DATABASES

Syllabus: ER model, relational model (relational algebra, tuple calculus), database design (integrity constraints, normal forms), query languages (SQL), file structures (sequential files, indexing, B and B+ trees), transactions and concurrency control.

1. Introduction

Database is a collection of organized information so that it can easily be searched, retrieved, managed and updated. A database management system (DBMS) is a set of programs designed to manage a database. It enables users to store, retrieve and modify information in a database with utmost efficiency along with security features. DBMS is applicable to various day-to-day fields such as transactions in banking; airline/railway/ hotel reservations; maintenance of student information in schools/universities; online retails; marketing and sales etc. It also allows its users to create their own databases. Different types of DBMS are available such as hierarchical, network, relational and object oriented.

1.1 Traditional File Processing Approach

File processing approach is generally more accurate and faster than the manual database system. Each user is responsible for the defining and implementation of the files required for the specific application. The implementation of required files sometimes creates redundancy of data, for example, one user keeps records for the savings account of the customer and another user may create the loan account of the same customer. This causes the duplicity of the records of the same customer. So, this practice is not feasible for real time applications. There is a need of centralized management of data. The data is created once and then accessed by different users. The data should be shared for different transactions. It should be self-describing in nature, which means the database system contains not only data but it describes the description of the database structure.

1.2 Database Management System

A database is a collection of related data. Data is a collection of raw facts or figures, processed to form information. Database management system is a collection of programs for the creation and maintenance of database. It is an efficient and reliable approach to retrieve data for many users. It provides various functions such as:

1. **Redundancy control**: It provides redundancy by removing duplicity of data by following rules of normalization.

2. **Data independence**: It provides independence to application programs from details of data representation and storage. It also provides an abstract view of the data to insulate application code from such details.

3. **Data integrity**: It promotes and enforces some integrity rules for reducing data redundancy and increasing data consistency.

4. **Concurrency control**: It supports sharing of data, so, it has to provide an approach for managing concurrent access of the database. Hence, preserving the inconsistent state and integrity of the data.

5. **Transaction management**: It provides an approach to ensure that either all the updates for a given transaction will execute or that none of them would execute.

6. **Backup and recovery**: It provides mechanisms for backing up data periodically and recovering from different types of failures, thus, preventing loss of data.
7. **Non-Procedural query language:** It provides with query language for retrieval and manipulation of data.

8. **Security**: It protects unauthorized access in the database. It ensures the access to authorized users.

2. Components Of Database Systems

DBMS consists of several components, namely software, hardware, data, procedures and data access language.These components are responsible for the definition, collection, management and use of data within the environment. Figure shows the components of database system. The description of each component is as follows:

1. **Software:** It is the collection of programs used by the computers within the database system. It is used to handle, control and manage the database. It includes the following software:
   - Operating system software like Microsoft Windows, Linux OS, Mac OS.
   - DBMS software such as Oracle 8I, MySQL, Access (Jet, MSDE), SQL Server etc.
   - Network softwares are used for sharing share the data of database among multiple users.
   - Application programs are developed like C++, VB, dotnet etc. are used to access database in dbms. These are used to acces and manipulate the data in the database.

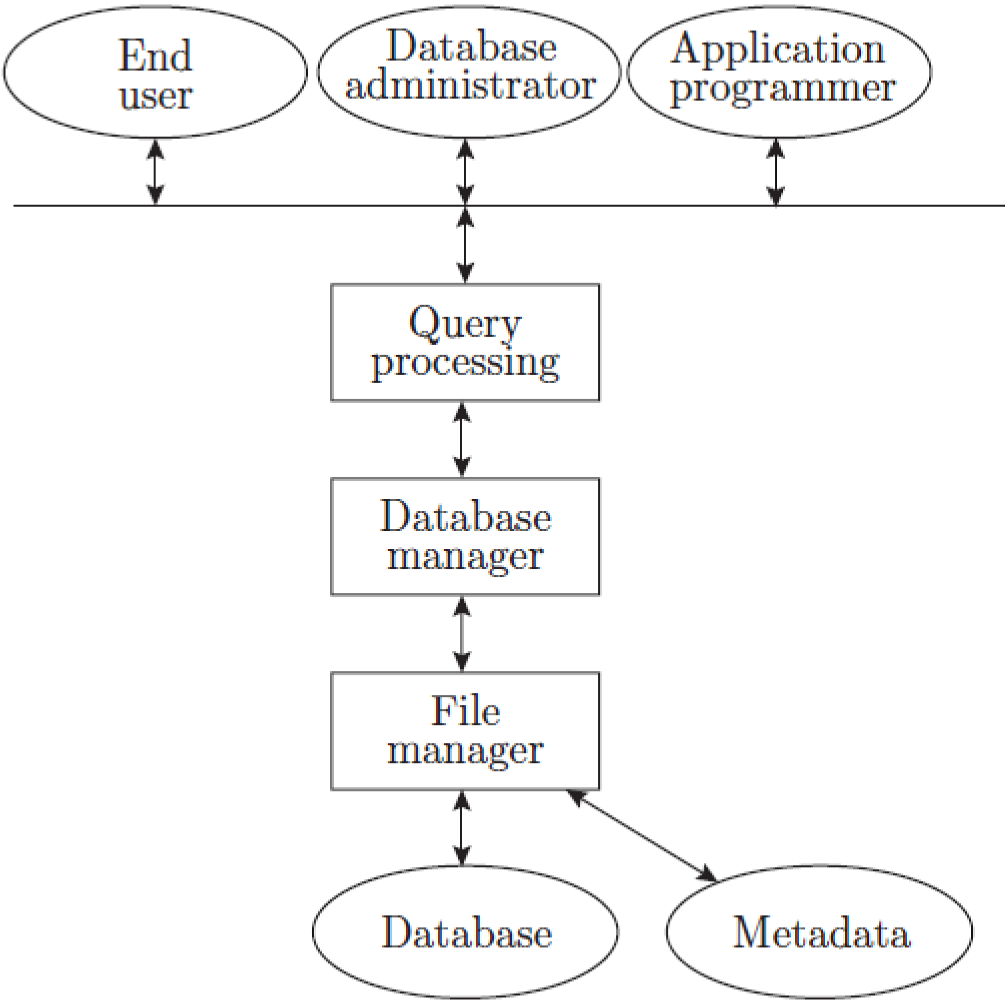
2. **Hardware**: It consists of all system's physical devices such as computers, storage devices, I/O channels, electromechanical devices etc. It also includes peripherals, such as, keyboard, mouse, modems, printers, etc.

3. **Data:** It is the collection of facts. The database contains the data and the metadata.

4. **Procedures**: There are the instructions and rules to design and use the database system. These includes the following:
   - Steps for the installation of DBMS
   - Steps to use the DBMS or application program
   - Steps for the backup of DBMS
   - Steps to change the structure of DBMS
   - Steps for the generation of reports.

5. **Data access language:** The users can use it to access the data to and from the database. The function of data access language is the entry of new data, manipulation of the existing data and the retrieval of the existing data in the database. The most popular database access language is SQL (Structured Query Language). Users can perform these functions with the help of commands. The role of administrator is to access, to create and to maintain the database.

6. **People:** Persons involved to access, to create and to maintain the database are called users. These are of various types according to the role performed by them (Fig.). These are as follows:
   - **System Administrator**: The role of system administrator is to supervise the general operations of DBMS.
   - **Database Administrator**: The role of database administrator (DBA) is to manage the DBMS.
   - **Database Designer**: The role of database designer is to design the structure of the database.
   - **Application Programmer**: The role of application programmer is to create the data entry forms, reports and procedures.
   - **End User**: The role of end user is to use the application programs by entering new data and manipulating and accessing existing data.



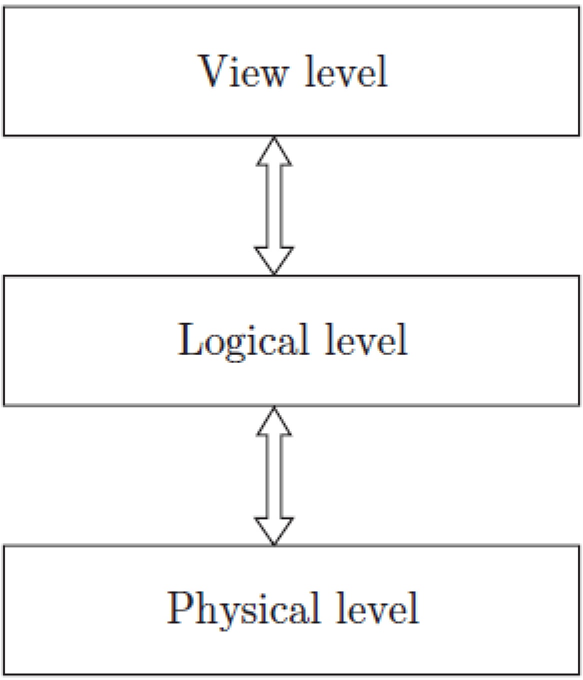
Components of database systems.

3. DBMS Architecture

It is an approach to outlook the database by users. It is means for the representation of data in an understandable way to the users. DBMS architecture can be used to divide the whole system to related and independent modules. It can be of 1-tier, 2-tier 3-tier or n-tier.

3.1 3-Tier Architecture

DBMS can be most widely used as 3-tier architecture. In this architecture, the database is divided into three tiers depending upon the kind of users (see Fig.).



The 3-tier architecture of DBMS.

1. **Internal schema or physical level:** It is also called Database Tier. Database exists in this tier. It also includes query processing languages, all relations and their corresponding constraints. It describes the physical storage structure of the database.

2. **Conceptual schema or logical level**: It is also called Application Tier. Server and program exists in this tier. It also describes the structure of the database.

3. **External schema or view level**: It is also called Presentation Tier. End user exists in this tier. An end user is capable of multiple views of database. It also includes all views generated by applications.

3.2 Data Independence

Data independence is defined, as the change at one level does not affect the higher level. It is of two types:

1. **Logical data independence**: It is defined, as the change in conceptual schema does not affect the external schema. For example, if the format of the table changes, the data lies in the table should not be changed.

2. **Physical data independence**: It is defined, as the change in internal schema does not affect the conceptual schema. Thus, does not affect the external schema. For example, if the storage system has been changed, then it does not affect the logical structure of the database.

4. Data Models

Data model is a collection of tools, which describes data, relationships, constraints and semantics. It gives the logical structure of the database. It describes the relationship of data in the database. Data models are of various types:

1. **Relational Model:** It is a collection of relations (tables). In relational model, each table is stored as a separate file.

2. **Entity—Relationship data model:** This model is based on the notion of real-world entities and relationship among them.

3. **Object-Based data model:** It defines the database as objects, its properties and its operations. In this model, objects with the similar structures comprise a class. The classes are organized into hierarchies. The operations on these classes are performed through methods.

4. **Semi-Structured data model:** It is also known as XML model. This model is used to exchange data over the web. It uses hierarchical tree structures. In this model, data can be represented as elements by using tags.
5. **Network model**: In this model, data is represented as record types. The data in this model has many-to-many relationship.

6. **Hierarchical model:** In this model, the data is represented as a hierarchical tree structure.

4.1 Relational Model

The database in relational model is represented as a collection of relations (tables). A relation is a kind of set. It is also a subset of a Cartesian product of an unordered set of ordered tuples. Relational model was proposed by E. F. Codd, which stores data in a tabular form. It consists of a table where rows represent records and columns represent the attributes. It has various terminologies as follows:

1. **Tuple:** It represents a single row of a table, which contains a single record for that relation.

2. **Relation instance:** It represents a finite set of tuples in the relational database system.

3. **Relation schema:** It represents the relation name, that is, table name, attributes and their names.

4. **Relation key:** It represents the unique key for the relation or table. Each row has one or more attributes, which can identify the row in the table uniquely.

5. **Attribute domain:** It represents the predefined value scope of each attribute.

4.1.1 Constraints in Relational Model

Constraints are the restrictions that one wishes to apply on database. The following constraints are applied on relational model.

1. **Key constraints:** Each relation has at least one minimal subset of attributes, which can identify a tuple uniquely.

   - No two tuples have identical value for key attributes.

- Key attribute does not have NULL value.

2. **Domain constraints:** Attributes have specific domain values in real world. For example, value of age can only be positive.

3. **Referential integrity constraints:** If a relation refers to a key attribute of a different relation then that key element must exist.

4.1.2 Relational Algebra

It is a procedural query language. It takes instances of relations as input and returns instances of relations as output. Operators are used to perform queries.

Notations of fundamental operations of relational algebra

Fundamental Operation	Symbol
Select	σ
Project	π
Union	$\cup$
Intersection	$\cap$
Set difference	$-$
Cartesian product	$\times$
Rename	ρ
Natural join	$\bowtie$

Fundamental operations of relational algebra are as follows (see Table):

1. **Select:** It is used to select rows from a relation. It is denoted by σ.
   Syntax of select $\sigma_p(r)$, r is relation and p is prepositional logic.
   p uses connectors and operators $\wedge, \vee, =, \neq, <, >, \leq, \geq$.
   For example, $\sigma_{empname}$= "John" (emp).

2. **Project:** It is used to project columns in a relation. It is denoted by π . The duplicate tuples are automatically eliminated. Syntax of projects π_A (r), r is relation and A is the attribute name in a relation.
   For example, $\pi_{empname, sal}$ (emp)

3. **Union:** It returns a relation instance, which contains all tuples occurring in the first relation or in the second relation. It is denoted as R!∪S, where R and S are two relations. The duplicate tuples are automatically eliminated. This operation is valid for the following:

   - Both relations must have the same number of attributes.
   - Attribute domains must be compatible.

4. **Intersection:** It returns a relation instance, which contains all tuples occurring in both relations. It is denoted as R ∩ S, where R and S are two relations.

5. **Set difference:** It returns a relation instance, which contains all tuples that occur in the first relation but not in the second relation. It is denoted as R −S, where R and S are two relations.

6. **Cartesian product:** It returns a relation instance, which contains all the fields of the first relation followed by all the fields of the second relation. It is denoted as R×S, where R and S are two relations.

7. **Rename**: It returns a relation but without any name. It is used to rename the output relation. It is denoted as r.

8. **Joins:** It returns combined information from two or more relations.

- **Condition joins**: It accepts a join condition ***c*** and a pair of relation instances as arguments, and returns a relation instance. It is denoted as $\sigma_c (R \times S)$.
- **uijoin**: It is a special case of condition joins where the condition ***c*** contains equalities.
- **Natural join**: It is a Cartesian product of two relations. It is denoted by $\bowtie$.

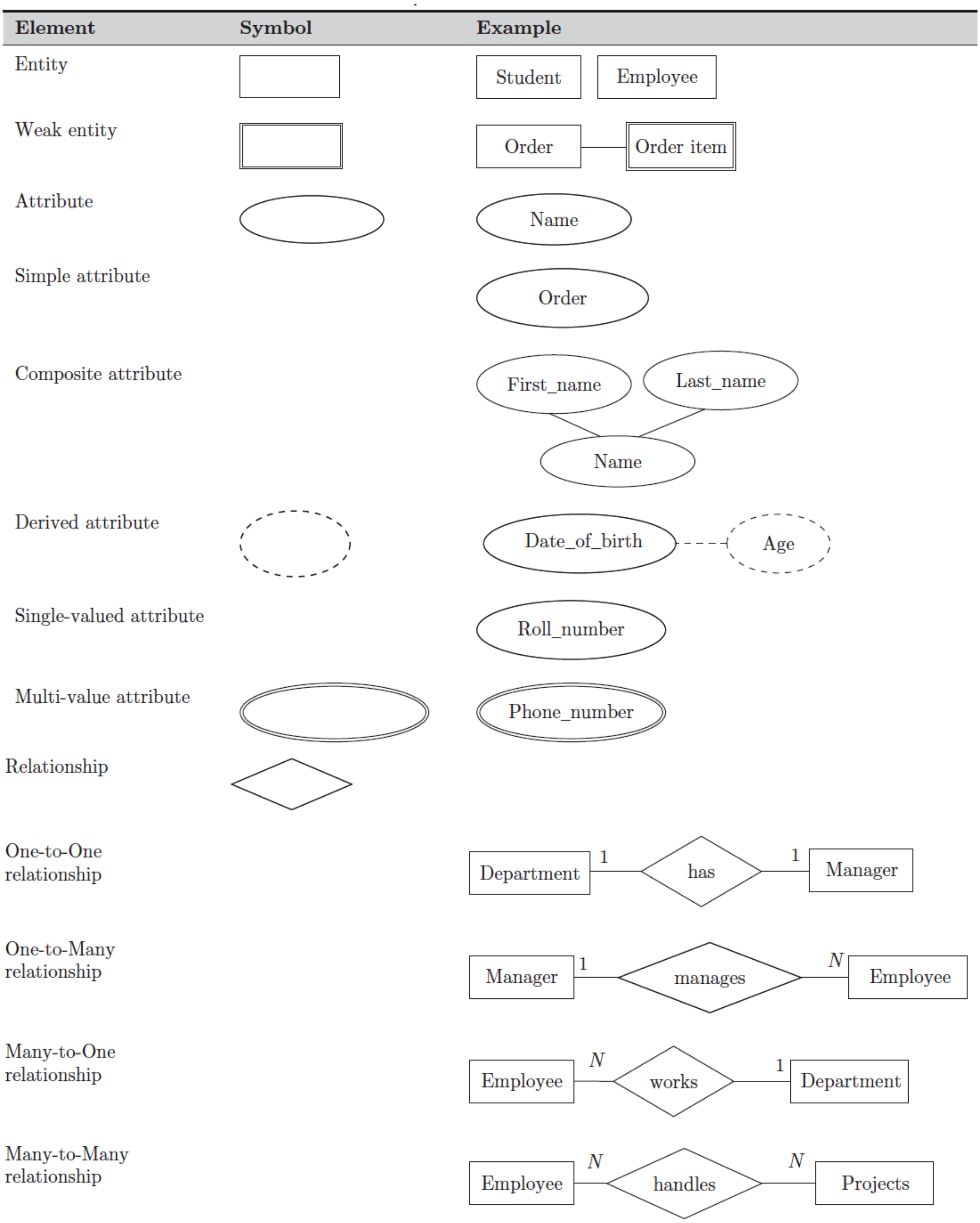
4.1.3 Tuple Calculus

It is a non-procedural query language. In this, number of tuple variables is specified. It is represented as { t | Condition}, where ***t*** is a tuple variable and Condition is a conditional expression.

Preliminaries of tuple calculus are as follows:
1. Constants
2. Predicates
3. Boolean and, or, not
4. ∃ there exists
5. ∀ for all

4.2 ER Model

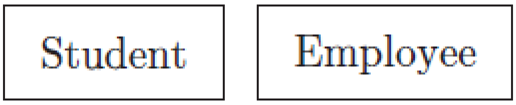
ER model represents the conceptual view of a database. It describes the relation of data to each other (Table). It was developed by Peter Chen in 1976. It views real world data as systems of entities and relationships. ER model has three basic elements: entity, attribute and relationship. These are discussed in the following sections.



4.2.1 Entity

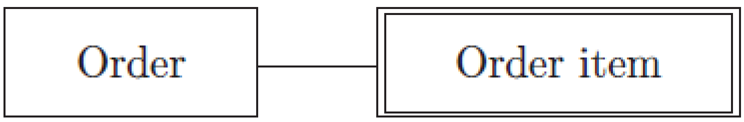
Entities represent the real-world things. These are data objects which maintain different relationships with each other, for example, Employee, Department, etc. These are represented by means of rectangles.

For example,



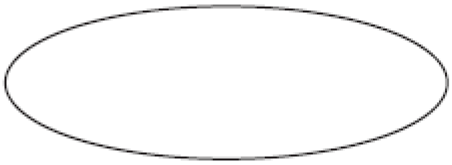
Entity set is a collection of similar types of entities. For example, all Employees set may contain all employees of all departments. Weak entity depends on the existence of another entity. A weak entity cannot be identified by its own attributes. It uses a foreign key combined with its attributes to form the primary key. It is represented by means of double rectangles.

For example, Details of Employee's spouse, order item, etc.

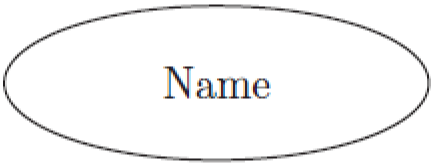


4.2.2 Attributes

Attribute is a property, trait or characteristic of an entity, relationship or another attribute. All attributes have values. A domain or range of values can be assigned to attributes. For example, name, class, age are attributes of the entity student. These are represented by ovals.



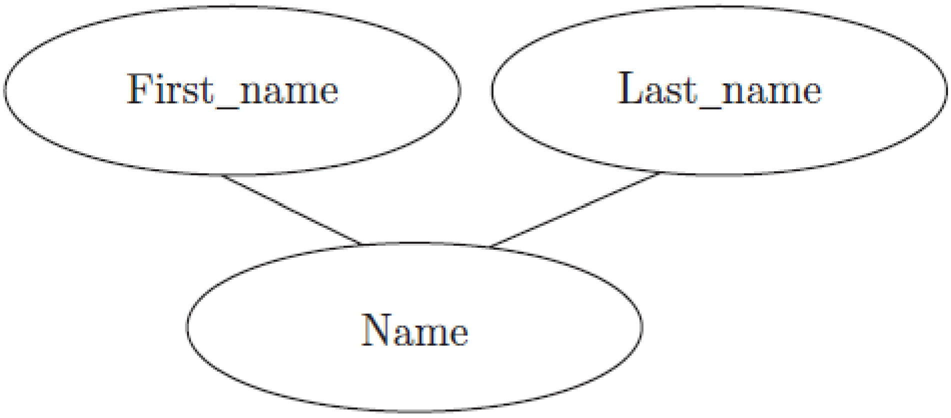
For example,



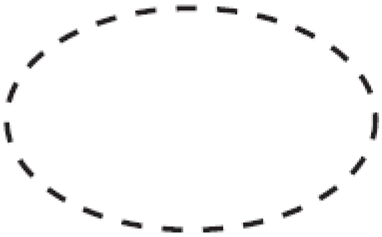
There are different types of attributes, listed as follows:

1. Simple attribute: Simple attributes contains atomic values. Atomic values cannot be divided into sub parts. Examples are mobile number, roll number.

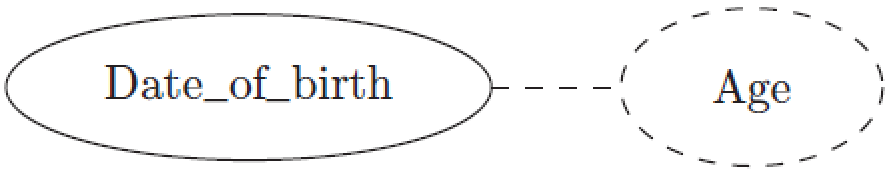
2. Composite attribute: Composite attributes are composition of many simple attributes. For example address can be divided into house number, street number, locality and city.



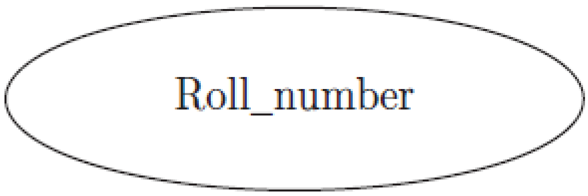
3. Derived attribute: Derived attributes are those whose value is derived from some other attribute in the database. For example, age of person can be calculated from date of birth. Dotted oval is used to represent derived attributes.



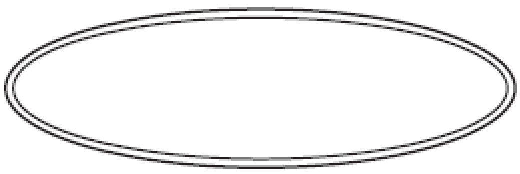
For example,



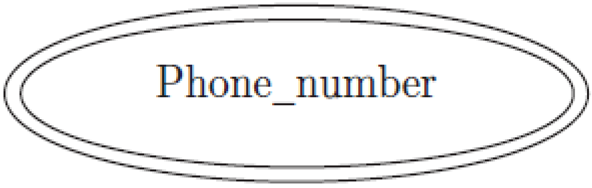
4. **Single-valued attribute:** Single valued attributes contain only one value for that attribute. For example age for person, blood group.



5. **Multi-value attribute**: In this, an attribute may contain more than one value. Multiple values are represented by double ovals.

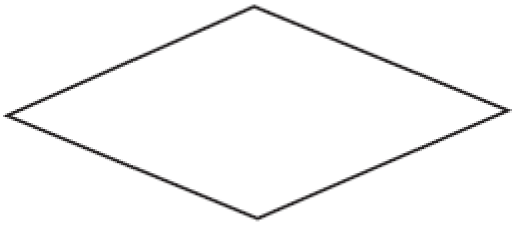


For example contact number, email ids.



4.2.3 Relationships

It represents the association among entities in a specified way. For example, employee entity has relation works at with department entity. Relationships are represented by diamond-shaped boxes.



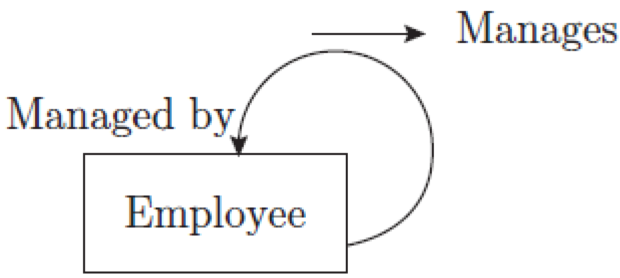
Some basic terminologies related to relationship are given below.

As we have discussed, relations are the core components in RDBMS, these relations are defined by two major characteristics– relationship set and the degree of relationship, defined in the following text.

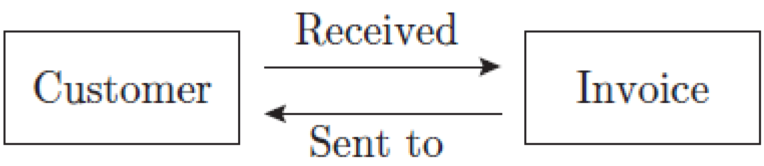
1. **Relationship set:** Relationship of similar type is called relationship set. It has attributes. These attributes are called descriptive attributes.

2. **Degree of relationship:** It defines the number of participating entities in a relationship. They are of the following types:

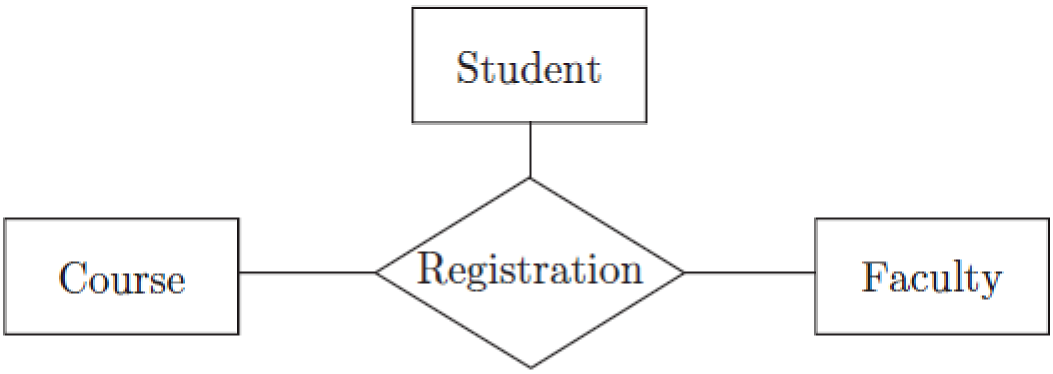
   - **Unary relationship (Degree 1):** One entity participates. For example,



- **Binary relationship (Degree 2):** Two entities participate. For example,



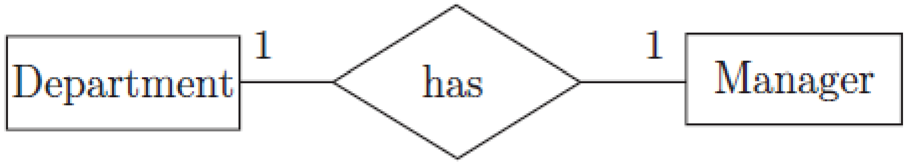
- **Ternary relationship (Degree 3):** Three entities participate. For example,



- n-ary relationship (Degree n): n entities participate.

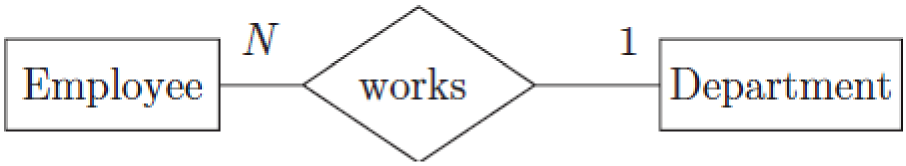
3. **Cardinality**: It defines the number of instances of an entity, which can be associated to the number of instances of other entity via relationship set.

   - **One to one**: One instance of an entity is associated with at most one instance of another entity with the relationship. It is represented as `1-1'.
     For example,



- **One to many**: One instance of an entity is associated with more than one instance of another entity with the relationship. It is represented as `1-N'. For example,

- **Many to one**: More than one instance of an entity is associated with another entity with the relationship. It is represented as `N-1'. For example,

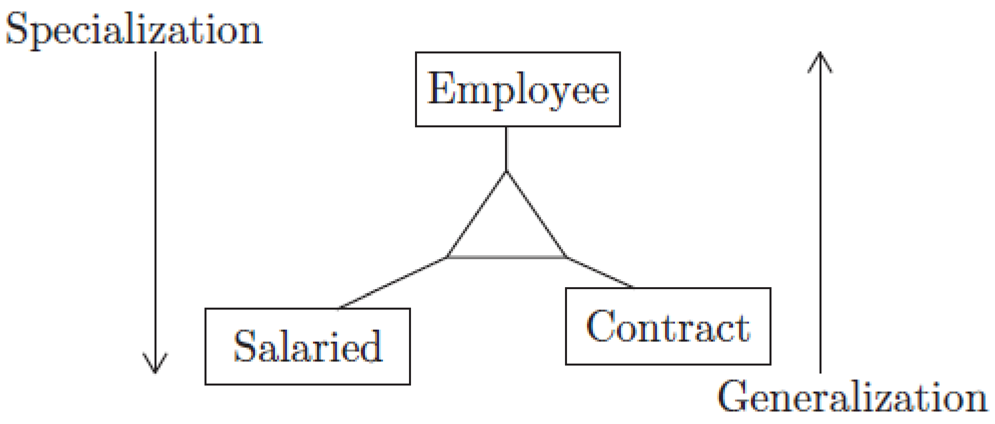


- **Many to many**: More than one instance of an entity is associated with more than one instance of another entity with the relationship. It is represented as `N-N'. For example,

4. **Generalization**: It is a collection of entity sets, having similar

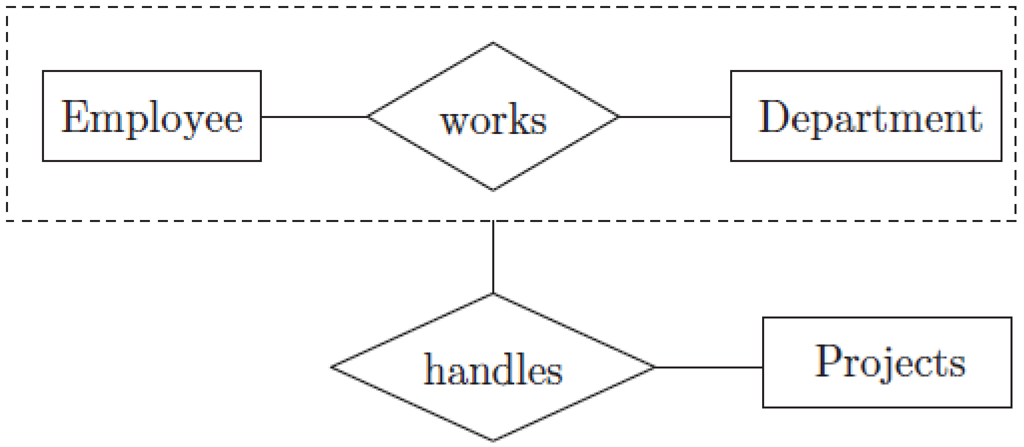
characteristics, brought together into one generalized entity. For example, salaried and contract employees are generalized as employee.

5. **Specialization**: It is the process of identifying subsets of an entity set. It is a reverse process of generalization. For example, employees are specialized as salaried and contract as shown in Fig



Specialization and Generalization.

6.Aggregation: It allows a relationship set participate in another relationship set (see Fig).



Aggregation.

5. Database Design

The design of a database consists of the following steps:
1. Identifying entities
2. Identifying relationships
3. Identifying attributes
4. Presenting entities and relationships: Entity relationship diagram (ERD)
5. Assigning keys
6. Defining the attribute's data type
7. Normalization

5.1 Integrity Constraints

Integrity constrains are applied to maintain the consistency in a database. This helps in providing the unique answer to a given query on the database. For example, if the answer to particular query is `x' then it should be `x' if such a query is carried out again (without adding/ deleting/modifying) on the same table.

1. **Domain integrity:** It defines a valid set of values for an attribute, for example, length or size, data type, etc.

2. **Entity integrity constraint**: It defines that the primary keys cannot be null. There must be a proper value in the primary key field.

3. **Referential integrity constraint**: It is specified between two tables. It is used to maintain the consistency among rows between the two tables.

4. **Foreign key integrity constraint:** There are two types of foreign key integrity constraints:

    - **Cascade update related fields:** Whenever the primary key of a row in the primary table is changed, the foreign key values are updated in the matching rows in the related table.

- **Cascade delete related rows:** Whenever a row in the primary table has been deleted, the matching rows are automatically deleted in the related table.

5.2 Normal Forms

Normalization is a technique of organizing the database tables, such that they have minimum redundancy. Following are the normal forms that are to be achieved for the process of normalization. The underlying concept is that, if we say a table to be satisfying an `x’ level normal form, then it is understood that it has also satisfied the `x-1’ level normal form.

1. First normal form: It defines that all the attributes in a relation must have atomic domains.

2. Second normal form: It defines that every non-prime attribute should be fully functionally dependent on prime key attribute. A prime attribute is a part of prime key. The relation must be in the First normal form.

3. Third normal form: It defines that no non-prime attribute is transitively dependent on prime key attribute. The relation must be in the Second normal form.

4. Boyce-Codd normal form: It defines that for any non-trivial FD, $X \rightarrow A$, then X must be a super key. It is an extension of the Third normal form.

5. Fourth normal form: It defines that for every multivalued dependency $X \rightarrow\rightarrow Y$ that holds over R, one of the following statements is true: (a) Y is the subset of X and (b) X is a super key.Also, sometimes called, Multi-valued Dependency Normal Form (MDNF).

6. Fifth normal form: It denies that for every join dependency $\bowtie$

{R1, ..., R_n} that holds over R, one of the following statements is true: (a) R_i = R and (b) the join dependency is implied by the set of those FDs over R in which the left side is a key.

Also, sometimes called, Project-Join Normal Form(PJNF).

5.3 Attribute Closure

Set of all attributes functionally determined by X is called closure of X. Closure set of X is denoted by X^+

Problem 1: Functional dependencies F = {A → B, B → C, C → D} is given, find closure of A, B, C and D.

Solution:

Closure of A = A^+ = (A, B, C, D)
Closure of B = B^+ = (B, C, D)
Closure of C = C^+ = (C, D)
Closure of D = D^+ = (D)

5.4 Key

It is a minimum set of attributes used to differentiate all the tuples of the table.

5.4.1 Superkey

It is a set of attributes that uniquely identifies each record in a table. It is a superset of candidate key. In other words, let R be the schema and X be the set of attributes over R. If closure of X (X^+) determines all the attributes of R, then X is called superkey.

Problem 2: Consider a schema R(ABCDE) and FDs {AB → C, C → D, B → E}. Find superkey.

Solution:

Find closure set of (A, B, C, AB).

Closure of A = A^+ = {A}

Closure of B = B^+ = {B, E}

Closure of C = C^+ = {C, D}

Closure of AB = AB^+ = {A, B, C, D, E}

So, AB is the superkey.

5.4.2 Candidate Key

It is an attribute or set of attribute that can act as a primary key of a table that uniquely identifies each record in a table. Every candidate key is a superkey but not vice versa.

In other words, candidate key is the minimal superkey. If X is a superkey and none of the proper subset of X is a superkey, then X is called the minimal superkey or candidate key.

Problem 3: Consider a schema R(ABCDE) and FDs {AB → C, C → D, B → EA}. Find the superkey.

Solution:

Find closure set of (A, B, C, AB)

Closure of A = A^+ = {A}

Closure of B = B^+ = {B, E, A, C, D}

Closure of C = C^+ = {C, D}

Closure of AB = AB^+ = {A, B, C, D, E}

So, AB and B are superkeys. But only B is the candidate key.

5.4.3 Primary Key

It is one or more data attributes that uniquely identify an entity. It does not allow null values.

1. **Alternate key**: The candidate key, which is not selected as a primary key.

2. **Composite key:** It consists of two or more attributes.

3. **Foreign key:** It is an entity that is the reference to the primary key of another entity.

5.5 Decomposition

It is required to eliminate redundancy from the schema. If a relational schema R has redundancy in the data, then decompose R into two R_1 and R_2 schema. There are two properties, which should be maintained when we perform decomposition, it should be a lossless join as well as dependency preserving.

5.5.1 Lossless Join

Let R be a relation schema and let F be a set of functional dependency (FD) over R. R is decomposed into R1 and R2. R_1 and R_2 are called lossless-join decomposition if $R = R_1 \bowtie R_2$ or if we can recover original relation from the decomposed relation.

(a) Algorithm for finding decomposition is lossless:

Step 1: Union of all decomposed sub-relation should be equal to relation R.

$$R_1 \cup R_2 \cup R_3 \cup ... \cup R_n = R$$

Step 2: Any two sub-relations R_i and R_j can be merged into R_{ij} with $R_1 \cup R_2$ only if

i. $R_i \cap R_j \neq \emptyset$ (null)
ii. $R_i \cap R_j = X$ then closure of $X(X^+) \supseteq R_i$
or
$R_i \cap R_j = X$ then closure of $X (X^+) \supseteq R_j$

Step 3: Repeat step 2 until `N' relations become one relation. If `N' relations become single relation, then composition is called lossless, otherwise not.

Problem 4: Consider a schema R (ABCDEFGHIJ) and functional dependencies {FDs = (AB → C, A → D, B → F, F → GH, D → IJ)} and decompositions
(a) {D = (ABCDE, BFGH, DIJ)}
(b) {D = (ABCD, DE, BF, FGH, DIJ)}
Check whether the decomposition is lossless or not.

Solution:

(a) Given
R1 = (ABCDE)
R2 = (BFGH)
R3 = (DIJ)
Apply algorithm for lossless decomposition:

Step 1:
$R_1 \cup R_2 \cup R_3$ ={(ABCDE) ∪ (BFGH) ∪ (DIJ)}= (ABCDEFGHIJ)= R
Step 1 satisfies the given condition, so it is true.

Step 2:
For R_1 and R_2:
$R_1 \cap R_2$ =(ABCDE) ∩ (BFGH)= B
Find closure of B = B^+ = {B, F, G, H}.
Condition (ii) is satisfied, so R_1 and R_2 can be merged together. After merging R_1 and R_2,
R_{12} = (ABCDEFGH)

Now merge R_{12} and R_3.

$R_{12} \cap R_3 = (ABCDEFGH) \cap (DIJ) = D$

Find closure of D = $D^+ = \{D, I, J\}$.

Condition (ii) is satisfied, so R_{12} and R_3 can bemerged together. After merging R_{12} and R_3

$R_{123} = (ABCDEFGHIJ)$

So, $R_{123} = R$, therefore, it is lossless decomposition.

(b) Given that

$R_1 = (ABCD)$

$R_2 = (DE)$

$R_3 = (BF)$

$R_4 = (FGH)$

$R_5 = (DIJ)$

Apply algorithm for lossless decomposition.

Step 1:

$R_1 \cup R_2 \cup R_3 \cup R_4 \cup R_5 = \{(ABCD) \cup (DE) \cup (BF) \cup (FGH) \cup (DIJ)\}$

$= (ABCDEFGHIJ) = R$

Step 1 satisfies the given condition, so it is true.

Step 2:

For R_1 and R_2

$R_1 \cap R_2 = (ABCD) \cap (DE) = D$

Find closure of D = $D^+ = \{D, I, J\}$.

Condition (ii) of step 2 does not satisfy, so R_1 and R_2 cannot be merged together.

For R_1 and R_3

$R_1 \cap R_3 = (ABCD) \cap (BF) = B$

Find closure of B = $B^+ = \{B, F, G, H\}$.

Condition (ii) of step 2 is satisfied, so R_1 and R_3 can be merged together.

After merging R_1 and R_3

R_{13} = (ABCDF)

For R_{13} and R_4

$R_{13} \cap R_4$ = (ABCDF) ∩ (FGH)= F

Find closure of F = F^+ = {F, G, H}

Condition (ii) of step 2 is satisfied, so R_{13} and R_4 can be merged together.

After merging R_{13} and R_4

R_{134} = (ABCDFGH)

For R_{134} and R_5

$R_{134} \cap R_5$ = (ABCDFGH) ∩(D IJ)=D

Find closure of D = D^+ = {D, I, J}

Condition (ii) of step 2 is satisfied, so R_{134} and R_5 can be merged together.

After merging R_{134} and R_5

R_{1345} = (ABCDFGHIJ)

For R_{1345} and R_2

$R_{1345} \cap R_2$ = (ABCDFGHIJ) ∩(DE)= D

Find closure of D = D^+ = {D, I, J}.

Condition (ii) of step 2 does not satisfy, so R_{1345} and R_2 cannot be merged together.

So, finally we left with two decompositions which cannot be merged into a single relation. So condition given in step 3 does not satisfy, therefore, it is not lossless decomposition.

5.5.2 Dependency Preserving

All the dependency should be preserved after the decomposition of schema R.

Let R be the relational schema with FD set F decomposed into R_1, R_2, R_3, ..., Rn with FD sets F_1, F_2, F_3, ...,Fn, respectively. The decomposition is said to be dependency preserved if

$F_1 \cup F_2 \cup F_3 \cup ... \cup F_n = F$

And composition is called non-dependency preserved if

$F_1 \cup F_2 \cup F_3 \cup ... \cup F_n \subset F$

(a) Algorithm to check dependency is preserved or not:

Step 1: Find all the FDs of sub-relations.

Step 2: Check that all the FDs of relation F is covered by FDs of subrelation in any form directly or indirectly.

Problem 5: Consider a schema R(ABCD) and FDs set F = (A → B, B → C, C → D, D → A) and decompositions D = (AB, BC, CD). Check decomposition is dependency preserving or not.

Solution:

Step 1: Find all the FDs of sub-relations.

	$R_1 = (AB)$	$R_2 = (BC)$	$R_3 = (CD)$
Direct Dependency	$A \to B$	$B \to C$	$C \to D$
Indirect Dependency	$B \to A$	$C \to B$	$D \to C$

To calculate indirect dependency, use closure property. In relation R_1, we have indirect dependency B → A. We have to first find closure of all attributes in that decomposition (like in R_1 we have A and B) by using FD set F and then check that we are getting attribute A in closure of B. So closure of B = B^+ = ABCD. So we can write that indirectly as we have three dependencies {B → A, B → C and B → D} but only B → A is valid for R_1 as we have only two attributes (A and B) in relation R_1.

Step 2: Check that all the FDs of relation F is covered by FDs of sub-relation in any form directly or indirectly.

(a) A → B (Directly covered by sub-relation FD)

(b) B → C (Directly covered by sub-relation FD)

(c) C → D (Directly covered by sub-relation FD)
(d) D → A (Indirectly covered by sub-relation FD by using {D → C then C → B and then B → A}).

All the dependency is preserved, so it is dependency preserved decomposition.

5.5.3 Relation between Two Functional Dependency (FD) Sets

Let F and G be two FD sets:

1. Set F and G are equal if and only if closure of F(F^+) = Closure of G(G^+)

2. Set F and G are equal only if both of the below conditions satisfy:
   - F covers G: All FD in G is logically implied by F.
   - G covers F: All FD in F is logically implied by G.

3. If all FD in G is logically implied by F but all FD in F is not logically implied by G then G ⊂ F.

Problem 6: Let there be two FD sets F and G, given as follows:
F = {A → B, B → C}
G = {A → B, AB → C, B → C, A → C}
Find the relation between both FDs.

Solution:

(a) F covers G:

Functional Dependency	Covered by F
$A \to B$	Direct covered
$AB \to C$	Indirect covered ($AB^+ = ABC$), so AB can determine C.
$B \to C$	Direct covered
$A \to C$	Indirect covered ($A^+ = ABC$), so A can determine B and C.

Functional Dependency	Covered by F
$B \rightarrow C$	Direct covered
$A \rightarrow C$	Indirect covered ($A^+ = ABC$), so A can determine B and C.

(b) G covers F

Functional Dependency	Covered by G
$A \rightarrow B$	Direct covered
$B \rightarrow C$	Direct covered

In our example, F covers G and vice versa. So F = G.

6. Query Languages (SQL)

SQL stands for Structured Query Languages, which is a standard computer language for relational database management and data manipulation. It is used to query, insert, update and modify data in the table. Some common RDBMS that use SQL are Oracle, Microsoft SQL Server, Access, Ingres, Sybase, etc. Raymond Boyce and Donald Chamberlin developed it in the early 1970s at IBM, but commercially released by Relational Software Inc. (now, Oracle Corporation) in 1979. Looking into the history it was the software named- VULCAN, that was procured by Ashton Tate and then by FoxPro and later was purchased by Microsoft. Other popular softwares were/are — Clipper and Gupta Technologies.

6.1 SQL Commands

The SQL commands are used to interact with relational databases. These commands can be classified into the following groups (see Tables)

1. **Data Definition Language (DDL):** It contains metadata, that is, data about data. All the integrity constraints and data base schemas are defined through DDL. These commands are used to create, modify and delete database objects. CREATE, ALTER, TRUNCATE and DROP are part of DDL. TRUNCATE command is used to delete complete data from an existing table, while DROP command is used to remove a table definition and all data, indexes, triggers and constraints for a table.

    - Syntax of create command
      CREATE TABLE table_name(column1 datatype, column2 datatype, column3 datatype, ... columnN datatype, PRIMARY KEY(one or more columns));
      For example, create table instructor (INST_ID char(5), name varchar(20),dept_name varchar(20), salary numeric(8,2));

    - **Syntax of alter command**
      ALTER TABLE table_name ADD column_name datatype;
      ALTER TABLE table_name DROP COLUMN column_name;
      ALTER TABLE table_name MODIFY COLUMN column_name datatype;
      ALTER TABLE table_name ADD CONSTRAINT Constraint UNI (column1, column2...);
      ALTER TABLE table_name ADD CONSTRAINT Constraint CHECK (CONDITION);
      ALTER TABLE table_name ADD CONSTRAINT PrimaryKey PRIMARY KEY (column1, column2...);
      For example, ALTER TABLE CUSTOMERS ADD GRADE char(1);

    - **Syntax of truncate command**
      TRUNCATE TABLE table_name;
      For example, TRUNCATE TABLE emp;

    - **Syntax of drop command**
      DROP TABLE table_name;
      For example, DROP TABLE emp;

SQL commands

Command	Description
CREATE	Creates a new table, a view of a table or other objects in the database
ALTER	Modifies an existing database (table)
DROP	Deletes a table, a view of a table or other objects in the database
SELECT	Retrieves data from one or more tables (database)
INSERT	Inserts new data record in the database
UPDATE	Modifies data in the database
DELETE	Deletes data from the database
GRANT	Gives a privilege to the user
REVOKE	Takes back privileges granted from the user

Clauses in SQL

Clause	Description
From	Equals to cross product
Where	Selects the tuples which satisfies the condition
Group by	Groups the table based on specified attribute
Having	Used to select groups based on condition

2. Data Manipulation Language (DML):

DML is used to manipulate the data in database. It allows to insert, update and delete data items. SELECT, INSERT, DELETE and

UPDATE are part of DML. Control statements BEGIN TRANSACTION, SAVEPOINT, COMMIT and ROLLBACK are also part of DML.

- **Syntax of select command**
  SELECT * FROM table_name;
  SELECT column1, column2, column FROM table_name;
  For example, SELECT empno, ename FROM emp;

- **Syntax of insert command**
  INSERT INTO TABLE_NAME (column1,column2,column3,...columnN)] VALUES (value1, value2, value3,...valueN);
  INSERT INTO TABLE_NAME VALUES (value1,value2,value3,...valueN);
  For example, INSERT into emp (empno,ename, sal, dept) VALUES (100, ABC,10000, Accounts);

- **Syntax of delete command**
  DELETE FROM table_name WHERE [condition];
  For example, DELETE FROM emp WHERE empno = 8;
- **Syntax of update command**
  UPDATE table_name SET column1 = value1, column2 = value2...., columnN = valueN WHERE [condition];
  For example, UPDATE mp SET sal = 12000 WHERE empid = 8;

2. **Data Control Language (DCL):** To assign or revoke access rights data control language is used. GRANT and REVOKE are used for DCL.

- **Syntax of grant command**
  GRANT privilege_name ON object_name TO {user_name | PUBLIC | role_name} [with GRANT option];
  For example, GRANT SELECT ON emp TO user1;

- **Syntax of revoke command**
  REVOKE privilege_name ON object_name FROM {User_name PUBLIC | Role_name};

For example, REVOKE SELECT ON emp TO user1;

7. File Structures

File structure mainly deals with how files are stored on the disk. Various file organisations are described below.

7.1 Sequential Files

It is a file organisation system where every file record contains an attribute to uniquely identify a particular record. Records are placed in a sequential order with some unique key.

7.2 Indexing

Indexing is a data structure mechanism to efficiently retrieve records from the database, for example, book index. It is defined based on its indexing attributes. Indexing is of three types:

1. **Primary index:** Indexing is based on ordering key field of file.
2. **Secondary index:** Indexing is based on non-ordering field of file.
3. **Clustering index:** Indexing is based on ordering non-key field of file.

Ordering field is the field on which the records of file are ordered. Ordered indexing is of two types: dense index and sparse index.

1. **Dense index:** For every search key value in the database, there is an index record. Index record has two parts: search key value and the pointer. The pointer is pointed to the actual record.

2. **Sparse index:** In this no index record is created for every search key.

7.3 B Tree

A B tree is a data structure that stores data in such a manner that search, insertions and deletions can be done in logarithmic time. B trees are a general form of binary trees where a node can have more than one child. The B-trees are efficient for those systems that read and write large blocks of data, that is, databases and file systems.

B trees are self-balancing trees. All the leaf nodes are at the same level. A B tree with order p has:

1. Root node may contain minimum 1 key
2. Minimum number of child =(p/2)-1
3. Maximum number of children = p
4. Maximum keys = p – 1

The order of B-tree can be found as follows:

$$p \times P + (p - 1)(K + P_r) \leq \text{Block size}$$

where p is order of the tree, P is the block pointer, P_r is the record pointer and K is the key pointer.

Problem 7: The order of B-tree index is the maximum number of children it can have. Suppose that a block pointer takes 6 bytes, the search field value takes 9 bytes, record pointer takes 7 bytes and the block size is 512 bytes. What is the order of the B tree?

Solution:

Given that block size = 512 B; record pointer (Pr) = 7 B;
block pointer (PB) =6 B; key pointer (K) = 9B.
So, we have

$$p \times P + (p - 1)(K + P_r) \leq \text{Block size}$$
$$6p + (p - 1)(9 + 7) = 512$$
$$p = 24$$

7.4 B+ Trees

It supports multilevel indexing. The leaf nodes of B+ tree represent actual data pointers. It ensures all leaf nodes are balanced, that is, at the same height. Leaf nodes are linked using link list.

B+ tree structure is such that B+ tree is of order n and it is fixed for every B+ tree.

The internal nodes contain at least [n/2] pointers, except the root node and at most n pointers. Leaf nodes contain at least [n/2] record pointers, at least [n/2] key values, at most n record pointers, at most n key values, and every leaf node contains one block pointer P to point to next leaf node and forms a linked list.

Order of internal nodes can be calculated as:

$$p \times P_B + (p - 1) \times k \leq \text{Block size}$$

Order of leaf nodes:

$$P_{leaf} \times [k + P_r] + P_B \leq \text{Block size}$$

where p is the order of internal nodes, P_r is record pointer, P_B is block pointer, k is key pointer, P_{leaf} is the order of leaf nodes.

Problem 8: The order of an internal node in a B+ tree index is the maximum number of children it can have. Suppose that a block pointer takes 6 bytes, the search field value takes 9 bytes, record pointer take 7 bytes and the block size is 512 bytes. What is the order of the internal node and leaf node?

Solution:

Given that block size = 512 B, record pointer (P_r)= 7 B,
block pointer (PB) = 6 B and key pointer (k) = 9 B.

Order of internal nodes:

$$p \times P_B + (p - 1) \times k \leq \text{Block size}$$

$$6p + (p - 1)9 = 512$$

$$p = 34$$

Order of leaf nodes:

$$P_{leaf} \times [k + P_r] + P_B \leq \text{Block size}$$

$$P_{leaf}\,[9 + 7] + 6 = 512$$

$$P_{leaf} = 31$$

8. Transactions And Concurrency Control

Transactions are series of read and write operations on database. When many users access same database at the same time, some control mechanism is required by databases to stay in consistent state. Following sections will provide description about transactions and their control mechanism.

8.1 Transactions

It is a series of reads and writes of database objects. It maintains the integrity of a database while running multiple concurrent operations. Transactions have four properties that a DBMS must ensure to maintain data. These are known as ACID properties:

1. **Atomicity:** Either all actions are carried out or none (no partial transaction).

2. **Consistency:** After the execution of transaction, the database must be in a consistent state (no concurrent execution of other transactions).

3. **Isolation:** All the transactions are carried out and executed as the only transaction in the system (no transaction will affect the existence of any other transaction).

4. **Durability:** Persistence of data even if the system fails and restarts.

8.2 Schedule

A chronological execution sequence of transactions is called schedule. It is a list of actions reading, writing, aborting or committing from a set of transactions. A schedule can have many transactions. Schedule can be further divided into two types–serial schedule and concurrent schedule.

8.2.1 Serial Schedule

A schedule is called serial schedule if all transactions are executed in a non-interleaving manner. Let there are two transactions T_1 and T_2 schedule S then schedule S is called serial schedule if one transaction executes after another shown in Fig.

T_1	T_2
Read (X)	
$X = X - Z$	
Write (X)	
Read (Y)	
$Y = Y + Z$	
Write (Y)	
	Read (X)
	$X = X + W$
	Write (X)

T_1	T_2
	Read (X)
	$X = X + W$
	Write (X)
Read (X)	
$X = X - Z$	
Write (X)	
Read (Y)	
$Y = Y + Z$	
Write (Y)	

Serial schedule.

8.2.2 Concurrent Schedule

A schedule is called concurrent schedule if transactions are executed in an interleaving manner or simultaneous execution of two or more transactions. Let there be two transactions $T_1$and T_2 in a schedule S, then schedule S is called concurrent schedule if both the transactions execute parallel. One of the scenarios is shown in Fig.

T_1	T_2
Read (X)	
X = X – Z	
	Read (X)
	X = X + W
Write (X)	
	Write (X)
Read (Y)	
Y = Y + Z	
Write (Y)	

Concurrent schedule.

8.2.3 Comparison between Serial and Concurrent Schedule

Table shows the comparison between serial and concurrent schedule.

Serial schedule vs. concurrent schedule

Serial Schedule	Concurrent Schedule
All serial schedules are consistent schedules	All serial schedules are not consistent schedules
Less throughput	More throughput
Poor resource utilization	Good resource utilization
More response time	Less response time
For the given transactions, the number of serial schedule is very much less than the number of concurrent schedule	For the given transactions, the number of concurrent schedule is more than the number of serial schedule

8.2.4 Problems Occurring due to Concurrent Schedule

In concurrent schedule, more than one transaction is executed simultaneously; and due to this some problem arises with concurrent schedule given as follows:

1. **WR problem (Read after Write):** WR problem is also known as dirty read problem or uncommitted read problem. Let there be two transactions T_i and T_j of schedule S. If transaction T_j reads a data item which is written by T_i, but till that time transaction T_i is not committed, then WR problem can occur. If in transaction T_i rollback or failure occurs, then database will be inconsistent due to uncommitted read by T_j transaction (Fig.).

Transaction T_i	Transaction T_j
Read (A)	
A = A + X	
Write (A)	
	Dirty Read
	Read (A)
	Write (B)
	A = A + Y
Read (B)	

Failure or rollback	
	Write (A)

Uncommitted read problem (WR problem).

Example: Let value of data item A = 1000, X = 100 and Y = 200, then transaction Ti will update the database with value 1100. Transaction Tj Will read data item value as 1100. Transaction Tj will update database with value 1300. As transaction Ti fails, the database value should be 1200. Therefore, this problem is known as uncommitted read problem or dirty read problem.

2. **RW problem (Write after Read):** RW problem is also known incorrect summary problem or unrepeatable read problem (Fig.). Let there be two transactions T_i and T_j of schedule S. Transaction T_i read a data item and T_j also read similar data item. Transactions T_i and T_j both have write operation on that data item. If in both transactions, read operation occurs before commit of the other transaction and before writing back that data item in database by other transaction then RW problem will arise.

ENTRI

Transaction T_i	Transaction T_j
Read (A)	
If (A > 0)	
A = A + 1	
	Read (A)
	If (A > 0)
	A = A + 1
Write (A)	
Commit	Write (A)
	Commit

Incorrect summary problem (RW problem)

Example: Let value of data item A = 100. Transaction T_i will read data item with value 100 and update database with value 101. Transaction T_j will read data item value as 100 because it will read before updating value of data item A by transaction T_i. Transaction T_j will update database with value 101. But data item `A' value should be 102 because both the transaction have commit successfully. Therefore, this problem is known as unrepeatable read problem.

3. **WW Problem (Write after Write):** WW problem in concurrent schedule is also known as lost update problem (Fig). Let there are two transactions T_i and T_j of schedule S. Transaction T_i reads a data item and updates it. Now, transaction T_j also writes similar data item with some other value and transaction T_j commits successfully. After commit of transaction T_j, transaction T_i will rollback. Thus, updated value of data item by transaction T_j will be lost.

Transaction T_i	Transaction T_j
Read (A)	
Write (A)	
	Write (A)
	Commit
Failure and Rollback	

Lost update problem (WW problem).

Example: Let the value of data item A=100. Transaction Ti read data item and update database with value 200. Let transaction Tj updated database with value 250 and commit successfully. After committing transaction Tj , transaction Ti rollback which set data item value to its initial value 100. So, this problem is known as lost update problem.

8.3 Classification of Schedule Based on Recoverability

8.3.1 Irrecoverable Schedule

Let there be two transactions Ti and Tj of schedule S. If transaction Tj reads a data item which is updated by transaction Ti and transaction Tj commits before the commit (or rollback) of transaction Ti , then the given schedule S is called irrecoverable schedule.

8.3.2 Recoverable Schedule

Let a schedule S have two Ti and Tj . If transaction Tj reads a data item which is updated by transaction Ti and transaction Tj is not allowed to commit (or rollback) before the commit (or rollback) of transaction Ti , then the given schedule S is called recoverable schedule. Recoverable schedule may suffer from uncommitted read, lost update and incorrect summary problem.

8.3.3 Cascading Rollback Recoverable Schedule

Let there be four transactions (T_1 ,T_2 ,T_3 ,T_4) in a given schedule S. In schedule S, if rollback of a transaction (T_1) results in the rollback of the other transactions (T_2 ,T_3 ,T_4) (because of their dependency on each other), then this is called cascading rollback.
If a schedule is recoverable and has no cascading rollback, then it is called cascading rollback recoverable schedule. Incorrect summary and lost update problems may exist in cascading rollback recoverable schedule.
Problems of no recoverability, Uncommitted Read problem (WR problem) and cascading rollback problem do not occur in such schedule.

8.3.4 Strict Recoverable Schedule

Let a schedule S have two Ti and Tj . If S is called a strict recoverable schedule then it satisfies these two conditions:

1. Schedule S should be cascading rollback recoverable schedule.
2. If one transaction Ti writes a data item `A', then the other transaction Tj is not allowed to write on that data item.

Only incorrect summary problem (RW problem) may arise in strict recoverable schedule. Irrecoverable, Uncommitted Read problem (WR problem), lost update and cascading rollback problems do not occur in such schedule.

8.3.5 Summary of Schedules Based on Recoverability

Schedule	Problem Exists	Problem Remove
Irrecoverable	All	None
Recoverable	Incorrect summary problem (RW), Uncommitted Read problem (WR problem), lost update (WW) and cascading rollback problem	Irrecoverable
Cascading rollback recoverable	Incorrect summary problem (RW) and lost update (WW).	Irrecoverable, Uncommitted Read problem (WR problem) and cascading rollback problem.
Strict recoverable	Incorrect summary problem (RW)	Irrecoverable, Uncommitted Read problem (WR problem), lost update (WW) and cascading rollback problem.