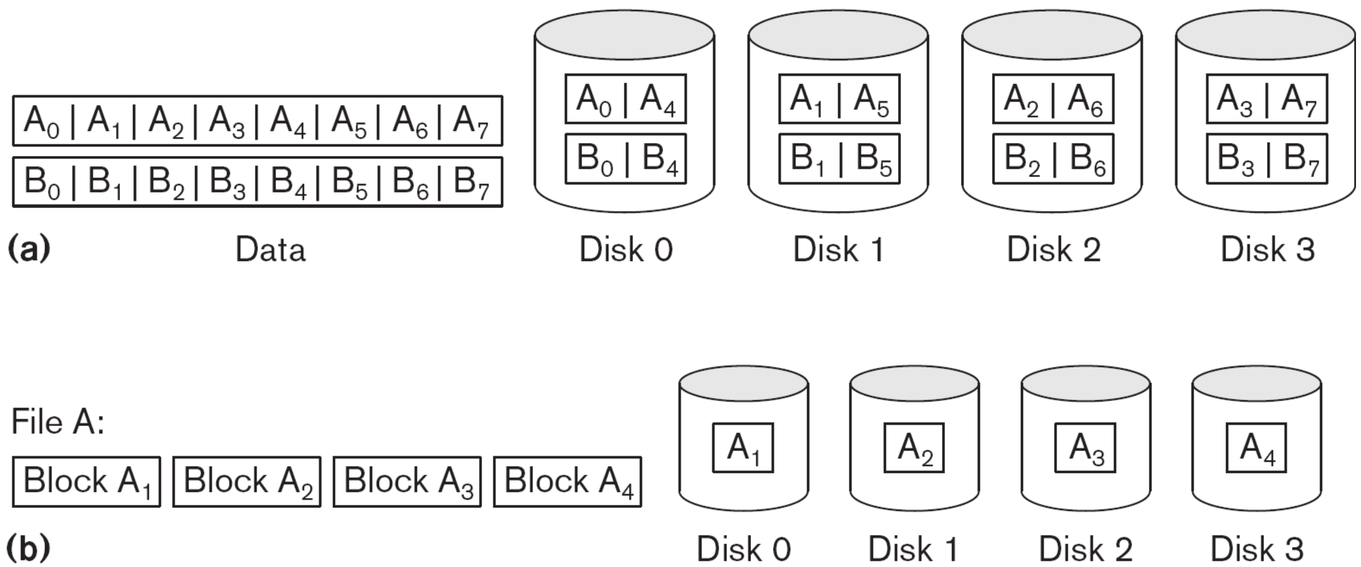
Parallelizing Disk Access using RAID Technology.

- 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 (cont.)

- 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 17.13
Striping of data across multiple disks. (a) Bit-level striping across four disks. (b) Block-level striping across four disks.



RAID Technology (cont.)

- 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 (cont.)

- 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 (cont.)

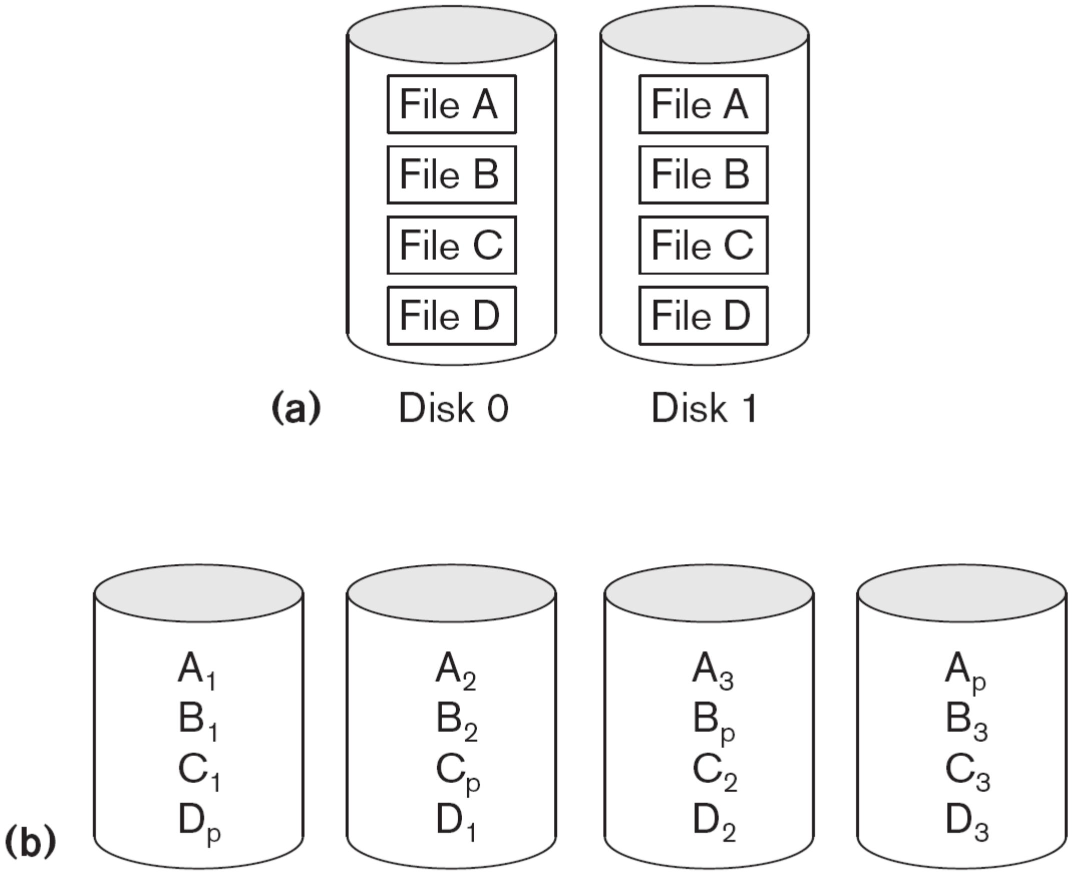


Figure 17.14
Some popular levels of RAID. (a) RAID level 1: Mirroring of data on two disks. (b) RAID level 5: Striping of data with distributed parity across four disks.

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 (cont.)

- 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