TRƯỜNG ĐẠI HỌC BÁCH KHOA HÀ NỘI
HANOI UNIVERSITY OF SCIENCE AND TECHNOLOGY

Database
Lesson 10. Storage and Indexing

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Learning Map

Sequence	Title
1	Introduction to Databases
2	Relational Databases
3	Relational Algebra
4	Structured Query Language – Part 1
5	Structured Query Language – Part 2
6	Constraints and Triggers
7	Entity Relationship Model
8	Functional Dependency
9	Normalization
10	Storage - Indexing
11	Query Processing
12	Transaction Management – Part 1
13	Transaction Management – Part 2

Outline

- Overview of database storage structures
- Physical database files
- Database index

Objectives

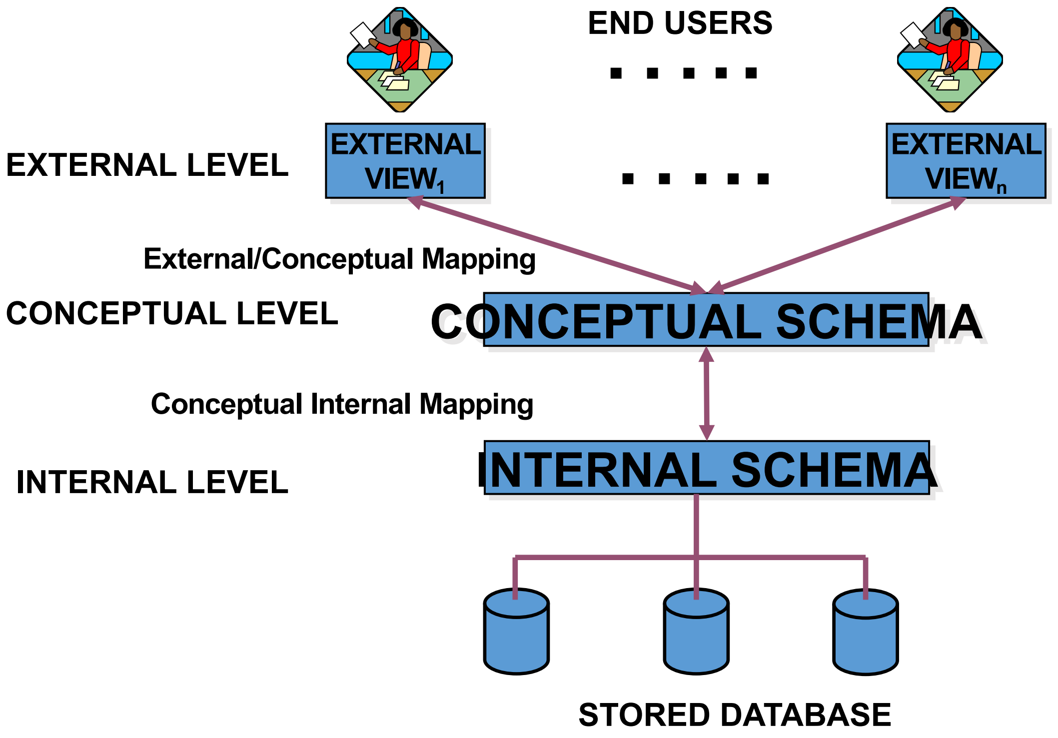
- Upon completion of this lesson, students will be able to:
  - Understand the physical database files
  - Understand the role of database indexes

Keywords

Heap file	Files of Unordered Records
Ordered file	Physically order the records of a file on disk based on the values of one of their fields (key field)
Index	A data structure that improves the speed of data retrieval operations
B-tree	A self-balancing tree data structure that keeps data sorted

1. Overview of database storage structures

- ***3-tier Schema Model (ANSI-SPARC Architecture)***



1. Overview of database storage structures

- ***How does Mariadb store data***

```
MariaDB [(none)]> SHOW VARIABLES LIKE 'datadir';
+---------------+-----------------+
| Variable_name | Value           |
+---------------+-----------------+
| datadir       | /var/lib/mysql/ |
+---------------+-----------------+
```

```
MariaDB [student_management]> show tables;
+------------------------------+
| Tables_in_student_management |
+------------------------------+
| class                        |
| enrolled                     |
| faculty                      |
| student                      |
+------------------------------+
```

```
:/var/lib/mysql/student_management# ls -la

ql mysql   4096 Mar 12 02:05 .
ql mysql   4096 May  5 06:06 ..
ql mysql   1547 Mar 12 02:05 class.frm
ql mysql 114688 Mar 12 02:21 class.ibd
ql mysql     65 Mar 12 01:59 db.opt
ql mysql   1466 Mar 12 02:03 enrolled.frm
ql mysql 114688 Mar 12 02:18 enrolled.ibd
ql mysql   1005 Mar 12 02:04 faculty.frm
ql mysql  98304 Mar 12 02:16 faculty.ibd
ql mysql   1101 Mar 12 02:00 student.frm
ql mysql  98304 Mar 12 02:23 student.ibd
```

the .frm table file stores the table's format
the .ibd file stores the table's data

1. Overview of database storage structures

● *How does Mariadb store data*

- the .frm file stores the table's format

```
MariaDB [student_management]> describe student;
+-------+-------------+------+-----+---------+-------+
| Field | Type        | Null | Key | Default | Extra |
+-------+-------------+------+-----+---------+-------+
| snum  | int(11)     | NO   | PRI | NULL    |       |
| sname | varchar(40) | YES  |     | NULL    |       |
| major | varchar(30) | YES  |     | NULL    |       |
| level | varchar(10) | YES  |     | NULL    |       |
| age   | int(11)     | YES  |     | NULL    |       |
+-------+-------------+------+-----+---------+-------+
```

```
root@285e07e9458f:/var/lib/mysql/student_management# cat student.frm
?

VM?\!  ?s?$??%?艂B??
??PRIMARY??InnoDB??f\P
                      (/?
N?
?snum?sname?major?level?age?root@285e07e9458f:/var/lib/mysql/student
```

● *How does Mariadb store data*

- the .ibd file stores the table's data

```
MariaDB [student_management]> select * from student;
+------+------------------+---------+-------+-----+
| snum | sname            | major   | level | age |
+------+------------------+---------+-------+-----+
|    1 | Nguyen Van A     | CS      | JR    |  18 |
|    2 | Nguyen Viet Cuong| History | JR    |  19 |
|    3 | Nguyen Hong Ngoc | CS      | JR    |  19 |
|    4 | Mark Juke        | History | JR    |  20 |
|    5 | Elon Mulk        | CS      | JR    |  20 |
|    6 | Donal Trump      | CS      | JR    |  20 |
|    7 | Obama            | CS      | JR    |  20 |
|    8 | Tan Dung         | History | SR    |  30 |
+------+------------------+---------+-------+-----+
```

```
root@285e07e9458f:/var/lib/mysql/student_management# cat student.ibd
???]&!?????????????????????????&&??????????????????????????]&??Y?&??Y?&???j?&???
?????????????????????????????i??????????????????????????????????????????????????
?????????????????????????????????????????????????????????????????????????????????
????????????i????????????????????????????????????????????????????????????????????
?????????????????????????????????????????????????????????j?&??Q?????????'??E?
9infimum
        supremum
                .?8?WNguyen Van ACSJR?8?:?cNguyen Viet CuongHistoryJR? 2?@??Nguyen H
ong NgocCSJR?    (0?1?iMark JukeHistoryJR?       0+?0??Elon MulkCSJR?
                                                              8-?Q?kDonal Trum
pCSJR?@'?W??ObamaCSJRH?????Tan DungHistorySR?pc??Q?'??root@285e07e9458f:/var/lib/mys
```

2. Physical database files

- Motivation
- Magnetic disks as data storage
- Primary file organizations

2.1. Motivation

- Databases typically store large amounts of data persistently on disks:
  - Databases are too large to fit entirely in main memory.
  - Disk - nonvolatile storage vs. Main memory - volatile storage
  - The cost of storage per unit is much cheaper

2.2. Magnetic disks as data storage

- A disk is a random access addressable device.
- Transfer of data between main memory and disk takes place in units of disk blocks.
- Typical disk block sizes: 4KB – 8KB.
- Disk I/O (read/write from disk to main memory) overhead is the key factor of database performance optimization.

2.2.1. Physical database design

- The process of physical database design involves choosing the particular data organization techniques that best suit the given application requirements (on SELECT, INSERT, UPDATE, DELETE).
- The data stored on disk is organized as files of records:
  - Primary file organizations: determine how the file records are physically placed on the disk, and hence how the records can be accessed.
  - Secondary organization or auxiliary access structure allows efficient access to file records based on alternate fields.

2.2.2. Placing File Records on Disk

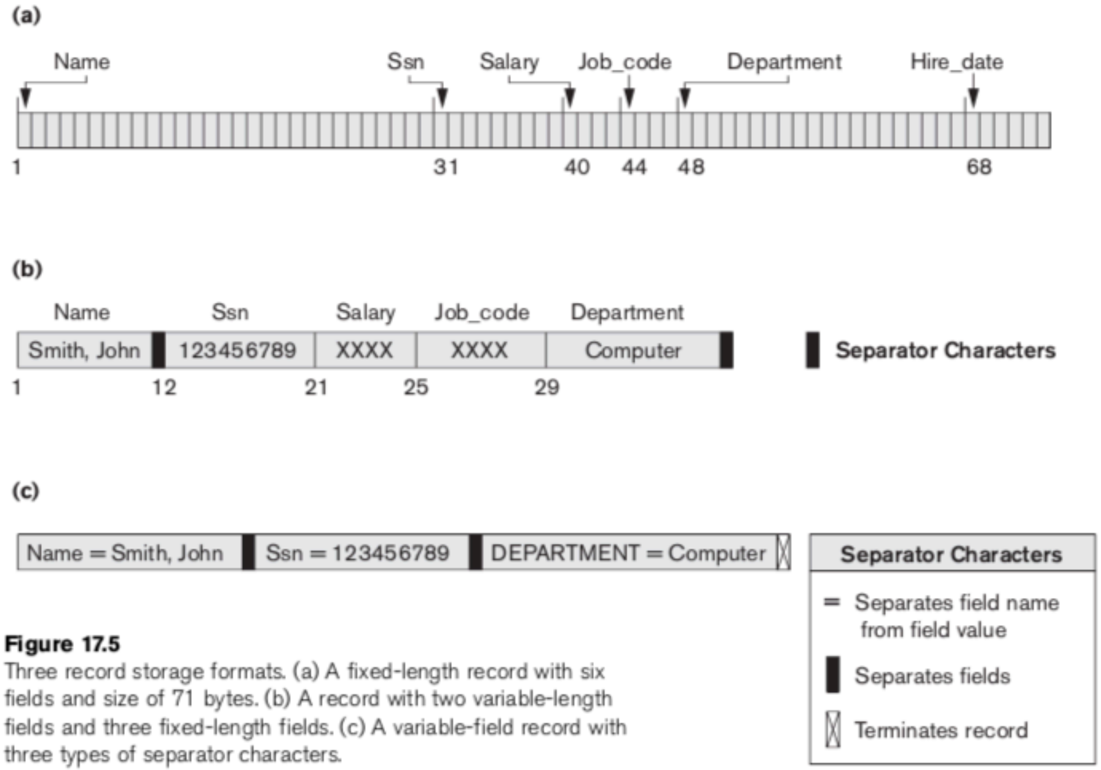


Figure 17.5
Three record storage formats. (a) A fixed-length record with six fields and size of 71 bytes. (b) A record with two variable-length fields and three fixed-length fields. (c) A variable-field record with three types of separator characters.

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2.3. Primary file organizations

- Files of Unordered Records (Heap Files)
- Files of Ordered Records (Sorted Files)
- Hashing Techniques

2.3. Primary file organizations

- **Files of Unordered Records (Heap Files)**
  - Records are placed in the file in the order in which they are inserted
  - INSERT: Inserting a new record is very efficient
    - New records are inserted at the end of the file
  - UPDATE/SELECT: Searching for a record on any search condition is not efficient – linear search
  - DELETE: leaves unused space in the disk block
    - require periodic reorganization

2.3. Primary file organizations

- **Files of Ordered Records (Sorted Files)**
  - Physically order the records of a file on disk based on the values of one of their fields (key field)
  - SELECT: binary search (very fast)
  - INSERT/DELETE/UPDATE: more expensive

2.3. Primary file organizations

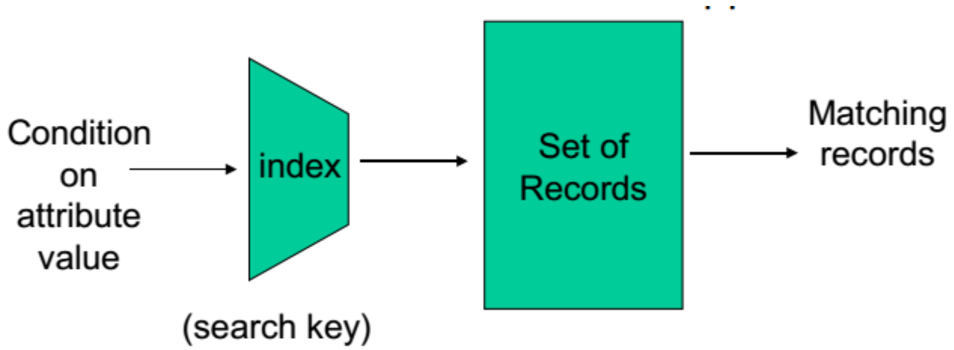
- **Hash files**
  - The address of the disk block in which the record is stored is the result of applying a hash function to the value of a particular field (hash field) of the record.
  - Very fast access to records for search on equality condition on the hash field.

3. Database indexes

- What is database index?
- Index data structures
- B+tree
- Spare vs. Dense index
- Clustered vs. Non-clustered index
- Index creation in SQL

3.1. What is database index?

- Auxiliary access structure (commonly index) allows efficient access to file records based on alternate fields

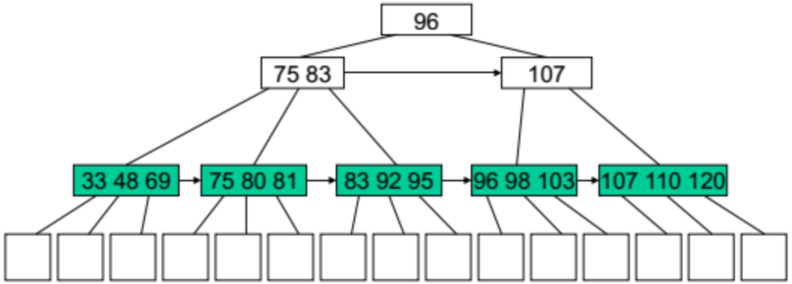


3.2. Index data structures

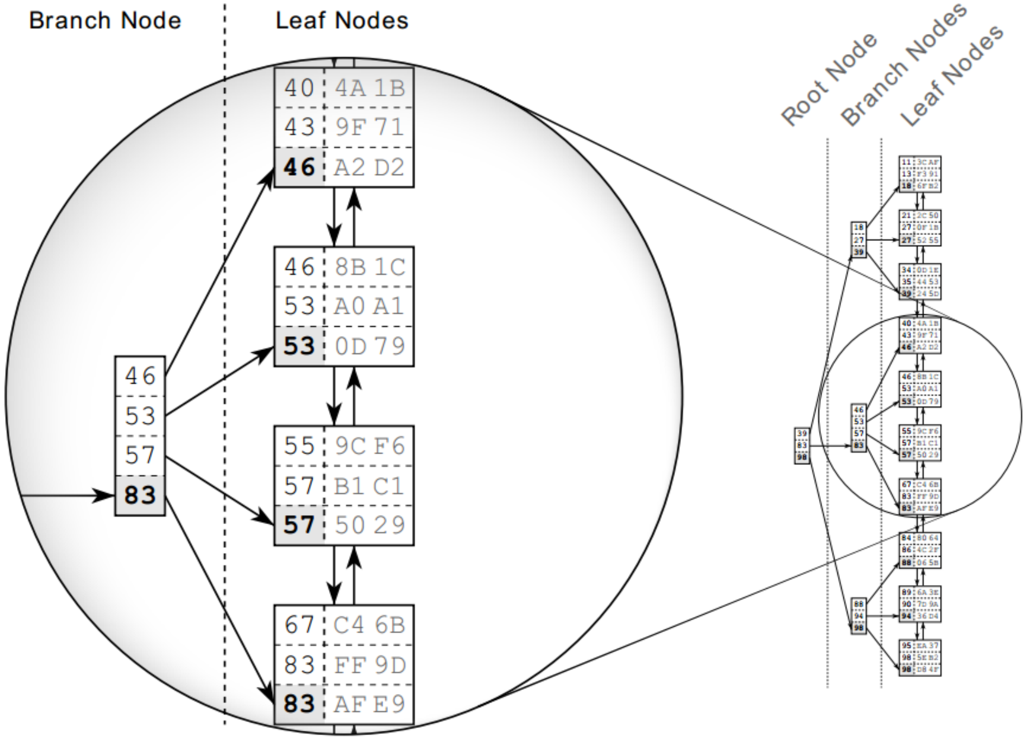
- Indexes can be implemented with different data structures.
  - B+-tree index
  - hash index
  - bitmap index (briefly)
  - dynamic hash indexes: number of buckets modified dynamically
  - R-tree: index for special data (points, lines, shapes)
  - quadtree: recursively partition a 2D plane into four quadrants
  - octree: quadtree version for three dimensional data
  - main memory indexes: T-tree, binary search tree

3.3. B+Tree

- Balanced tree of key-pointer pairs
- Keys are sorted by value
- Nodes are at least half full
- Access records for key: traverse tree from root to leaf



3.3.1. Example: B+ tree



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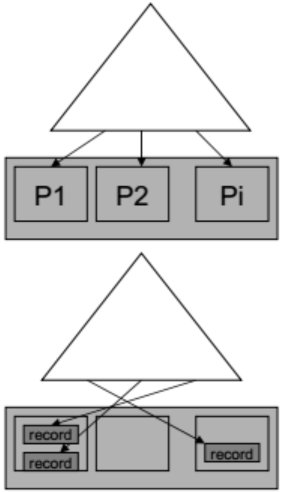
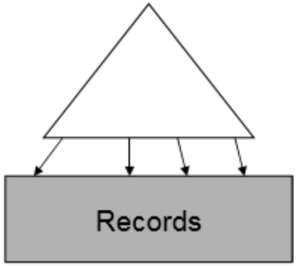
3.4. Spare vs. Dense index

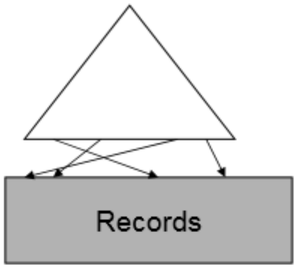
- Sparse index
  - pointers to disk pages at most one pointer per disk page usually much less pointers than records
- Dense index
  - pointers to individual records one key per record usually more keys than sparse index optimization: store repeating keys only once, followed by pointers



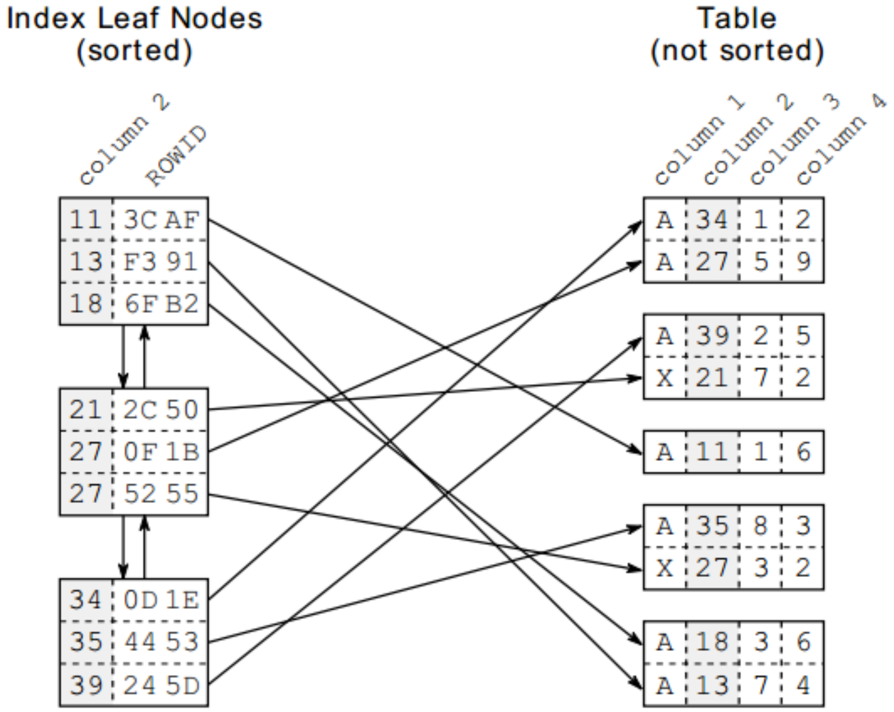
3.5. Clustered vs. Non-Clustered

- Clustered index on attribute X
  - This index controls the placement of records on disk
  - only one clustering index per table
  - dense or sparse
- Non-clustered index on attribute X
  - no constraint on table organization
  - Can have more than one index per table
  - always dense





3.5.1. Example: Non-clustered index



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3.6. Creating Index

- CREATE [UNIQUE|FULLTEXT|SPATIAL] INDEX index_name [index_type] ON tbl_name (index_col_name,...) [index_option] [algorithm_option | lock_option] ...
- index_type: USING {BTREE | HASH}

Remark

- Databases typically store data persistently on disks
  - Files of unordered records (Heap files)
  - Files of ordered records (Sorted files)
  - Hash files
- Index allows efficient access to file records based on “indexed” fields

Quiz 1.

Quiz Number	1	Quiz Type	OX	Example Select
Question	Does heap files support INSERT query efficiently?			
Example	A. Yes B. No			
Answer	A			
Feedback	New records are appended to the end of the head file			

Quiz 2.

Quiz Number	2	Quiz Type	OX	Example Select
Question	Are ordered files better for heavy Insert operation?			
Example	A. Yes B. No			
Answer	B			
Feedback	Insertion to ordered files requires reorganizing w.r.t. new records			

Summary

- Overview of database storage structures
  - 3-tier Schema Model (ANSI-SPARC Architecture)
  - How Mariadb stores data
- Physical database file structures
  - Motivation
  - Magnetic disks as data storage
  - Primary file organizations
- Database index
  - What is database indexes?
  - Index data structures
  - B+tree
  - Spare vs. Dense index
  - Clustered vs. Non-clustered index
  - Index creation in SQL

Next lesson: Query processing

- Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom. Database Systems: The Complete Book. Pearson Prentice Hall. the 2nd edition. 2008: Chapter 7
- Nguyen Kim Anh, Nguyên lý các hệ cơ sở dữ liệu, NXB Giáo dục. 2004: Chương 7