Last Minute Notes – DBMS

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Database Management System is an organized collection of interrelated data that helps in accessing data quickly, along with efficient insertion, and deletion of data into the DBMS. DBMS organizes data in the form of tables, schemas, records, etc.

DBMS over File System (Limitations of File System)

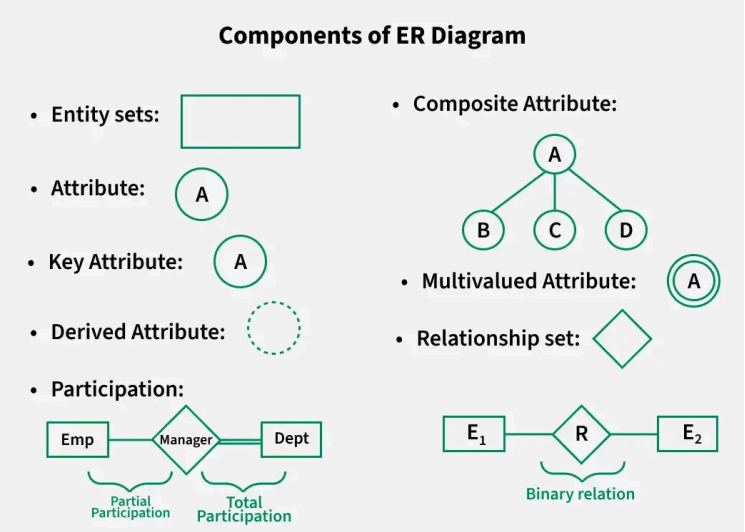
The file system has numerous issues, which were resolved with the help of DBMS, the issues with the file system are:

- **Physical Access Management:** Users are responsible for managing the physical details required to access the database.
- **File System Suitability:** File systems are effective for handling small databases but lack efficiency for larger ones.
- **Concurrency Issues:** For large databases, the operating system struggles to manage concurrency effectively, leading to potential conflicts.
- **Single-User Access:** In a file system, only one user can access the entire dataset at a time, limiting scalability and multi-user functionality.
- **Data access:** In a file system, accessing data was difficult and insecure as well. Accessing data concurrently was not possible.
- **No Backup and Recovery:** There is no backup and recovery in the file system that can lead to data loss.

ER-Model

ER Diagram

An ER diagram is a model of a logical view of the database which is represented using the following components:



- **Entity:** The entity is a real-world object, represented using a rectangular box.
    - **Strong Entity:** A strong entity set has a primary key and all the tuples of the set can be identified using that primary key
    - **Weak entity:** When an entity does not have sufficient attributes to form a primary key. Weak entities are associated with another strong entity set also known as identifying an entity. A weak entity's existence depends upon the existence of its identifying entity. The weak entity is represented using a double-lined or bold-lined rectangle.

- **Attribute:** Attribute is the properties or characteristics of the real-world object. It is represented using an oval.
    - **Key attribute:** The attribute which determines each entity uniquely is known as the Key attribute. It is represented by an oval with an underlying line.
    - **Composite Attribute:** An attribute that is composed of many other attributes. E.g. address is an attribute it is formed of other attributes like state, district, city, street, etc. It is represented using an oval comprises of many other ovals.
    - **Multivalued Attribute:** An attribute that can have multiple values, like a mobile number. It is represented using a double-lined oval.
    - **Derived attribute:** An attribute that can be derived from other attributes. E.g. Age is an attribute that can be derived from another attribute Data of Birth. It is represented using a dashed oval.

- **Relationship:** A relationship is an association between two or more entities. Entities are connected or related to each other and this relationship is represented using a diamond.

- **Participation Constraint:** It specifies the maximum or a minimum number of relationship instances in which any entity can participate. In simple words, participation means how an entity is linked to a relationship.

  Total Participation: Every entity in the entity set participates in at least one relationship in the relationship set.
  Example:
  In the "Manages" relationship between Emp (Employee) and Dept (Department):
  If every department must have a manager, then Dept has total participation in the "Manages" relationship.

  Partial Participation: Some entities in the entity set participate in the relationship, but not all.
  Example:
  In the same "Manages" relationship:
  If not all employees are managers, then Emp has partial participation in the "Manages" relationship.

Cardinality in DBMS

Cardinality of relation expresses the maximum number of possible relationship occurrences for an entity participating in a relationship. Cardinality of a relationship can be defined as the number of times an entity of an entity set participates in a relationship set. Let's suppose a binary relationship R between two entity sets A and B. The relationship must have one of the following mapping cardinalities:

- **One-to-One:** When one entity of A is related to at most one entity of B, and vice-versa.
- **One-to-Many:** When one entity of A is related to one or more than one entity of B. Whereas B is associated with at most one entity in A.
- **Many-to-One:** When one entity of B is related to one or more than one entity of A. Whereas A is associated with at most one entity in B.
- **Many-to-Many:** Any number of entities of A is related to any number of entities of B, and vice-versa.

The most commonly asked question in ER diagram is the minimum number of tables required for a given ER diagram. Generally, the following criteria are used:

Cardinality	Minimum No. of tables
1:1 cardinality with partial participation of both entities	2
1:1 cardinality with a total participation of at least 1 entity	1
1:n cardinality	2
m:n cardinality	3

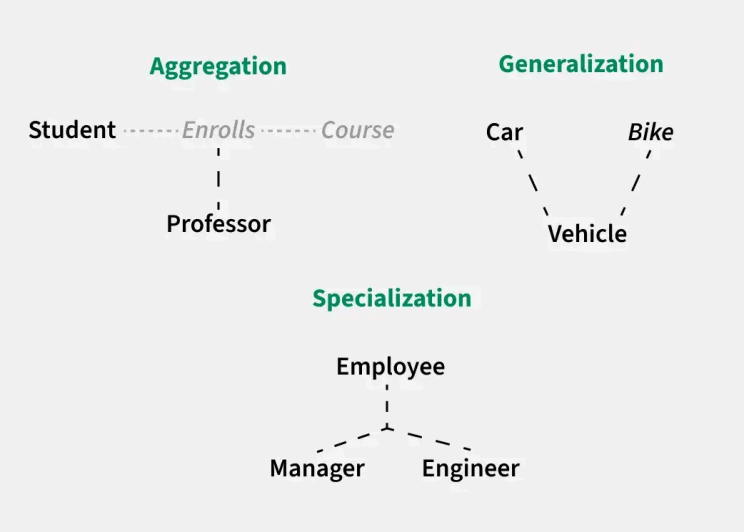
- If the relation is one-to-many or many-to-one then two or more relational tables can be combined.
- If the relation is many-to-many two tables cannot be combined.
- If the relation is one-to-one and there is total participation of one entity then that entity can be combined with a relational table.
- If there is total participation of both entities then one table can be obtained by combining one table and both entities of the relation.

Note: This is a general observation. Special cases need to be taken care of. We may need an extra table if the attribute of a relationship can't be moved to any entity side.

Specialization: It is a top-down approach in which one entity is divided/specialized into two or more sub-entities based on its characteristics.

Generalization: It is a bottom-up approach in which common properties of two or more sub-entities are combined/generalized to form one entity. It is exactly the reverse of Specialization. In this, two or lower level entities are generalized to one higher level entity.

Aggregation: Aggregation is an abstraction process through which relationships are represented as higher-level entity sets.



Read more about Introduction to ER Model.

Database Design

Database design Goals: The prime goal of designing a database is:

- To have zero redundancy in the system
- Loss-less join
- Dependency preservation
- Overcome all the shortcomings of conventional file system

According to E.F. Codd (Codd's Rule in DBMS), "All the records of the table must be unique".

Integrity Constraints Of RDBMS

Integrity constraints are rules that ensure data in a database is accurate and consistent. The main types are:

1. **Entity Integrity:** Each record must have a unique identifier (primary key).
2. **Referential Integrity:** Relationships between tables must be consistent (using foreign keys).
3. **Domain Integrity:** Data in each field must meet certain rules (e.g., correct type or range).
4. **User-Defined Integrity:** Custom rules set by users for specific needs.

Key Terms in Relational Databases

- **Table:** A collection of rows (records) in a database.
- **Record:** A single row in a table, containing data fields.

- **Field:** A column in a table, also called an attribute.
- **Domain:** The set of possible values a field can have.
- **Key:** A method for identifying specific records in a table.
- **Index:** A tool that speeds up database queries and searches.
- **View:** A virtual table created from data in actual tables.
- **Tuple:** Another word for a record or row in a table.
- **Relation:** Another term for a table.
- **Cardinality:** The total number of rows in a table.
- **Degree:** The number of columns in a table.
- **Schema:** The structure of a table, including its name, fields, and allowed values.
- **Prime Attributes:** Unique attributes used to identify rows, part of the primary or candidate key (e.g., student ID).
- **Non-Prime Attributes:** Attributes not part of any key, may have duplicates, and provide additional information (e.g., student's first name, date of birth).

Keys in database

Keys of a relation: There are various types of keys in a relation which are: **primary key**, **candidate key**, **super key**, and **alternate key**. Let's take a table called STUDENT

student_id	name	email	phone
1	Alice	alice@xyz.com	1234567890
2	Bob	bob@xyz.com	9876543210
3	Charlie	charlie@xyz.com	5555555555

1. Primary Key

The **primary key** is the unique identifier for each record. In this case, `student_id` is the primary key because each student has a unique ID. **Primary Key:** `student_id`

2. Candidate Key

The minimal set of attributes that can determine a tuple uniquely. There can be more than 1 candidate key of a relation and its proper subset can't determine tuple uniquely and it can't be NULL. In this case, both `student_id` and `email` can uniquely identify a student. **Candidate Keys:** `student_id`, `email, phone`.

3. Super Key

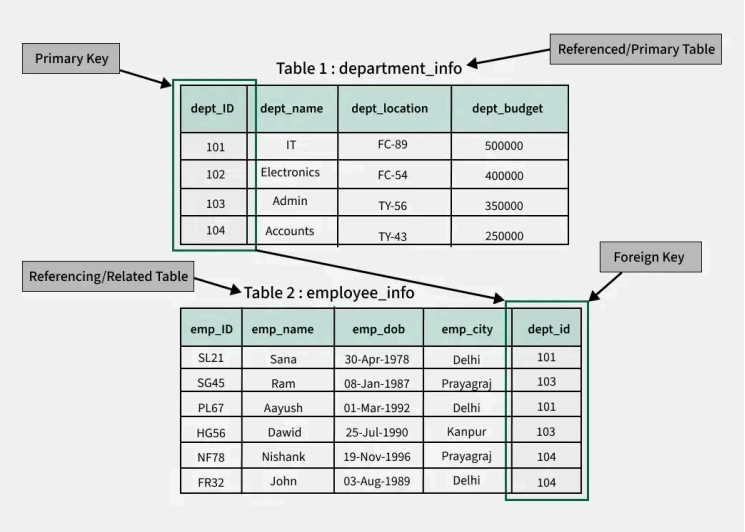
A **super key** is any combination of columns that uniquely identifies a record. It can include extra attributes beyond what is necessary for uniqueness. A candidate key is always a super key but vice versa is not true. For example, `student_id` combined with `phone` or `email` would still uniquely identify a student. **Super Keys:** `student_id`, `student_id + phone`, `email + phone` etc.

4. Alternate Key

An **alternate key** is any candidate key that is not chosen as the primary key. In this case, since `student_id` is the primary key, `email` becomes the alternate key. **Alternate Key:** `email`, phone.

5. Foreign Key

Foreign Key is a set of attributes in a table that is used to refer to the primary key or alternative key of the same or another table.



Functional Dependency

It is a constraint that specifies the association/ relationship between a set of attributes. It is represented as A->B, where set A can determine the values of set B correctly. The A is known as the **Determinant**, and B is known as the **Dependent.**

Types of Functional Dependencies in DBMS:

1. **Trivial Functional Dependency:** A functional dependency where the right-hand side is a subset of the left-hand side.
   Example: `A → A` (any attribute depends on itself).

2. **Non-Trivial Functional Dependency:** A functional dependency where the right-hand side is not a subset of the left-hand side.
   Example: `Student_ID → Student_Name` (Student_ID determines Student_Name).
3. **Multivalued Functional Dependency:** When one attribute determines a set of values for another attribute, but not directly.
   Example: `Student_ID →→ Student_Courses` (A student may have multiple courses).
4. **Transitive Functional Dependency:**
   When one attribute depends on another through a third attribute.
   Example: `Student_ID → Student_Name` and `Student_Name → Department`, so `Student_ID → Department`.

All dependencies can relate to a `Student` table where `Student_ID` is the key.

Armstrong's Axioms: It is a statement that is always considered true and used as a starting point for further arguments. Armstrong axiom is used to generate a closure set in a relational database.

Armstrong Axiom	
Primary Rules	**Secondary Rules**
Reflexive: If $Y \subseteq X$ then $X \rightarrow Y$	**Union:** If $X \rightarrow Y$, and $Y \rightarrow Z$, then $X \rightarrow YZ$
Transitivity: If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$	**Decomposition:** If $X \rightarrow YZ$, then $X \rightarrow Y$ and $X \rightarrow Z$
Augmentation: If $X \rightarrow Y$, then $XZ \rightarrow YZ$	**Composition:** If $X \rightarrow Y$ and $Z \rightarrow W$, then $XZ \rightarrow YW$
	Pseudo Transitivity: If $X \rightarrow Y$ and $WY \rightarrow Z$, then $WX \rightarrow Z$

Armstrong Axiom

Attribute Closure(X^+): All attributes of the set are functionally determined by X.

- **Prime Attribute:** An attribute that is part of one candidate key.
- **Non-prime Attribute:** An attribute that is not a part of any candidate key.

Example: If the relation R(ABCD) {A->B, B->C, C->D}, then the attribute closure of

A will be (A^+)={ABCD} [A can determine B, B can determine C, C can determine D]
B will be (B^+)={BCD} [B can determine C, C can determine D]
C will be (C^+)={CD} [C can determine D]
D will be (D^+)={D} [D can determine itself]

Note: With the help of Attribute closure, we can easily determine the Superkey [*The set of attributes whose closure contains all attributes of a relation*] of a relation, So

in the above example A is the superkey of the given relation. There can be more than one superkey in a relationship.

Example: If the relation R(ABCDE) {A->BC, CD->E, B->D, E->A}, then the attribute closure will be

A^+= {ABCDE}
B^+= {BD}
C^+= {C}
D^+= {D}
E^+= {ABCDE}

Steps to Find a Candidate Key (Minimal Super Key)

- **Identify all Super Keys:**
  A super key is any set of attributes that can uniquely identify a record. Start by considering combinations of attributes that can act as super keys.
- **Remove Redundant Attributes:**
  Check if any attribute in the super key is unnecessary. If removing an attribute still allows the set to uniquely identify records, it is redundant. Continue removing until no more attributes can be removed without losing uniqueness.
- **Minimal Super Key = Candidate Key:**
  After eliminating unnecessary attributes, the resulting set is a **Candidate Key**.

Equivalence sets of Functional Dependency

If two sets of a functional dependency are equivalent, i.e. if A^+= B^+. Every FD in A can be inferred from B, and every FD in B can be inferred from A, then A and B are functionally equivalent.

Minimal Cover or Canonical Cover

A **minimal cover** is the smallest set of functional dependencies that preserves the same information.
Steps:

1. **Single attribute on the right-hand side:** Break dependencies like $AB \to C$ into $AB \to B$ and $AB \to C$.
2. **Remove unnecessary attributes:** Eliminate attributes on the left-hand side if not needed.

3. **Remove redundant dependencies:** If a dependency is implied by others, remove it.

Example: Given: $AB \rightarrow C, A \rightarrow B, BC \rightarrow A$, Minimal cover could be: $A \rightarrow B, B \rightarrow C, BC \rightarrow A$.

Normalization: Normalization is used to eliminate the following anomalies:

- **Insertion Anomaly**
- **Deletion Anomaly**
- **Updation Anomaly**
- **Join Anomaly**

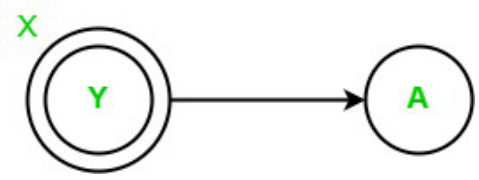
Normalization was introduced to achieve integrity in the database and make the database more maintainable.

Normal Forms

1. First Normal Form: A relation is in first normal form if it does not contain any multi-valued or composite attribute. If the data is in 1NF then it will have high redundancy. First Normal Form (1NF) is considered the default state for any relational table.

2. Second Normal Form: A relation is in the second normal form if it is in the first normal form and if it does not contain any partial dependency.

- **Partial Dependency:** A dependency is called partial dependency if any proper subset of candidate key determines non-prime (which are not part of candidate key) attribute.
  Let R be the relational schema and X, Y, A is the set of attributes. Suppose X is any candidate key, Y is a proper subset of candidate key, and A is a Non-prime attribute.



Partial Dependency

Y->A will be partial dependency iff, Y is a proper subset of candidate key, and A is a non-prime attribute.

- **Full Functional Dependency:** If A and B are an attribute set of a relation, B is fully functional dependent on A, if B is functionally dependent on A but not on any proper subset of A.

3. Third Normal Form: A relation is in the third normal form if it is in the second normal form and it does not contain any transitive dependency. For a relation to be in Third Normal Form, either LHS of FD should be super key or RHS should be the prime attribute.

4. Boyce-Codd Normal Form: A relation is in Boyce-Codd Normal Form if the LHS of every FD is super key. The relationship between Normal Forms can be represented as **1NF, 2NF, 3NF or BCNF.**

Read more about Normal Forms.

Design Goal	1NF	2NF	3NF	BCNF
Zero Redundancy	High redundancy	Less than 1NF	Less than 2NF	No redundancy
Loss-less decomposition	Always	Always	Always	Always
Dependency preservation	Always	Always	Always	Sometimes Not possible

Properties of Decomposition:

Loss-less Join Decomposition: There should not be the generation of any new tuple because of the decomposition.
If [R1 ⋈ R2 ⋈ R3.....⋈ Rn] = R then loss-less join decomposition , If [R1 ⋈ R2 ⋈ R3 ..... ⋈ Rn] ⊃ R then lossy join decomposition.

Consider the relation R(A,B,C) with the functional dependencies: A→B , B→C . Decompose R into R1(A,B) and R2(B,C) :

To check for a lossless join, ensure the common attribute B is a candidate key in at least one of the decomposed relations:

- In R1(A,B), A→B, so A is a key.
- In R2(B,C), B→C, so B is a key.

When R1 and R2 are joined on B, no information is lost. Therefore, the decomposition is lossless.

Dependency Preserving Decomposition: There should not be the loss of any tuple because of the decomposition. Let R be a relation with Functional dependency F. After decomposition R is decomposed into R_1, R_2, R_3.....R_n with FD set F_1, F_2, F_3..... F_n respectively. If F_1, F_2, F_3.....$F_n \equiv F$, then the decomposition is dependency preserving otherwise not.

Suppose we have a relation R(A,B,C) with the functional dependencies: A→B , B→C. If we decompose R into R1(A,B) and R2(B,C) :

- R1 preserves the dependency A→B.
- R2 preserves the dependency B→C.

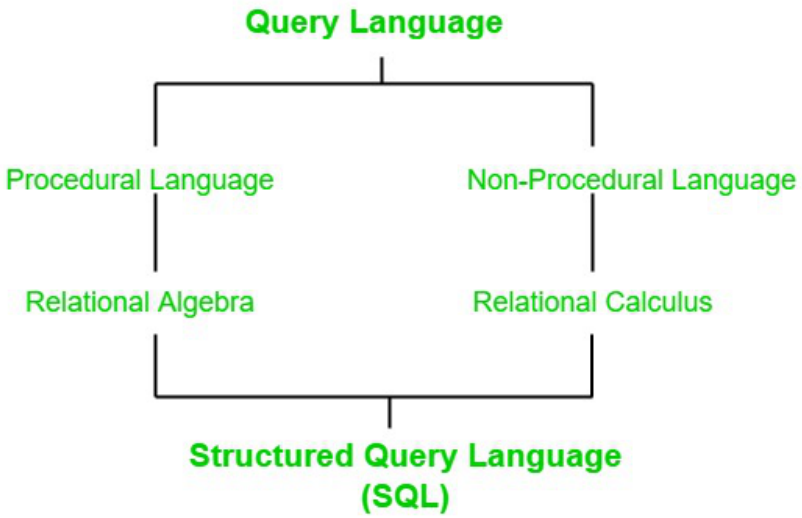
Since all original functional dependencies are preserved in at least one of the decomposed relations, dependency preservation is achieved.

Data Retrieval (SQL, RA)

Commands to Access Database: For efficient data retrieval, insertion, deletion, updation, etc. The commands in the Database are categorized into three categories, which are as follows:

- **DDL [Data Definition language]:** It deals with how data should store in the database. DDL commands include CREATE, ALTER, DROP, COMMENT, and TRUNCATE
- **DML [Data Manipulation language]:** It deals with data manipulation like modifying, updating, deleting, etc. DML commands include SELECT, INSERT, DELETE, UPDATE, LOCK TABLE, MERGE, CALL, AND EXPLAIN PLAN.
- **DCL [Data Control Language]:** It acts as an access specifier, and includes GRANT, AND REVOKE.

Query Language: Language using which any user can retrieve some data from the database.



Note: Relational model is a theoretical framework RDBMS is its implementation.

Relational Algebra: Procedural language with basic and extended operators.

Basic Operator	Semantic
σ(Selection)	Select rows based on a given condition
π (Projection)	Project some columns
X (Cross Product/ Cartesian Product)	Cross product of relations, returns **m*n** rows where m and n are numbers of rows in R1 and R2 respectively.
U (Union)	Return those tuples which are either in R1 or R2. Maximum number of rows returned **= m+n** Minimum number of rows returned = **max(m,n)**
– (Minus)	R1-R2 returns those tuples which are in R1 but not in R2. Maximum number of rows returned = **m** Minimum number of rows returned = **m-n**
ρ(Rename)	Renaming a relation to another relation.

Extended Operator	Semantic
(Intersection)	Returns those tuples which are in both relation R1 and R2. Maximum number of rows returned = min(m,n)

Extended Operator	Semantic
	Minimum number of rows returned = 0
⋈ (Conditional Join)	Selection from two or more tables based on some condition (Cross product followed by selection)
⋈(Equi Join)	It is a special case of conditional join when only an equality condition is applied between attributes.
⋈ (Natural Join)	In natural join, equality condition on common attributes holds, and duplicate attributes are removed by default. **Note:** Natural Join is equivalent to the cross product of two relations have no attribute in common and the natural join of a relation R with itself will return R only.
⟕(Left Outer Join)	When applying join on two relations R and S, Left Outer Joins gives all tuples of R in the result set. The tuples of R which do not satisfy the join condition will have values as NULL for attributes of S.
⟖(Right Outer Join)	When applying join on two relations R and S, Right Outer Joins gives all tuples of S in the result set. The tuples of S which do not satisfy the join condition will have values as NULL for attributes of R.
⟗(Full Outer Join)	When applying join on two relations R and S, Full Outer Joins gives all tuples of S and all tuples of R in the result set. The tuples of S which do not satisfy the join condition will have values as NULL for attributes of R and vice versa.
/ (Division Operator)	Division operator A/B will return those tuples in A which is associated with every tuple of B. **Note:** Attributes of B should be a proper subset of attributes of A. The attributes in A/B will be Attributes of A- Attribute of B.

Read more about Relational Algebra.

Relational Calculus: Relational calculus is a non-procedural query language. It explains what to do but not how to do it. It is of two types:

- **Tuple Relational Calculus:** The tuple relational calculus is based on specifying the number of tuple variables. Each variable usually ranges over a particular database relation. It is of the form
  {t| cond(t)}
  where **t** is the tuple variable and **cond(t)** is a conditional expression involving t. The result of such query is the set of tuples of t that satisfy cond(t).
- **Domain Relational Calculus:** It is a non-procedural query language equivalent in power to Tuple Relational Calculus. Domain Relational Calculus provides only the description of the query but it does not provide the methods to solve it
  $\{x_1, x_2, ..., x_n \mid cond\ (x_1, x_2, ..., x_n, x_{n+1}, x_{n+2}, ..., x_{n+m})\}$
  where, $x_1, x_2, ..., x_n, x_{n+1}, x_{n+2}, ..., x_{n+m}$ are domain variables ranging over domains, and **cond** is a condition.

SQL: Structured Query Language, lets you access or modify databases. SQL can execute queries, retrieve data, insert records, update records, delete records, create a new database, create new tables, create views, and set permissions on tables, procedures, or views.

SQL Commands:

Operator	Meaning
SELECT	Selects columns from a relation or set of relations. It defines WHAT is to be returned. **Note:** As opposed to Relational Algebra, it may give duplicate tuples for the repeated values of an attribute.
FROM	**FROM** is used to define the Table(s) or View(s) used by the SELECT or WHERE statements
WHERE	**WHERE** is used to define what records are to be included in the query. It uses conditional operators.
EXISTS	**EXISTS** is used to check whether the result of a correlated nested query is empty (contains no tuples) or not.
GROUP BY	**GROUP BY** is used to group the tuples based on some attribute or set of attributes like counting the number of students GROUP BY the department.

Operator	Meaning
ORDER BY	**ORDER BY** is used to sort the fetched data in either ascending or descending according to one or more columns.
Aggregate functions	Find the aggregated value of an attribute. Used mostly with GROUP BY. e.g.; count, sum, min max. **select count(*) from the student group by dept_id** **Note:** we can select only those columns which are part of GROUP BY.
Nested Queries	When one query is a part of another query.
UPDATE	It is used to update records in a table.
DELETE	It is used to delete rows in a table.
LIKE	LIKE operator is used with the WHERE clause to search a specified pattern in a column.
IN	IN operator is used to specify multiple values in the WHERE clause.
BETWEEN	It selects values within a range.
Aliases	It is used to temporarily rename a table or a column heading.
HAVING	The HAVING clause was added because the WHERE keyword could be used with aggregate functions.

Read more about SQL

SQL Subqueries: A subquery in SQL is a query nested inside another query to provide intermediate results for the outer query.

Execution Flow

FROM –> Cross-product of relations (tables)

↓

WHERE –> Apply selection condition (σ) to filter rows

↓

GROUP BY –> Group rows based on specified column(s)

↓

HAVING –> Filter groups based on aggregate conditions

↓

SELECT –> Choose and project the required columns

↓

DISTINCT –> Remove duplicate rows (if specified)

↓

ORDER BY –> Sort the result set (ascending/descending)

File Structure

File organization: It is the logical relation between records and it defines how file records are mapped into disk blocks(memory). A database is a collection of files, each file is a collection of records, and each record contains a sequence of fields. **The blocking Factor** is the average number of records per block.

Strategies for storing files of records in block:

- **Spanned Strategy:** It allows a partial part of the record to be stored in the block. It is suitable for variable-length records. No wastage of memory in spanned strategy but block access time gets increases.
- **Unspanned Strategy:** Data cannot be stored partially, the whole block will be occupied, this can lead to internal fragmentation and wastage of memory but block access time is reduced. This is suitable for fixed-length records.

File organizations is of following types:

- Sequential File Organization
- Heap File Organization
- Hash File Organization
- B^+ Tree File Organization
- Clustered File Organization

Sequential File: In this method, files are stored in sequential order one after another.

- **Blocking factor:** $\left\lfloor \frac{Block\ Size}{Record\ Size} \right\rfloor$
- **Number of record blocks:** $\left\lceil \frac{Total\ number\ of\ records}{Blocking\ factor} \right\rceil$
- **Average number of blocks accessed by linear search:** $\left\lfloor \frac{number\ of\ record\ blocks}{2} \right\rfloor$
- **Average number of blocks accessed by binary search:** $\lfloor log_2\ number\ of\ record\ blocks \rfloor$

Index File:

- **Index blocking factor:** $\left\lfloor \frac{number\ of\ record\ blocks + 1}{2} \right\rfloor$
- **First level index block:** $\left\lceil \frac{number\ of\ record\ blocks}{index\ blocking\ factor} \right\rceil$
- **Number of block accesses:** $\lfloor log_2\ (first\ level\ index\ blocks) \rfloor + 1$

Indexing Type:

1. Single level Index

- **Primary Index(Sparse):** A primary index is an ordered file(ordered with key field), records of fixed length with two fields. The first field is the same as the primary key of the data file and the second field is a pointer to a data block, where the key is available. In Sparse indexing, for a set of database records there exists a single entry in the index file.
    - **Number of index file entries ≤ Number of database records.**
- **Secondary Index (Dense):** Secondary index provides secondary means of accessing a file for which primary access already exists. In Dense indexing, for every database record, there exists an entry in the index file. The index blocking factor is the same for all indexes.
    - **Number of database records = Number of entries in the index file**
    - **Number of block accesses=** $\lceil log_2\ (single\ level\ index\ block) \rceil + 1$
- **Clustered Index(Sparse):** A clustering index is created on a data file whose records are physically ordered on a non-key field (called a Clustering field). Almost one clustering index is possible.
    - **Single-level index blocks=** $\left\lceil \frac{Number\ of\ distinct\ values\ over\ non\ key\ field}{Index\ blocking\ factor} \right\rceil + 1$
    - **Number of block accesses=** $\lceil log_2\ (single\ level\ index\ block) \rceil + 1$

2. Multilevel Index

- **Indexed sequential access method:** Second level index is always sparse.
    - **Level 1** = "first-level index blocks" computed by index
    - **Level 2** = $\left\lceil \frac{Number\ of\ blocks\ in\ level\ (1)}{index\ blocking\ factor} \right\rceil$
    - **Level n** = $\left\lceil \frac{Number\ of\ blocks\ in\ level\ (n-1)}{index\ blocking\ factor} \right\rceil = 1$
    - **Number of blocks** = $\sum_{i=1}^{n}(Number\ of\ blocks\ in\ level\ i)$
    - **Number of block access** = n+1
- **B-Tree:** Also known as Baye's or balanced Search Tree. At every level, we have Key and Data pointers, and data pointer points either block or record.
    - **Root node:** B-tree can have children between **2** and **p**, where p is the Order of the tree.
    - **Internal Node:** $\lceil \frac{n}{2} \rceil$ to n children.
    - **Leaf nodes** all are at the same level.
    - **Block size** = p × (size of block pointer) + (p-1)× (Size of key field + size of record pointer)
    - **Minimum number of nodes** = $1 + (^{2[(\frac{p}{2})^h - 1]}_{(\frac{p}{2})-2})$
    - **Maximum number of nodes** = $\frac{p^{h+1}-1}{p-1}$
    - **Minimum height** = $(\lceil log_p\ l \rceil)$ l is the number of leaves
    - **Maximum height** = $\left\lfloor 1 + log_{\frac{p}{2}}\frac{l}{2} \right\rfloor$
- **B$^+$ Tree:** It is the same as B-tree. All the records are available at the leaf (last) level. B$^+$ tree allows both sequential and random access whereas in B-tree only random access was allowed. Each leaf node has one block pointer and all the leaf nodes are connected to the next leaf node using a block pointer.
    - **Order of non-leaf node**= [p × size of block pointer] + [(p-1) × size of key field] <= Block size.
    - **Order of Leaf node**= [(p_{leaf} -1) × (size of key field + size of record pointer) + p × (size of block pointer) <= Block size]

Transaction and Concurrency Control

A transaction is a unit of instruction or set of instructions that performs a logical unit of work. Transaction processes are always atomic in nature either they will execute completely or do not execute.

Transaction Properties:

- **Atomicity:** Either execute all operations or none of them. It is managed by the transaction Management Component.
- **Consistency:** Database must be consistent before and after the execution of the transaction. If atomicity, isolation, and durability are implemented accurately, consistency will be achieved automatically.
- **Isolation:** In concurrent transactions, the execution of one transaction must not affect the execution of another transaction. It is managed by the Concurrency Control component.
- **Durability:** After the commit operation, the changes should be durable and persist always in the database. It is managed by the Recovery Management component.

Read more about Transaction Properties.

Transaction States:

A transaction in DBMS goes through various states during its execution to ensure consistency and reliability in the database.

States of Transactions:

1. **Active**:
   - Transaction is executing its operations.

2. **Partially Committed**:
   - Transaction has completed its final step but is yet to be made permanent.

3. **Committed**:
   - All changes are successfully saved in the database.

4. **Failed**:
   - An error or issue prevents the transaction from completing.

5. **Aborted**:
   - Changes are rolled back, and the transaction is terminated.

Flow:
Active → Partially Committed → Committed
Active → Failed → Aborted

Read more about Transaction States.

Schedule: Sequences in which instructions of the concurrent transactions get executed. Schedules are of two types:

- **Serial Schedule:** Transactions execute one by one, another transaction will begin after the commit of the first transaction. It is inconsistent and the system's efficiency is so poor due to no concurrency.
    - The number of possible serial schedules with n transactions = **n!**
- **Non-Serial Schedule:** When two or more transactions can execute simultaneously. This may lead to inconsistency, but have better throughput and less response time.
    - The number of possible non-serial schedules with n transactions = Total Schedule – Serial Schedule

$$\binom{n_1+n_2+n_3+\ldots\ldots\ldots+n_n}{n_1!\,n_2!\,n_3!\ldots\ldots n_n!} - n!$$

Serializability: A schedule is said to be serializable if it is equivalent to a serial schedule. It is categorized into two categories: Conflict Serializability, and View Serializability.

Conflict Serializability: A schedule will be conflict serializable if it can be transformed into a serial schedule by swapping non-conflicting operations. It is a polynomial-time problem.

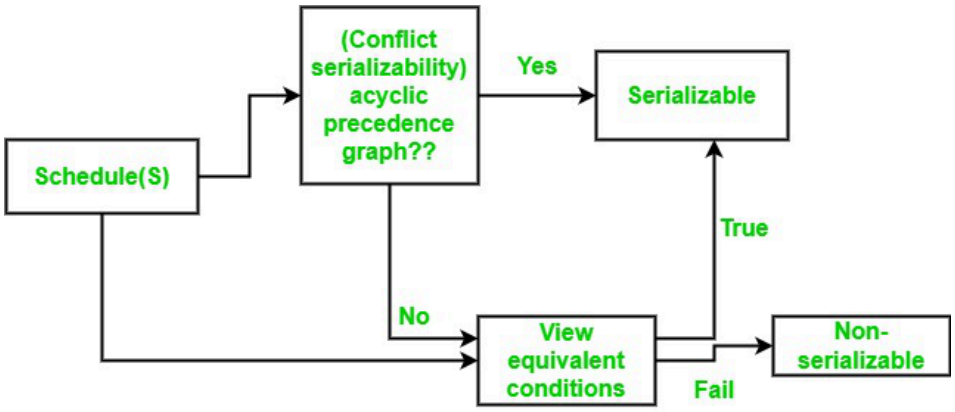
- **Conflicting operations:** Two operations will be conflicting if
    - They belong to different transactions.
    - They are working on the same data item.
    - At least one of them is the Write operation.

View Serializability: A schedule will be view serializable if it is view equivalent to a serial schedule. It is an NP-Complete Problem.

- Check whether it is conflict serializable or not, if Yes then it is view serializable.
- If the schedule does not conflict with serializable then check whether it has blind write or not. If it does not have blind write then it is not view serializable. [To be view serializable a schedule must have a blind write]
- If the schedule has blind write, Now check whether the schedule is view-equivalent to any other serial schedule.
- Now, draw a precedence graph using given dependencies. If no cycle/loop exists in the graph, then the schedule would be a View-Serializable otherwise not.

Types of Schedule based recoverability:

- **Irrecoverable Schedule:** A transaction is impossible to roll back once the commit operation is done.
- **Recoverable Schedule:** A schedule is recoverable if a transaction T_i reads a data item previously written by Transaction T_j, the commit operation T_j appears before the commit operation of T_i.
- **Cascadeless Recoverable Schedule:** Cascadeless Schedule avoids cascading aborts/rollbacks (ACA). Schedules in which transactions read values only after all transactions whose changes they are going to read commit are called cascadeless schedules. Avoids that a single transaction abort leads to a series of transaction rollbacks.
    - **Cascading rollback:** When failure of a single transaction leads to a series of transaction rollbacks.
- **Strict Recoverable Schedule:** If there is no read or write in the schedule before the commit, then such schedule are known as a Strict recoverable schedule.



Serializability Checking

Concurrency Control with Locks:

To achieve consistency, isolation is the most important concept. Isolation can be achieved using locking very easily. A schedule acquires a lock prior to accessing the transaction and the lock is released when the transaction is completed. A locking protocol is a set of rules followed by all transactions while requesting and releasing locks. Locking protocols restrict the set of possible schedules.

Lock Types:

Binary Locks

- It is in two states: Locked(1) or Unlocked(0)

- When an object is locked it is unavailable to other objects.
- When an object is unlocked then it is open to transactions.
- An object is unlocked when the transaction is unlocked.
- Every transaction locks a data item before use and unlocks/releases it after use.
- Issues with binary locks: Irrecoverability, Deadlock, and Low concurrency.

Shared/Exclusive Locks:

- **Shared (S Mode):** It is denoted by lock-S(Q), the transaction can perform a read operation, and any other transaction can also obtain the same lock on same data item at the same time and can also perform a read operation only.
- **Exclusive (X Mode):** It is denoted by lock- X(Q), the transaction can perform both read and write operations, any other transaction can not obtain either shared/exclusive lock.

Two-Phase Locking: This protocol requires that each transaction in a schedule will be two phases: i.e. Growing phase and the shrinking phase.

- In the growing phase, transactions can only obtain locks but cannot release any lock.
- In the shrinking phase, transactions can only release locks but can not obtain any lock.
- The transaction can perform read/write operations in both the growing as well as in shrinking phase.
  Rules for 2-PL:
    - Two transactions cannot have conflicting locks.
    - No unlock operation can precede a lock operation in the same transaction.
    - No data are affected until all locks are obtained.
- **Basic 2-PL:**
    - **Rule**: A transaction must acquire a lock before accessing a data item and release it after use.
    - **Phases**:
        1. **Growing Phase**: Locks are acquired but not released.
        2. **Shrinking Phase**: Locks are released but no new locks are acquired.

    - **Ensures**: Serializability but not deadlock-free.
- **Strict 2-PL:**

    - **Rule**: A transaction holds all exclusive (write) locks until it commits or aborts.
    - **Phases**:
        1. **Growing Phase**: Locks are acquired.
        2. **Release Phase**: Locks are released only after commit/abort.

    - **Ensures**: Serializability and prevents cascading rollbacks.
- **Rigorous 2-PL:**
    - **Rule**: A transaction holds all locks (read and write) until it commits or aborts.
    - **Phases**:
        1. **Growing Phase**: Locks are acquired.
        2. **Release Phase**: All locks are released only after commit/abort.

    - **Ensures**: Serializability and strict schedules (stronger than Strict 2PL).
- **Conservative 2-PL:**
    - **Rule**: A transaction acquires **all required locks upfront** before executing.
    - **Key Feature**: If all locks cannot be acquired at the start, the transaction waits and does not proceed.
    - **Prevents**: Deadlocks completely.
    - **Trade-off**: May cause delays if locks are unavailable.

Timestamp Ordering Protocol: Each transaction gets a unique timestamp when it starts.

Rules:

- **Read Rule**: A transaction can read an item only if its timestamp ≥ last write timestamp of the item.
- **Write Rule**: A transaction can write an item only if its timestamp ≥ last read and last write timestamps of the item.

Ensures serializability by executing transactions in timestamp order.

timestamp.

Thomas Write Rule: A protocol in timestamp ordering where outdated write operations (with a timestamp older than the current write timestamp of a data item)

are ignored instead of aborting the transaction.

1. **Rule**: Ignore a write if the transaction's timestamp (TS) is older than the data's write timestamp (WTS).
2. **Logic**: The outdated write is discarded because a newer write has already been performed.
3. **Prevents**: Unnecessary aborts of transactions.
4. **Allows**: Greater concurrency compared to basic timestamp ordering.

Used in timestamp ordering protocols to optimize write operations.

See Last Minute Notes on all subjects here.

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